“Researching a sustainable environment and sustaining research in Mathematics, Science and Technology Education”

12 January - 15 January 2016
Tshwane University of Technology
Arts Campus, Pretoria
South Africa

LONG PAPERS
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Acknowledgements

We take great pleasure in thanking our sponsors for their generosity and support for this our 24th SAARMSTE Annual Conference:

CASIO

Tshwane University of Technology

ROUTLEDGE, Taylor & Francis Group
Foreword: LOC Chairperson – Prof Thapelo Mamiala

It is with pleasure to welcome you to the 24th Annual Conference of the Southern African Association for Research in Mathematics, Science and Technology Education (SAARMSTE) held at Tshwane University of Technology, Tshwane. The institution plays a critical role in human resource development in the Science, Technology, Engineering and Mathematics (STEM) fields. The institution regards the opportunity to host this prestigious international event as an honour.

It is through such anticipated international conversations that continental and local solutions may be developed in order to improve on sustainable teaching and learning environment in MSTE. According to AU Commission, Africa needs more research graduates to renew ageing professoriate, contribute to economic development and boost research. These conversations will certainly add value in responding to the continental challenges.

The LOC and members of Tshwane SAARMSTE group welcome both the international and national presenters as well as the key note speakers. During the period of the conference a total of 223 presentations will take place. The LOC and the Tshwane SAARMSTE group wish to express its appreciation to all the participants for adding value to the conference through your contributions. It is through such contributions that xenostat syndrome and creation of sustainable teaching and learning environment may now be addressed in MSTE.

In order for the conference to be at this level of organisation there have been collective efforts by various stakeholders. To all the LOC members, I just want to say “ke leboga go menagane” (thank you, thank you and thank you in Setswana). No words may express our gratitude to the SAARMSTE EXCO for always being willing to assist when at times we were becoming “disorientated”. To Carolyn Stevenson-Miln we thank you for always making time to provide advice and being hands-on from the start with regard to preparations.

We hope that during your stay in Tshwane you will make time to explore the capital city of the Republic of South Africa.

LOC Chairperson – Prof Thapelo Mamiala
Message from SAARMSTE President

On behalf of the SAARMSTE executive committee, I welcome you all to our 24th annual conference. The annual conference is SAARMSTE’s major event that brings together delegates from Southern Africa and all over the world, and hence provides an opportunity for networking sharing and learning. We are delighted to have Tshwane University of Technology in Pretoria host this conference and we hope that the deliberations contribute towards further development of Mathematics, Science and Technology education in Southern Africa and beyond. The theme of this year’s conference; *Researching a sustainable environment and sustaining research in Mathematics, Science and Technology education*; cautions and challenges us not to be limited to the confines of our research fields but to be looking beyond and consider the wider educational, social and environmental implications of our research. We should always reflect critically about the impact of what we research and do, as well as the nature of the impact we make.

Organising a conference is not an easy task; it is a huge task and demands a lot of time and commitment. I thank Tshwane University of Technology for hosting the conference, I thank the local organising committee for their planning, organisation, time and dedication, I thank all authors whose papers make the conference and all delegates. I thank the reviewers whose feedback helped shape the papers, and the editors who put these proceedings together.

Finally, a special thank you to all those that have supported the conference, without their generosity, the conference and publication of these proceedings would have been difficult. Wishing you all a great conference.

Mercy Kazima
SAARMSTE President
January 2016
24th SAARMSTE ANNUAL CONFERENCE PAPERS

Review Policy of SAARMSTE 2016 Conference Papers
Tshwane University of Technology, Pretoria 12-16 January 2016

Long Papers

All long papers were reviewed in their entirety by at least two external reviewers and 3 reviewers in total. Reviewers were selected from among the list of SAARMSTE Journal Reviewers (African Journal for Research in Mathematics, Science and Technology Education) all of whom are internationally known in their field. The reviewers’ suggestions were considered by members of the Programme Committee, who made final decisions. Where there was agreement among two reviewers, their recommendations were generally accepted by the Programme Committee. Where there was disagreement, the Programme Committee appointed one other reviewer, whereupon the committee took account of the new review together with the first two reviews and made a final decision. In cases where papers were accepted with conditions, authors were advised to make changes in order to have their papers accepted, or provide a compelling argument as to why the conditions were not adhered.

Short Papers, Posters, Snapshots, Round Tables and Symposia

For these presentations, only an extended abstract (1-2) pages was reviewed. Reviewers were drawn from SAARMSTE members and authors of long papers. Agreement was reached by consensus on each abstract and the Programme Committee informed authors of the decision. Authors were given opportunities to rework their abstract according to the reviewers’ suggestions.

Professor Willy Mwakapenda

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Table of Contents

SAARMSTE COMMITTEES .......................................................................................................................... 1
  SAARMSTE Executive 2015-2016........................................................................................................... 1
  SAARMSTE LOC 2015-2016................................................................................................................... 1

ACKNOWLEDGEMENTS ............................................................................................................................ 2

FORWARD LOC CHAIRPERSON ............................................................................................................. 3

MESSAGE – SAARMSTE PRESIDENT ........................................................................................................ 4

REVIEW POLICY STATEMENT .................................................................................................................. 5
  SAARMSTE REVIEWERS 2016 ................................................................................................................ 6

PART A: MATHEMATICS LONG PAPERS .............................................................................................. 11

The Unheard Voice of Educators: South African Mathematics Educators’ Views on Implementation of the
Curriculum and Assessment Policy Statement (CAPS) in the FET Band Education
Jogymol Alex & John Mammen .................................................................................................................. 12

Relationships between activity, content and depth of mathematics teachers’ talk in a professional
learning community
Tinoda Chimhande & Karin Brodie ............................................................................................................. 23

Teacher perceptions of the successes and challenges of a mathematics homework drive for primary
learners
Mellony Graven ....................................................................................................................................... 36

The Potential and Challenges of Using GeoGebra to Teach Geometrical Constructions in Botswana Junior
Secondary Schools: The Case of Gaborone-West Schools
Kagelelo W. Kagiso & Alakanani A. Nkhwalume ....................................................................................... 46

Exploring motivational factors and self-regulated learning strategies as predictors of students’ anxiety in
mathematics learning
Elias Kaphesi ......................................................................................................................................... 59

Exploring the relationships between student affective constructs and their learning strategies in
mathematics
Elias Kaphesi ......................................................................................................................................... 72

Relationships among perceived difficulty of a mathematics problem, confidence in problem solving and
achievement in mathematics of First Year Mathematics Students at the University of Malawi-The
Polytechnic
Elias Kaphesi ......................................................................................................................................... 86

Adaptation of mathematical knowledge for teaching for number concepts and operations measures for
use in Malawi
Dun Nkhoma Kasoka, Mercy Kazima & Arne Jakobsen ............................................................................ 100
Teaching for the test or setting up students for failure: A case study of a linear algebra class in Zimbabwe
Cathrine Kazunga; Sarah Bansilal .......................................................... 111

Documentary analysis of learning dispositions promoted within the transition between Grade R and Grade 1 in the South African Curriculum and Assessment Policy
Mellony Graven & Roxanne Long .......................................................... 123

Investigating a Preservice Secondary School Teacher’s Mathematical Knowledge for Teaching Equations
Florence Mamba ........................................................................... 136

Content knowledge and pedagogical content knowledge conversations
Jeanette Marchant & Karin Brodie .......................................................... 148

Teachers’ use of productive questions in promoting mathematics classroom discourse
Duncan Mhakure & Mark Jacobs .......................................................... 160

How can high school teachers modify classroom instruction to meet the needs of mathematically gifted students in the regular classroom?
Michael Kainose Mhlolo .................................................................... 172

The work of teaching mathematics from a commognitive perspective
Reidar Mosvold ........................................................................... 186

The challenges of constructing mathematical meaning through symbolisation at secondary school level: Some instructional strategies
Paul Mutodi & Mogege Mosimege .......................................................... 196

Prospective Mathematics teachers’ circle geometry technological content knowledge in a GeoGebra-based environment
Kim Agatha Ramatlapana .................................................................. 208

Measuring of Attitudes of Learners towards Mathematics
Leelakrishna Reddy ........................................................................... 221

Analysing Annual National Assessments to improve both teaching and assessment practices
Nicky Roberts & Patrick Barmby .......................................................... 234

Five years on: learning programme design for primary after-school maths clubs in South Africa
Debbie Stott ...................................................................................... 250

Materials ‘borrowing’ and adapting: Overviewing ‘Big Books’ interventions in primary mathematics classrooms
Hamsa Venkat & Mike Askew .......................................................... 261

A sociological analysis of the South African foundation phase numeracy workbooks
Peter Pausigere ........................................................................... 578

PART B: SCIENCE LONG PAPERS .......................................................... 269

Evaluating the effectiveness of the Experimento programme: Insider accounts from Multipliers in Gauteng province
Washington T. Dudu ........................................................................... 270
The Influence of Gender, Teacher, and Scientific Practices on Students Engagement in Science Learning in Finland and the United States
Jari Lavonen, Justin Bruner, Janna Linnansaari, Kalle Juuti, Katarina Salmela-Aro, Joe Krajcik, Barbara Schneider ..........................................................283

South African Curriculum and Assessment Policy Statement (CAPS) compared with selected international syllabi on the teaching of Mechanics at secondary level.
Francis Mavhunga & Israel Kibirige ..............................................................................296

A case study on the incorporation of learners’ socio-cultural background in the teaching of Natural Sciences at three township schools in South Africa
Lydia Mavuru & Umesh Ramnarain ...........................................................................314

Designing a teacher development programme for improving the content knowledge of grade 12 mathematics and science teachers
David Mogari, Jeanne Kriek, Harrison Atagana & Chucks Ochonogor .........................339

Using a three-tier multiple-choice questionnaire to identify the misconceptions that Grade 10 learners from three underperforming Dinaledi Schools in Soweto hold about simple electric circuits.
Sumayya Moosa & Umesh Ramnarain ...........................................................................352

Validating a questionnaire instrument for investigating the achievement goal orientation of Grade 10 Physical Sciences learners in five Soweto township schools
Pio Mupira, Umesh Ramnarain & Xenia Kyriacou ..........................................................366

Students’ perspectives on teacher practices in Physical Science and their implications on inquiry based instruction
Dorothy Cynthia Nampota ............................................................................................405

Explicating the Philosophy of Ubuntu into Science Education: A Project Experience
Meshach Ogunniyi ........................................................................................................417

Investigating the impact of Dialogical Argumentation Instructional Model on Grade 3 learners’ conceptions of the causes and effect of water pollution
Lorraine Philander & Florence February ......................................................................432

Students’ perceptions of the Physics Laboratory Classroom Environment at the University of Johannesburg
Leelakrishna Reddy ......................................................................................................447

Investigating teachers’ use of manipulatives to teach grade 3 equivalent fractions
Themane K M & K Luneta ............................................................................................462

Enduring educational inequalities: The state of physical sciences laboratories and scientific inquiry opportunities for learners in some of the schools in post-apartheid South Africa
Maria Tsakeni ..............................................................................................................475

PART C: TECHNOLOGY LONG PAPERS ..................................................................488

A comparative analysis of beginner and veteran teachers’ procedural and pedagogical knowledge in ICT-enhanced classroom
Janet Bolaji Adegbenro & Mishack Gumbo ..................................................................489
Evaluating the Perceived Motivational Effect of 3D Support Lectures on Students’ Academic Performance in Higher Education
Thelma de Jager .................................................................................................................. 504

Understanding socio-technical interaction in implementation of ICT in schools: Case study of Maputo Province, Mozambique
Lucia Ginger & Irene Govender .......................................................................................... 517

Inspiring and Sustaining Learners’ and Their Communities’ Interest in Science, Engineering and Technology
Leila Goosen & Patricia Gouws .......................................................................................... 530

Bridging the Innovation Chasm: Computer Systems Engineering students’ attitude, biasness and perception towards entrepreneurship and innovation
Vusumuzi Malele, Khumbulani Mpofu & Mammo Muchie .................................................. 542

Imperatives to consider in the teaching of design skills in Technology: An indigenous perspective
Richard Maluleke & Mishack T Gumbo .............................................................................. 555

At the cross-roads: Perceptions of barriers to the implementation of learning technologies by in-service teachers in South Africa
Kudakwashe Mamutse ....................................................................................................... 566
Part A
Mathematics
Long Papers
The aim of the study was to gather and assess educators’ views on the implementation of the Curriculum and Assessment Policy Statement (CAPS) in Further Education and Training (FET) Mathematics curriculum. The theoretical frameworks rest on theories and reviews on curriculum reforms, professional development of educators and educators as significant stakeholders in senior secondary school education. The study adopted an interpretivist research paradigm, qualitative research approach with an open-ended questionnaire survey research design. Data were collected from 38 mathematics educators, one each from 38 out of 72 senior secondary schools in Mthatha Education District in the Eastern Cape Province of South Africa. The responses were analysed through content analysis. The analysed data revealed that educators identified challenges such as lack of time for syllabus coverage, resources and financial constraints in the implementation of CAPS. Despite these, most of the educators were satisfied with the in-service training given to them by the Department of Education and the support from the School Management Teams. The findings led the authors to conclude that educators’ views on national reforms were generally positive.

Key-words: Educators’ views, implementation of CAPS.

INTRODUCTION

The South African school curriculum was subjected to considerable pressure to change from its situation in the past in order to enable the country’s citizens to cope with the changing socio-political, economic and technological environment within the context of the ‘new’ democracy (Ndou, 2008). Central to these transformations was the need for equal educational opportunities to all South Africans. Over the course of 1996 and 1997, various curriculum committees representing a range of stakeholders were charged with producing the new curriculum (Ndou, 2008). This process resulted in the implementation of an interim core syllabus in 1995, a document that was succeeded by Curriculum 2005’s implementation in 1999 (King, 2003). The introduction of C2005 was a significant attempt at curriculum reform in South African education to overturn the legacy of apartheid education (Ndou, 2008). The introduction of OBE and C2005 was an unprecedented curriculum reform in the history of South Africa (Ono & Ferreira, 2010). This curriculum was heavily criticised due to its high inaccessibility, lack of resources in underprivileged schools and incompetence of teachers. This ultimately contributed to the partial failure of C2005 to achieve its intended outcomes. This was followed by the curriculum review in 2000, called “Draft National Curriculum Statement (NCS) by the education minister in 2001 and a Revised National Curriculum Statement (RNCS) in 2002 (King, 2003). This curriculum came into effect in Further Education Band (FET) in 2006 and the first cohort of matric learners wrote their National Senior Certificate
Examination in 2008. A further revision of the curriculum, Curriculum and Assessment Policy Statement (CAPS) came into effect in the FET band in 2012. This was an amendment to improve the implementation of NCS. For that, a single comprehensive curriculum and assessment policy document was developed for each subject (Department of Basic Education, 2011). According to the Department of Basic Education, CAPS is not a new curriculum, but an amendment to the National Curriculum Statement (NCS). It therefore still follows the same process and procedure as the 2002 NCS Grades R–12 curriculum (Pinnock, 2011). The Council for Quality Assurance in General and Further Education and Training, UMALUSI points out that while the RNCS / NCS had positive support generally, there was considerable criticism of various aspects of its implementation, including teacher-overload, confusion and stress arising from discrepancies in the documentation and demands on teachers’ time, as well as prevalent learner underperformance in international and local assessments (UMALUSI, 2014, p.11). The amendments made in the CAPS were to address four main concerns such as complaints about the implementation of the NCS, teachers who were overburdened with administration about the NCS, different interpretations of the curriculum requirements and under performance of learners as identified by a task team and reported to the Minister of Education in October 2009 (DBE, 2009).

According to Sahlberg (2005), lack of appreciation and the understanding of the change process are the most common reason for implementation frustrations. To find out about the implementation process of this new curriculum of Mathematics, the researchers approached senior secondary school educators in the Mthatha Education District. The research question that is addressed in the paper is: What are the educators’ views on implementation of the Curriculum and Assessment Policy Statement (CAPS) of Mathematics in the FET band education?

Theoretical framework

The theoretical framework (TF) of the present study rests on more than one theory. The theories on curriculum reform, curriculum implementation, professional development of educators and educators as significant stakeholders in senior secondary school education are among others pertinent. This is because (a) the move to NCS and CAPS involved reform, the challenges educators faced to adapt to the new ways of implementing a nationally conceived curriculum demands the TF on curriculum reform; (b) the need to develop educators already in service professionally to empower them to shoulder the challenge demands the TF on professional development and (c) educators’ own obligation to adapt to policy imperatives as pertinent stakeholders in the change to CAPS demands the TF on significant stakeholders.

The four core elements of the curriculum are teaching; learning; assessment and resources used for teaching and learning (Department of KZN, n.d.). The design of curricular materials and their presentation should accommodate the culture of the society that the curriculum is seeking to serve (Chikumbu & Makamure, 2000). A good understanding of change and a clear conception of the curriculum are necessary conditions for improved implementation of new curriculum into practice (Sahlberg, 2005).

Significance of the study
In South Africa, the process of curriculum change after 1994 found that teachers were ill-prepared for the new demands placed on them (Ndou, 2008). According to Bennie and Newstead (1999), the factors that can restrict innovation in curriculum among others are (a) issues of time, (b) parental expectations, (c) public examinations, (d) unavailability of required instructional materials, (e) lack of clarity about curriculum reform, (f) teachers’ lack of skills and knowledge, and (g) the initial mismatch between the teacher’s “residual ideologies” and the principles underlying the curriculum innovation. It was reported by Jansen and Christie (1999) that when OBE was implemented in KwaZulu-Natal and Mpumalanga, most of the teachers were not certain as to which available resources should be utilised. According to Fennema and Franke (1992), teachers’ content knowledge influences classroom instruction and the richness of learners’ mathematical experiences. Improving the subject knowledge of teachers must be a top priority for any intervention (Taylor, 2008). Bush, Joubert, Kiggundu and van Rooyen (2009) suggest that in South African education system, the responsibility for managing teaching and learning is shared among Principals, School Management Teams (SMT), Head of Departments (HOD) and classroom educators, where educators manage curriculum implementation in the classrooms, HODs have the responsibility for ensuring effective learning and teaching across their learning areas and phases while Principal and SMTs have the whole school role. The SMT has the responsibility of managing the implementation of curriculum change on account of societal demands impending from the political and socio-economic terrains (Ndou, 2008). Carter and Richards (1999) point out on the universal issue of time that, the teachers' believe that if they do not spend their time ‘covering’ the ‘curriculum’ they will be damaging the students”. The extent to which time is used for teaching and learning is the most valid and obvious indicator of the extent to which the school is dedicated to its central task (Taylor, 2008). Mkandawire (2010) reports that it is very difficult to implement a curriculum successfully if the education system has limited funding capacities. To have the effective implementation of the curriculum, the minimum standard of one textbook per learner per subject was adopted as a norm for the Department of Education of KZN. It is also very important that all schools must have adequate curriculum resources that support teaching and learning (Curriculum Management and Delivery Strategy of Department of KZN, n.d.). The present study is significant as it tries to report on educators’ challenges as mentioned above in the implementation of CAPS in the South African secondary school mathematics curriculum.

The South African Mathematics Curriculum, NCS and CAPS

Feza and Webb (2005) cite earlier studies (like Davies, 1986; Samuel, 1990 and Hartshorne, 1992) to point out that, in South Africa in 1948, a system of ‘Bantu Education’ was introduced for black people based in the homelands and they were taught with a different and inferior curricula, usually with no Mathematics or Science. The Department of Education introduced NCS curriculum, which was modern and internationally benchmarked, into Grade 10 in 2006. It required the learners to do seven subjects in Grades 10 to 12 of which Mathematics or Mathematical Literacy was a compulsory subject. This was to ensure that all learners are prepared for life and world in an increasingly technological, numerical and data driven world (Pandor, 2006). According to CAPS, which came into effect in 2012 in the case of FET phase Mathematics, learners should be exposed to mathematical experiences that give them many opportunities to develop their mathematical reasoning and creative skills in preparation for more abstract mathematics in Higher/Tertiary Educational Institutions (DBE,
Probability, Euclidean Geometry and measurement were added and Transformation Geometry and Linear Programming were removed from the main topics in the FET Mathematics curriculum. This curriculum change was a cause for deeper concern on the future of secondary school Mathematics in South Africa. The Mathematics evaluation team appointed by UMALUSI (2014, p.48) reported that the addition of high demand topics like Euclidean Geometry and Probability, together with the increase in demand in Statistics and Data Handling, and a slight increase in demand in Algebra, means that the CAPS is likely to be significantly more demanding than the NCS.

**METHODOLOGY**

The present study adopted a positivist research paradigm adopting a qualitative approach with an open-ended descriptive survey design. In this cross-sectional study, the sample consisted of 38 educators, one each from 38 schools out of the 72 in the Mthatha Education District. The members in the sample were those attending an in-service mathematics professional development session emphasising pedagogical content knowledge (PCK). Hence, the sampling was purposive as they were pertinent stakeholders and those directly involved in implementing the reformed Mathematics FET curriculum at the time of data collection. The sampling was convenient because it was easy to get a cohort of educators from many schools at one venue. The self-developed instrument was a survey questionnaire with qualitative open-ended questions. Items included those to gather biographical data, educators’ views on the implementation of CAPS in terms of the topics taught and views on the changes in the CAPS FET Mathematics curriculum as compared to that of NCS. The questionnaires were administered by the lead researcher after getting the approval from the Department of Education. Also, the purpose of research was explained and informed consent was sought. As responsible stakeholders, the educators gladly volunteered. The responses were analysed through content analysis. The relatively small sample that was involved in the study limits the generalisability.

**RESULTS AND ANALYSIS**

The biographical data collected from the educators indicated that out of 38 educators, 29 (76%) were qualified to teach in senior secondary schools and 28 (74%) had more than 5 years of experience.

**Table 1: Educators’ responses on the curriculum implementation of CAPS (N=38)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Response</th>
<th>positive</th>
<th>%</th>
<th>negative</th>
<th>%</th>
<th>no response</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Support given by the Dept. of Education: that the training given by Department in Euclidean geometry &amp; Probability was adequate</td>
<td></td>
<td>36</td>
<td>94</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Support by School Management in the implementation of CAPS</td>
<td></td>
<td>30</td>
<td>79</td>
<td>7</td>
<td>18</td>
<td>1</td>
<td>3</td>
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<tr>
<td>Human resources availability</td>
<td></td>
<td>14</td>
<td>37</td>
<td>16</td>
<td>42</td>
<td>8</td>
<td>21</td>
</tr>
<tr>
<td>Textbooks and other resources availability</td>
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<td>23</td>
<td>60</td>
<td>14</td>
<td>37</td>
<td>1</td>
<td>3</td>
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</tbody>
</table>
### Financial Implications (Money is Budgeted) in Terms of Buying New Textbooks/Additional Staff

<table>
<thead>
<tr>
<th></th>
<th>10</th>
<th>26</th>
<th>24</th>
<th>63</th>
<th>4</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experience in Completing the Syllabus</td>
<td>8</td>
<td>21</td>
<td>27</td>
<td>71</td>
<td>3</td>
<td>8</td>
</tr>
</tbody>
</table>

### Educators’ Experiences in the Implementation of CAPS

#### Training Given by Department of Education in Euclidean Geometry and Probability

Majority of the educators, 36 out of 38 (94%) responded positively to the support given by the Department of Education in terms of the training given in Euclidean geometry and Probability. There were comments such as “they (workshops) are fruitful and capacitate teachers with necessary skills”; “Good and effective” and “A lot has been done by the Department in terms of giving educators adequate skills on Probability”. In general, the educators appreciated the effort of the subject advisor in arranging and conducting successful training in the new topics.

#### Support by the School Management Team

There were mixed feelings about the support given by the School Management Teams (SMTs). 30 (79%) educators responded positively to the support given by the SMTs. There were comments such as “The SMT is very supportive”; “They supplied me with everything needed”; “Management supported us by buying textbooks and teaching aids”; “They (SMTs) were very supportive, they even asked someone who taught the topics before in NATED 550 to help me”. It was also mentioned that in one school, “the SMT frequently encouraged learners to work harder and asked for cooperation in order to tackle the changes in the curriculum”. In one school a security person was organised to guard the educator whenever she had Saturday classes and afternoon classes. Seven (18%) educators commented that they were not supported financially by their SMTs. One educator commented that there was no availability of resources due to insufficient funds.

#### Human Resources, Textbooks and Other Resources Availability (LTSM)

Only 14 (37%) educators responded positively indicating that there are enough educators in the classrooms. 16 (42%) educators were concerned about the overcrowded classrooms, increase in the number of topics and less human resources to manage them. 8 (21%) educators did not indicate any responses. Majority of the educators commented that even though they had textbooks available for Grade 12 learners, there was serious shortage of textbooks in Grade 10 and 11. Most of the schools were managing with only one textbook. There were comments such as “we do not have books for Grade 10 that are CAPS compliant” and “We still have a problem with Grade 11 textbook, we only have ‘Siyavula’ which were supplied by Department of Education”. Many educators were concerned about unavailability of computers, reference books and study guides. Non availability of calculators was a big concern in many schools.

#### Financial Implications in Terms of Buying New Textbooks/Additional Staff etc.

Majority of schools rely on only the textbooks supplied by the Department of Education. Only 26% of the educators from the sample responded that money was budgeted and that they had no problem in terms of buying new textbooks. 63% of the educators responded that they could not buy textbooks and resources due to shortage of funds. There were concerns such as “curriculum changes had wasted a lot of money on the purchase of textbooks” and “We are still using old NCS books due to
unavailability of funds”. The appointment of new qualified educators was a main concern due to financial implications.

**Experience in terms of completing the syllabus**

Educators raised the concerns that the Pace Setter was too congested. “Additional topics needed extra time than allocated”; “The topics were lengthy for Grade 10 and that Grade 10 learners were not coping with the syllabus they had to cover”; “Euclidean Geometry syllabus was too long to finish and extra classes were conducted” were some of the concerns raised by the educators. In general it felt that CAPS was lengthy and a bit loaded for learners in all grades.

**The difficulties faced by the learners**

Shortage of teachers, textbooks and calculators were mentioned as a challenge by many educators (32%). 55% (21 out of 38) of educators commented that learners were struggling with topics like Probability and Euclidean Geometry. “Lack of basic knowledge” was also pointed out as one of the reasons for struggling in these topics. “Proving of theorems” was one of the major difficulties faced by learners. Absenteeism was also mentioned as one of the issues faced by one school.

**Educators’ views and suggestions on the changes**

In an open ended question on the general views and suggestions on the CAPS curriculum, one educator mentioned that “The new curriculum means waste of time and money and educators need to be trained and it takes time to fully understand the new curriculum”. It was mentioned that “There has been a lot of continuous changes. So the changes have to be sustained”; “Government needs to employ more mathematics teachers in the foundation phase and senior phase”; “Formal training is needed along with curriculum changes”; “Preparation from junior school should be improved”; “For most of the Grade 10 learners most of the topics seem to be new and this makes the topic to lag for a longer period and in turn syllabus does not get finished on time”; “Employment of teachers in foundation phase is recommended”; “The changes would affect the Mathematics results negatively as learners complain that the two topics are more difficult than transformation geometry and linear programmes”; “Venn diagrams should be introduced in the senior phase” “Circle geometry should be divided between Grade 10 and Grade 11” and “More support is needed from the Department”. On the positive side, some educators believed that “the introduction of CAPS was a great move from the Department of Education”. There were positive comments such as “Documents for CAPS are clear and well understandable”. “CAPS is a very good curriculum as it allows for logical thinking”. “It creates globally competitive mathematics learners”; “CAPS equips learners before they go to university”; “It is a good change so that the learners do not struggle in tertiary level”; “For the learners to be ready for CAPS in the FET Curriculum, measures should be taken” and “There should be an external exam in grade 9”. It was also suggested that efforts should be made to accommodate learners from disadvantaged educational backgrounds.

**DISCUSSION**

In the light of the new CAPS curriculum which is being implemented in South Africa, it is important to examine ways to assist educators to implement the necessary changes. The factors that can restrict innovation in curriculum are issues of time, parental expectations, public examinations, unavailability of required instructional materials, lack of clarity about curriculum reform, teachers’ lack of skills and...
knowledge, and the initial mismatch between the teacher’s “residual ideologies” and the principles underlying the curriculum innovation (Bennie & Newstead, 1999). The present study looked at the different factors that concerned the educators in the implementation of the CAPS curriculum such as, the training offered by the Department of Education, support by the SMTs, resources and time constrains due to added topics in the new curriculum. Even though it emerged from the study that CAPS equips learners before they go to university and it also encourages leaners to think deeply than just memorising concepts as it was envisaged by Department of Education, the study established that there were challenges in implementing the CAPS curriculum. The concerns emerged from the results of the study are discussed under the following themes.

Training by the Department of Education

Most of the educators participated in the study were qualified and experienced educators. Most of them had experiences in teaching the NCS and CAPS syllabus. Many educators suggested that the documents for CAPS were clear and well understandable. Fennema and Franke (1992) believe that teacher’s content knowledge influences classroom instruction and the richness of learners’ mathematical experiences. To increase the PCK of educators in Euclidean Geometry and Probability, the Department of Education in Mthatha District conducted a series of workshops. Educators responded positively to the support and appreciated the effort of the subject advisor in arranging and conducting successful training in the new topics. According to Bennie (1999), when Probability was introduced in C2005, the issue of the content knowledge of teachers was an area of concern. Probability being a complex topic and their observations of the difficulties teachers had with both Probability and Data Handling, and the limited extent of training teachers were given for C2005, they were concerned about the implementation of the Mathematics curriculum (Bennie, 1998). The situation in Mthatha District is a better situation than in the implementation of OBE in Kwazulu-Natal and Mpumalanga where most of the educators were not certain as to which available resources should be utilised as observed by Jansen and Christie (1999). This is in line with the suggestion by Taylor (2008) that intensive in-service training, in the order of weeks per year, is required to equip teachers with the knowledge they need to teach effectively.

Support by the School Management Teams

There were mixed feelings about the support given by the management. Most of the educators believed that their SMTs were very supportive in different aspects of the implementation of the CAPS curriculum though some educators commented that they were not supported financially by the school management due to insufficient funds. The study by Bush et al., (2009) in eight disadvantaged schools in South Africa revealed that the management of teaching and learning was adversely affected by the weak grasp by some of the principals of the new curriculum that was introduced (NCS). The present study revealed that there was much support from the SMTs in implementing the CAPS curriculum. The participants in the study also revealed that the subject advisor, most of the principals and SMTs as well as teachers performed their duties as curriculum leaders and managers who contributed to the effective management of the curriculum as suggested by the Curriculum Management and Delivery Strategy of Department of KZN (n.d.). The study also has similar results with the study conducted by Ndou (2008) on the implementation of C2005 in selected schools in Limpopo Province, where most of the SMTs were acquainted with significant knowledge and skills on curriculum change management.

Topics, syllabus coverage and time constrains
Majority of the educators were of the opinion that CAPS is a very good curriculum as it allows for logical thinking and it creates globally competitive mathematics learners. They raised concerns over learners’ lack of basic skills in Mathematics. It was suggested that learners should have a sound knowledge of basic concepts from Senior Phase. The suggestions that came from the educators were that the preparation from junior school should be improved; there should be an external exam in Grade 9 and Government needs to employ more mathematics teachers in the Foundation Phase and Senior Phase. It was also noticed that for most of the Grade 10 learners most of the topics seemed to be new and this makes the topic to lag for a longer period and in turn syllabus does not get finished on time. Bennie (1998) described a situation when the Curriculum 2005 was introduced, the document required that learners study Statistics from Grade 1 to Grade 9 and the document was designed accordingly for the different phases. When the MALATI materials were tried in the Senior Phase, however, they were faced with learners who had no prior experience of Statistics at school. This placed a constraint on the amount and the nature of the work trialled. Similar situation also was experienced when the Grade 9’s had to do a number of basic Probability activities before the actual Mathematics in the problems could be brought out. This led to frustration on the part of learners and teachers on the time being taken up by the topic (Bennie, 1999). A similar situation was also experienced by many educators participated in the study.

There were concerns that the changes would affect the Mathematics results negatively as learners complain that the two topics are more difficult than Transformation Geometry and Linear Programming, which were removed. CAPS has difficult topics compared to NCS. Removal of certain topics was a bit of concern as they were the topics learners found easy in the NCS curriculum. Lengthy syllabus in Grade 10 was a concern as educators struggled to finish it on time. One educator suggested that Venn-diagrams should be introduced in the Senior Phase. Circle geometry should be divided between Grade 10 and Grade 11 so as to have time to finish the syllabus. In Mathematics, the number of sub-topics in the CAPS has increased in each grade compared with those in the NCS, and overall, there was an increase of 15% in the total number of sub-topics prescribed across the FET phase. The evaluation team appointed by UMALUSI also raised concerns on the increase in breadth, especially in a curriculum that was already challenging for teachers to manage. They commented that ‘this increase in breadth could lead to teachers either omitting certain sub-topics, or compromising on the depth at which the sub-topics are dealt with’ (UMALUSI, 2014, p.46). A similar situation was also expressed by Bennie (1999) when Probability was introduced in C2005. While acknowledging the role that the introduction of new topics into the curriculum can play in challenging and broadening teachers’ views of Mathematics, they were concerned by the challenge put to teachers and learners by C2005 to explore new topics like Probability as well as to tackle all the other demands created by curriculum change. This kind of situation was evident from the responses in the present study.

It was a concern that there has been a lot of changes continuously and one educator mentioned that the new curriculum means waste of time and money and teachers need to be trained and it takes time to fully understand the new curriculum. So the changes have to be sustained. The time spent on workshop to familiarise with new topics was also a concern. This was a similar concern noted by Carter and Richards (1999) on curriculum coverage.

**Lack of resources and shortage of educators**
Lack of text books was one of the major concerns raised by many educators in the rural settings. Most of the schools relied on the Departmental supply of textbooks. Even though the minimum standard of one textbook per learner per subject was adopted as a norm by some Department of Education such as DoE, KZN, in Mthatha, many schools were not supplied with it. Financial constraints in the schools directly affected the teaching, as educators lacked reference books for their preparations. Learners attending classes without calculators was a major concern. The concerns from many educators in the present study was in line with Mkandawire (2010), who proposed that it was very difficult to implement a curriculum successfully if the education system had limited funding capacities. It was suggested that employment of teachers in the Foundation Phase was needed as learners lack basic skills in Mathematics. Educator-learner ratio must be monitored as Mathematics is a demanding subject. Phakathi (2015) reported that a report by the maths, science and technology ministerial task team, drafted in 2013, found that the country had a "serious lack of qualified, skilled and experienced mathematics, science and technology teachers". It was also noted by Fredericks (2015) that some schools do not even offer mathematics due to the non-availability of qualified competent maths teachers for the FET phase. The study also confirms such concerns raised from practising educators.

Disadvantaged educational background of learners

Learners from disadvantaged settings do suffer financially in terms of buying calculators and new text books unless it is supplied by Department of Education. Schools in the disadvantaged areas work on minimal budget and curriculum changes affect negatively on the effectiveness of its implementation. But efforts should be made to accommodate learners from disadvantaged educational backgrounds. South Africa faces the challenge of providing quality mathematics education for its multi-cultural society of 43 million people (Howie, 2003). Mji and Makgato (2006) noted that even the schools that offer mathematics and science do not have facilities and equipments to promote effective teaching and learning. Lack of appropriate learner support materials, general poor quality of teachers and teaching are some of the factors that have contributed to the lacking in the necessary informal mathematical knowledge of disadvantaged learners from the impoverished learning environments (Maree, Aldous, Hattingh, Swanepoel & van der Linde, 2006). The situation revealed by the present study is confirmatory to the findings mentioned by the above studies.

CONCLUSIONS AND RECOMMENDATIONS

The majority of the educators in Mthatha District, on varying degrees, had positive responses on the training by the Department of Education and the support given by the SMTs and negative responses on the implementation process due to shortage of educators, lack of textbooks, lack of basic skills of learners in Mathematics, lengthy syllabus, resources availability and financial constraints on teacher training. The positive responses outweighed the negative responses. Hence the conclusion of the study is that the educators in general are happy with the professional support and other enabling factors despite the concerns on the challenges experienced due to the curriculum reforms. In order to ensure effective teaching of the Mathematics CAPS curriculum, major issues are to be attended to by the Department of Education.

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Relationships between activity, content and depth of mathematics teachers’ talk in a professional learning community

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This paper explores how different activities of the Data Informed Practice Improvement Project (DIPIP) support different foci and emphases of teachers’ talk at different levels of depth. We examine conversations of mathematics teachers working in one professional learning community of the DIPIP project in terms of the changes in content and depth across different activities and over time. The analysis reveals two findings. First, the focus of teachers’ conversations was different in each activity which suggests that there is a relationship between activity and content. Second, the depth of teachers’ conversations was predominantly at the same level across all the activities. Therefore there is not enough evidence in this study to suggest that there is a relationship between activity and depth in teachers’ talk. Understanding the relationships between activity, content and depth can improve the quality of mathematics teachers’ talk in a professional learning community.

Key words: Professional learning community; Teacher conversations

Introduction

Teachers’ talk in a professional learning community (PLC) is “a discussion between peers that allows teachers to explicitly articulate, appreciate and extend their understanding of practice” (Nsibande, 2007, p. 4). PLC conversations can unlock the tacit knowledge of teachers, make that knowledge public and shared, and therefore subject to deliberate and thoughtful changes (Ayers, 2001). Teachers can grow professionally from talk by learning new knowledge and practices while at the same time unlearning some of their long held and often difficult to uproot ideas, beliefs, and practices (Corrigan & Loughran, 2008). The content and the quality of teachers’ talk may change or shift as a result of their professional growth over a period of time. Understanding how the content and depth shifts is important because it informs us about what teachers know and how they know it, what they are learning from the conversations and the possibilities and limitations for deeper conversations about mathematical content and pedagogy.

Professional learning communities can become rich sites for teachers’ professional development as they provide opportunities for teachers to talk, think and learn together about their practice and learners’ thinking. These opportunities determine what teachers talk about and the quality of their talk (Prestridge, 2009). Opportunities for teachers’ talk can emanate from watching videotapes of either their own teaching or the teaching of others (van Es & Sherin, 2008; Borko, Jacobs, Eiteljorg, & Pittman, 2008); participating in a lesson study where teachers jointly plan, observe, analyse and refine lessons (Posthuma, 2012; Coe, Carl & Frick, 2010) or engaging in error analysis in a number of activities, including test analysis, lesson planning and lesson reflection (Brodie & Shalem, 2011). Videotapes, lesson study and error analysis activities can afford teachers opportunities to deliberate on important issues regarding their classroom practices and learners’ thinking. However, teachers might be overly defensive or empathetic when analysing their own or others’ practices, which can hamper their professional growth. To overcome this limitation, professional learning communities...
can structure their discussions in particular ways that shape the way teachers talk and engage in group activities.

Productive teachers’ talk is characterised by a clear focus and an evolving structure that provides opportunities for teachers to learn in and from practice (Crespo, 2002; Brodie, 2014). Often, teachers’ talk is organised using protocols which provide mechanisms for fostering useful talk and avoiding defensiveness (Little, 2003). Protocols should not constrain the power or ability of teachers to share opinions and ask questions; rather, they organize the discussion and can create a safe atmosphere for asking questions and admitting to weaknesses in teachers’ practices and knowledge (Brodie, 2014). Although teachers in a professional learning community can and should negotiate the focus of their talk, protocols are helpful to maintain the focus of their talk in the varying activities. Crespo (2002) argues that the structure of teachers’ talk is not rigid but evolves, being influenced by what teachers focus on. Therefore research which shows how teachers’ conversations evolve is important. In this paper we explore the relationships between activity, content and depth in teachers’ conversations in order to understand how different activities that the teachers engage in support different foci and emphases of their talk at different levels of depth.

Content of teachers’ talk

Clark (2001) argues that “good conversations require good content” (p. 176) and good content makes teachers’ talk productive. The content of teachers’ talk includes practical and personal topics that elicit interest and help teachers make sense of their own experiences (Clark, 2001). The content of teachers’ talk may take various forms which depend on the activity teachers are engaged in, for example, teachers may talk about their classroom practices, mathematics concepts and learners’ data both in general and specific terms.

Studies of mathematics teachers’ talk (Hindin, Morocco, Mott & Aguilar, 2007; Rowland, 2012; Marchant & Brodie, 2016) found that teachers talk about their content knowledge and pedagogical content knowledge. Hindin, Morocco, Mott & Aguilar (2007) studied a group of mathematics teachers who were designing instruction to improve learners’ understanding, and found that teachers were verbally sharing their specialized content knowledge and pedagogical content knowledge for facilitating learners’ learning of the concepts. Rowland (2012) explored mathematics teachers’ conversations about integrating technology in their classrooms and found that teachers reflected on: how they planned their lessons to allow the use of available technology; difficulties in integrating technology in every lesson; and what was working and not working in their individual classrooms. Teachers were able to learn from their own and others’ reflections about classroom experiences. Rowland (2012) also found that during the professional learning community conversations, teachers talked about common mathematical problems which they discussed and solved together using their content knowledge. Thus, conversations were used as a forum to pool teachers’ collective content knowledge, to rearticulate their problems and to explore possible solutions (Miller, 2008).

Marchant and Brodie (2016) investigated teacher knowledge conversations in one professional learning community which was part of the DIPIP project and found that the community spent significant time on both pedagogical content knowledge (PCK) and content knowledge (CK) conversations. More time was spent on PCK than CK conversations, which was to be expected, because the DIPIP project focuses on pedagogical content knowledge. An unexpected result was that the teachers spent one third of their time on content knowledge conversations, because, as Marchant
and Brodie (2016) noted, in many cases pedagogical content knowledge conversations triggered content knowledge conversations. Content knowledge conversations were found to be most prominent in lesson planning and error analysis activities while pedagogical content knowledge conversations dominated in lesson reflection activities (Marchant & Brodie, 2016). In another study, Sun, Wilhelm, Larson and Frank (2014) found that conversations among mathematics teachers in a professional learning community often happen through seeking advice from each other. Such conversations were triggered by one colleague asking for strategies to teach some problematic mathematical concepts. Within these conversations with colleagues, teachers in their study talked about how they teach particular mathematical concepts, why some concepts are difficult for learners, and how they react to certain learners’ strategies or difficulties (Sun, Wilhelm, Larson & Frank, 2014).

These studies on the content of teachers’ talk have shown that teachers’ conversations tend to shift between talk on pedagogical content knowledge and content knowledge. A relationship between activity and content has also been suggested. These observations have prompted the following important questions about the content of mathematics teachers’ talk in a PLC for this study: what do teachers focus on in their talk as they engage in different activities; what appears to drive their focus; and does this focus vary over time.

**Depth of teachers’ talk**

In this paper we regard the depth of teachers’ talk as a measure of the quality of teachers’ engagement with mathematical ideas, issues of practice and learners’ thinking. There is some research (Marchant & Brodie, 2016; Eskelson, 2012; Coburn & Russell, 2008) on the relationships between the depth of teachers’ talk in professional learning communities and the activities they engage in. Marchant and Brodie (2016) used a coding scheme similar to the one used in the current analysis while investigating teacher knowledge conversations in one professional learning community of the DIPIP project. In both pedagogical content knowledge (PCK) and content knowledge (CK) conversations, they found that most of the level 3 (of 4 levels, defined below) conversations occurred during lesson planning and lesson reflection. The link between level 3 conversations and the two activities was attributed to the lengthy discussions that characterise lesson planning and lesson reflection which often lead to some substantial new understanding, a key requirement for level 3 conversations.

Coburn and Russell (2008) used the definitions of low, medium, and high depth categories to compare types of activities and depth of teachers’ talk between two groups of mathematics teachers teaching two different curricula. Teachers in each group engaged in slightly different activities. Activities observed in the first group were: task analysis, working on mathematics problems for the purposes of learning how to teach the lessons; analysis of strategies learners were using for solving mathematical problems; and structured reflection on practice. In contrast, types of activities in the second group were: explanation about how to use the curriculum, doing mathematics problems to learn how to do them, and mapping activities. Coburn and Russell (2008) found that different activities tended to result in different levels of depth. Activities in the first group resulted in discussions that were, on average, at a medium degree of depth while most of the activities in the second group resulted in discussions that were at a low degree of depth. The disparity of the depth of conversations between teachers in the first group and the second group suggests that activities that teachers engaged in appeared to influence the depth of teachers’ conversations.
Eskelson (2012) investigated mathematics teachers’ conversations in a teacher-initiated professional learning community by examining the depth of teachers’ talk associated with the various types of activities and how the depth changed over time. He identified five activities: work with mathematical tasks, unstructured reflection on practice, structured reflection on practice, discussion of instructional moves, and modeling instruction. Using a slightly adjusted version of Coburn and Russell’s (2008) categories of depth, Ekelson’s analysis showed that each of these activities typically produced discussions that were at a medium depth. This finding suggests that different activities did not influence the depth of the conversation and contradicts the findings of Marchant and Brodie (2016) and Coburn and Russell (2008). Our study examines this relationship further in relation to different activities in the DIPIP project and investigates whether the depth of conversation changes across activities and over time.

**Shifts in teachers’ talk**

What teachers talk about and the quality of their talk - content and depth - may change or shift as a result of teachers’ learning through engaging in professional learning activities over a period of time. Shifts may be in terms of content or depth of talk or both. Identification and analysis of shifts in the content and depth of teachers’ talk can inform an understanding of the possibilities and limitations for deeper discussions of content and pedagogy within the professional learning community. Understanding shifts also has the potential to highlight where there is need for greater teacher participation and engagement (Barret, 2009). Shifts in content and depth of teachers’ talk may indicate both positive and negative aspects of professional growth which can be understood in ways which further teachers’ professional development.

The literature reviewed in this paper has revealed some useful relationships between activity and content and activity and depth of teachers’ talk. Most of the studies reviewed argue that the activity that teachers engage in influences the content of their talk. However, there are not many studies of this kind and so more evidence is needed and there is some contradictory evidence on the influence of activity on the depth of teachers’ conversations, which is explored further in this study. In this paper, we examine what teachers choose to talk about, how they talk about their chosen foci and how the depth of their talk shifts over time in relation to different activities. This study which focuses on one professional learning community in the DIPIP project was guided by the following research questions:

1. What do teachers focus on in their talk as they engage in different activities and what appears to drive their focus? Does this focus vary over time?
2. What is the depth of teachers’ talk in relation to different activities and does the depth change over time?

**Methodology**

**DIPIP project design**

The DIPIP project is based on the principles of the professional learning community model of professional development which is a deliberate departure from the traditional model of professional development. The traditional model is characterised by once-off, one-size-fits-all, large and fragmented workshops for teachers based on the expertise of the individuals delivering the session. The PLC model supports teachers to talk, think and learn together in small groups and determine the
content based upon their teaching and learning needs. In the DIPIP project teachers are engaged in a developmental sequence of activities that supports them to identify and engage with learner errors (see Brodie and Shalem, 2011 for more detail). Learner errors are important as they provide a route into learner thinking. Teachers are encouraged to identify the reasoning, both valid and invalid, that underlies learners’ errors, so that they can build on this reasoning to develop the correct mathematical concepts (Brodie, 2013).

Sample

In this paper, we present an analysis of teachers’ conversations in one PLC of the DIPIP project, which consisted of nine mathematics teachers from a high school located in a suburb in Johannesburg. The mathematics department had eleven members, six of whom participated in the DIPIP project in 2012 and nine in 2013. The teachers had between 3 and 36 years of teaching experience, with the majority of teachers having taught between 3 and 9 years. Most of the teachers have diploma qualifications, two with an additional ACE, and three with degrees, one B.Ed and two BAs. Table 1 shows the details of a sample of 11 meetings that were coded out of a total of 37 meetings that were held and recorded in 2012 and 2013. There were 25 meetings in 2012 and 7 meetings were coded. In 2013 there were 12 meetings and 4 were coded.

Table 1. Summary of coded meetings.

<table>
<thead>
<tr>
<th>Date of meeting</th>
<th>Activity type</th>
<th>Type of data</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 March 2012</td>
<td>Error Analysis¹</td>
<td>Audio</td>
<td>01: 35: 53</td>
</tr>
<tr>
<td>8 March 2012</td>
<td>Error Analysis</td>
<td>Audio</td>
<td>01: 14: 23</td>
</tr>
<tr>
<td>7 June 2012</td>
<td>Readings and Discussion</td>
<td>Audio</td>
<td>01: 13: 39</td>
</tr>
<tr>
<td>19 July 2012</td>
<td>Lesson Planning</td>
<td>Audio</td>
<td>01: 15: 58</td>
</tr>
<tr>
<td>16 August 2012</td>
<td>Lesson Reflection</td>
<td>Audio</td>
<td>01: 44: 26</td>
</tr>
<tr>
<td>30 August 2012</td>
<td>Lesson Reflection</td>
<td>Audio</td>
<td>00: 58: 25</td>
</tr>
<tr>
<td>6 September 2012</td>
<td>Lesson Reflection</td>
<td>Audio</td>
<td>01: 06: 35</td>
</tr>
<tr>
<td>14 February 2013</td>
<td>Error Analysis</td>
<td>Video</td>
<td>01: 09: 31</td>
</tr>
<tr>
<td>15 April 2013</td>
<td>Readings and Discussion</td>
<td>Audio</td>
<td>01: 17: 54</td>
</tr>
<tr>
<td>29 April 2013</td>
<td>Readings and Discussion</td>
<td>Video</td>
<td>01: 06: 11</td>
</tr>
<tr>
<td>1 August 2013</td>
<td>Lesson Reflection</td>
<td>Audio</td>
<td>01: 18: 51</td>
</tr>
</tbody>
</table>

The sample was chosen to reflect the range of activities that took place each year, and at the same time to

¹ We note here that although we call the first activity type “error analysis”, in fact all meetings involved some form of error analysis. In this case, the focus was analyzing learner errors on tests, and so might be better called “test analysis”.

27
be able to compare similar activities across the two years. There were two different facilitators – in 2012 the facilitator was a university-based member of the DIPIP team, while in 2013 the facilitator was a teacher at the school, who had been part of the community in 2012 and who was chosen by the PLC in consultation with the DIPIP team\(^2\). The total time for all the sessions in 2012 was 9 hours and 9 minutes and in 2013 was 4 hours and 52 minutes. The total coded time was 6 hours and 29 minutes in 2012 which makes 72% of total session time and 3 hours and 42 minutes in 2013 which makes 77% of the total session time.

**Coding**

In order to analyse teachers’ talk in the DIPIP professional learning communities, a coding scheme was developed, which focuses on what teachers talk about and how they talk about it. The coding scheme has three main components: Activity, Content and Depth. Activity codes indicate which of the DIPIP activities the teachers are discussing (see Figure 1 below).

![Figure 1. DIPIP coding scheme.](image)

There are six substantive Activity codes: error analysis; curriculum mapping; learner interviews; readings and discussion; lesson planning and lesson reflection. In this paper we do not discuss curriculum mapping and learner interviews. The substantive Activity codes are coded further with Content and Depth codes. The four Activity codes: set up; closure; off topic; and watch video were not coded further and were not used in the analysis.

Content codes are underpinned by the kind of knowledge teachers are expected to draw on and to develop. “Learner” includes talk where teachers focus on learners’ understanding, strategies, language, attitudes or participation. “Mathematics” includes teacher talk about mathematics, for example the teachers solving mathematical problems themselves or talking about their own mathematical knowledge. “Practice” focuses on talk related to instruction and resources in class that is not about learner thinking; and “DIPIP Priorities” includes talk on eliciting and understanding learner thinking and reasoning behind the error. An important difference should be noted between

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\(^2\) The school-based facilitators received training from the DIPIP team for eight two-hour sessions per year.
learner understanding under “Learner” and learner thinking under “DIPIP priorities”. Learner understanding refers to the more superficial features of what learners do or say – a description of their knowledge or strategies, while learner thinking refers to the reasoning behind the learner’s error, a deeper level of analysis on the part of the teachers. Probing was discussed as a means to elicit and understand learner thinking. The other DIPIP priorities are not explained here because they are not discussed in this paper. The Content codes were developed from work by Borko and her colleagues (Borko, Jacobs, Eiteljorg & Pittman, 2008) to reflect DIPIP goals.

The Depth codes were developed by drawing on work on mathematics teachers’ noticing (van Es, 2011). Each of the content areas is coded according to four levels. Level 1 includes little or no evidence for what might be impressionistic, descriptive or evaluative comments. There is no engagement with mathematical ideas. Level 2 includes a move towards more interpretive and analytic comments, based on specific evidence. There is some engagement with mathematical ideas and attempts to explain issues mathematically. Level 3 has a more strongly analytic focus, informed by evidence. There is engagement with ideas with some new understandings for some of the participants. Level 4 maintains the strongly analytic focus of level 3 and teachers make appropriate generalisations based on evidence and can critique the knowledge based on their own evidence. General and new mathematical ideas are discussed substantially.

Procedure

The coding was done using a software programme called Studiocode™, which allows the video and audio recordings to be plotted along a timeline and coded. The first step was to create conversation units. A conversation unit is a sequence of turns on a single topic. Each conversation unit was then labelled according to Activity. Thereafter the six substantive activities were coded further in terms of Content and Depth. To ensure the coding reliability, the two authors together with a doctoral student coded three PLC meetings in another community and then discussed the coding results. Inter-rater percentages of agreement were found to be 78%. Thereafter, the first author coded all the sessions and the second author reviewed these. Disagreements were resolved by discussion.

Analysis and discussion of data

In order to analyse teachers’ talk in the PLC, a Studiocode™ scripting report template was developed, which captures the time spent by the community on each Activity, Content and Depth code. A script report was generated for each DIPIP activity that teachers in this PLC engaged in. The time spent on each Content and Depth code in different sessions of the same Activity was combined for each year and converted to a percentage of the total time for all the coded conversation units. The time for content codes under learner were combined as learner understanding in the analysis. Percentages of the coded time³ were used to track the changes in foci and depth of teachers’ talk over the two years; and to explore the relationships between activity, content and depth. The results for the content and depth codes are presented and analysed separately to provide answers to the research questions and enable us to examine closely the activity-content and activity-depth relationships.

The content of teachers’ talk

³ Coded time is the time the PLC spent on each of the following DIPIP activity codes: error analysis, readings and discussion, lesson planning and lesson reflection. Time spent on set-up, closure, off topic and watch video is not included.
Table 2 provides a summary of the coded time and their percentages for all the content codes in each activity for the eleven PLC meetings over the two years.

**Table 2.** Summary of the content of teachers’ talk in 2012 and 2013.

<table>
<thead>
<tr>
<th>Activity</th>
<th>DIPIP ACTIVITIES IN 2012</th>
<th></th>
<th>DIPIP ACTIVITIES IN 2013</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Meetings</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td><strong>Error Analysis</strong></td>
<td><strong>Time</strong></td>
<td><strong>%</strong></td>
<td><strong>Time</strong></td>
<td><strong>%</strong></td>
</tr>
<tr>
<td>Learner Understanding</td>
<td>00:48</td>
<td>30</td>
<td>00:19</td>
<td>28</td>
</tr>
<tr>
<td>Maths General</td>
<td>00:05</td>
<td>7</td>
<td>00:25</td>
<td>35</td>
</tr>
<tr>
<td>Maths Explicit</td>
<td>00:50</td>
<td>32</td>
<td>00:18</td>
<td>26</td>
</tr>
<tr>
<td>Practice</td>
<td>01:00</td>
<td>38</td>
<td>00:31</td>
<td>45</td>
</tr>
<tr>
<td><strong>DIPIP: Learner Thinking</strong></td>
<td>00:09</td>
<td>58</td>
<td>00:24</td>
<td>36</td>
</tr>
<tr>
<td><strong>DIPIP: Probing</strong></td>
<td>00:01</td>
<td>2</td>
<td>00:02</td>
<td>5</td>
</tr>
<tr>
<td><strong>DIPIP: Reproduces Blame</strong></td>
<td>00:09</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DIPIP: Working as Community</strong></td>
<td>00:01</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Coded Time</strong></td>
<td>02:38</td>
<td>01:09</td>
<td>01:11</td>
<td>01:35</td>
</tr>
</tbody>
</table>

**Error Analysis**

The DIPIP protocol for the analysis of the test encouraged teachers to first talk about each question in the test in terms of what it was assessing - by asking the question: what concepts are required to get this item correct? After discussing each question, teachers identified the frequent errors learners made. The teachers then discussed the possible reasons behind each error by putting themselves in the position of the learner and trying to understand how the learners were thinking when they made the errors (Brodie, 2014). Teachers then discussed possible ways in which their teaching or the curriculum could be linked to the errors. They deliberated on some strategies they might be using that could perpetuate learner errors. The analysis in Table 2 shows that in 2012 the teachers’ talk in Error Analysis sessions focused on learner thinking (38%), practice (32%) and learner understanding (30%). In 2013 there was no talk on learner understanding and some talk on mathematics explicit concepts (30%), practice (34%) and learner thinking (36%).

**Readings and Discussion**
Based on the error analyses, the community decided on a critical concept (Brodie & Shalem, 2011), which gave rise to many of the errors, and on which they would prepare joint lessons. Teachers discussed papers which they were given to read as preparation for planning lessons together in relation to the critical concepts. The idea of the readings and discussions was for teachers to see that research has identified many of the errors they see in their classrooms and has some explanations for why these occur so pervasively. Typical concepts were: the meaning of variables, expressions and equations; and the use of the equal sign. The papers identified key misconceptions in each of these concepts and the reasoning behind them. After discussing the concepts and misconceptions in the papers, teachers talked about different strategies that they could use to teach the difficult mathematical concepts. Table 2 shows that the teachers’ conversations in these sessions in 2012 focused predominantly on learner thinking (45%), with less on learner understanding (28%) and practice (26%). In 2013 teachers’ there was more talk on learner understanding (42%) with less talk on practice (23%) and on learner thinking (22%).

Lesson Planning

There were no discussions on lesson planning in 2013. In 2012, teachers’ discussions were on the concepts they had chosen from their readings and discussion and how to develop lessons on these concepts. They discussed how they were going to teach expressions, equations and formulae together so that learners would be able to differentiate between the three. Explicit mathematical language and concepts were focused on as the teachers discussed the planned concepts. The results in Table 2 show that teachers focused predominantly on practice (51%) and explicit mathematical concepts (35%). It is significant that the lesson planning session gave the most focus on mathematical concepts of all the activities, because the teachers were discussing the mathematics concepts they were going to teach and actually solved some of the problems. This result is similar to Marchant and Brodie’s (2016) findings that lesson planning allowed for more content knowledge conversations.

Lesson Reflection

Each teacher was given their lesson videotapes to watch and identify the errors that learners made in class and to see how they (teachers) dealt with those errors in class. Each teacher chose an episode in which they thought they had engaged well with a learner error and one where they thought they had engaged not so well. The aim of reflecting on the lessons was to provide teachers with the opportunity to look into their practice with their colleagues and use the feedback they got in the PLC to inform how they will work with learner errors in the future. Table 2 shows that the focus of teachers’ conversations in these sessions was on practice - 76% in 2012 and 71% in 2013. This can be linked to the fact that teachers’ discussions were mainly on how they dealt with learner responses in class and other PLC members helped in how the teacher could have dealt with learner responses. Teachers also talked about what they did in class, the activities that their learners were engaged in, learners’ responses and errors, how they dealt with learner errors in their lessons and their mannerisms after watching their own videos, which they were not aware of. In both years there was some talk on learner understanding which can be attributed to episodes where teachers talked about what could have led learners to commit the errors that they had identified in their lessons. In 2012 there was some talk on learner thinking while in 2013 there was none, but in 2013 there was some talk on probing learner thinking, which is also a DIPIP priority.

Discussion of content
Table 3. Content of teachers’ talk across the activities.

<table>
<thead>
<tr>
<th>Activity</th>
<th>DIPIP ACTIVITIES IN 2012</th>
<th>DIPIP ACTIVITIES IN 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Error Analysis</td>
<td>Readings &amp; Discussion</td>
</tr>
<tr>
<td>Learner Understanding</td>
<td>30</td>
<td>28</td>
</tr>
<tr>
<td>Maths General</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Maths Explicit</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Practice</td>
<td>32</td>
<td>26</td>
</tr>
<tr>
<td>DIPIP: Learner Thinking</td>
<td>38</td>
<td>45</td>
</tr>
<tr>
<td>DIPIP: Probing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIPIP: Reproduces Blame</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIPIP: Working as Community</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

There are different activity-content relationships in the teachers’ talk that emerge from Table 3 above based on the percentage of time teachers spent on each content code in each activity over the two years. Table 3 shows that in this PLC, different DIPIP activities support different foci over the two years. Learner thinking and practice were prominent in error analysis in both years. Teachers spent most of their time trying to understand how the learners were thinking when they made the errors and discussing possible ways in which their teaching could be linked to the errors. During readings and discussion teachers focused on learner thinking and learner understanding, with some focus on practice. The readings supported discussions about how to improve learner understanding and thinking in the difficult mathematical concepts and the teachers discussed some implications for practice. The lesson planning session in 2012 gave the most focus on practice and mathematics concepts because the teachers were discussing the mathematics concepts they were going to teach and actually solved some of the problems. In lesson reflection sessions, practice was predominant as teachers talked about what they did in class, the activities that their learners were engaged in and how they dealt with learner errors in their lessons.

There were significant changes in content for some activities from 2012 to 2013. The percentage of time teachers spent on learner understanding in error analysis decreased from 30% in 2012 to 0% in 2013. In 2012, teachers regarded learner understanding as the main contributor to learner errors but after learning about how learner errors occur they started to realise how their practice contributes to these errors. This realisation could have led to a decrease in the percentage of talk about learner understanding in error analysis. There was an increase in the percentage of talk about learner understanding during readings and discussion from 28% in 2012 to 42% in 2013 as teachers began to deliberate more about the learners’ strategies. The teachers’ focus on practice during lesson reflection decreased slightly from 76% in 2012 to 71% in 2013. Talk about learner thinking also decreased from
10% in 2012 to 0% in 2013 during lesson reflection. These small decreases can be accounted for by the discussions on probing which occurred for the first time in 2013. Probing is a part of practice but is coded as a DIPIP priority because the DIPIP project encouraged probing as a means to understand learner thinking. While talk about probing increased, we see that talk about learner understanding also increased, while talk about learner thinking, another DIPIP priority decreased.

The depth of teachers’ talk

Table 4 provides a summary of the time and percents that teachers spent at each level of depth in each activity for the eleven PLC meetings over the two years.

Table 4. Summary of the depth of teachers’ talk in 2012 and 2013.

<table>
<thead>
<tr>
<th>Depth</th>
<th>DIPIP ACTIVITIES IN 2012</th>
<th>DIPIP ACTIVITIES IN 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Activity</td>
<td>Error</td>
<td>Readings &amp; Discussion</td>
</tr>
<tr>
<td></td>
<td>Time</td>
<td>%</td>
</tr>
<tr>
<td>Level 1</td>
<td></td>
<td></td>
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<tr>
<td>Level 2</td>
<td>00:52</td>
<td>33</td>
</tr>
<tr>
<td>Level 3</td>
<td>01:28</td>
<td>56</td>
</tr>
<tr>
<td>Level 4</td>
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<td>12</td>
</tr>
<tr>
<td>Coded Time</td>
<td>02:38</td>
<td>01:08</td>
</tr>
</tbody>
</table>

Table 4 shows that the depth of teachers’ talk in error analysis in 2012 was mostly at level 3 (56%) and level 2 (33%) while in 2013 it was mostly at level 2 (62%). Teachers’ talk on readings and discussion was mostly at level 3 (44%) and level 2 (35%) in 2012 and in 2013 level 2 discussions increased to 79% while level 3 discussions dropped to 6%. There was also an increase in the level 1 discussions during readings and discussion from 0% in 2012 to 15% in 2013. Level 2 discussions were prominent in teachers’ talk about lesson planning in 2012 with a percentage of 45%, while there was also some level 3 and 4 discussion – adding up to 51% together. Teachers’ discussions in lesson reflection were mostly at level 2 in 2012 with 54% and level 3 in 2013 with 51%. Level 3 discussions during lesson reflection increased to 51% in 2013 while the level 1 discussions declined to 10% in 2013.

Discussion of depth

Table 4 shows that level 2 discussions were prominent across all the activities for both 2012 and 2013, supporting Eskelson’s (2012) finding that different activities do not influence the depth of the conversation. However, the decrease from level 3 to level 2 in Error Analysis and Readings and

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4 There was only one session on Lesson Reflection in 2013 so the percentages may suggest that the changes are bigger than they really are.
Discussion over the two years and an increase in level 3 from level 2 and level 1 in Lesson Reflection over the two years suggests some nuance in this finding and shows that the depth of conversations did shift over time, in different directions, for the different activities. We are currently analysing the different facilitation practices over the two years and hope that this will give some explanation for the differences in depth.

Conclusions

The aim of this study was to explore the relationships between activity, content and depth in mathematics teachers’ conversations in a professional learning community. We have presented some evidence which shows that teacher conversations during particular activities were more focused on specific content over the two years as follows: error analysis focused more on learner thinking; readings and discussion focused more on learner understanding; lesson planning focused more on practice and mathematics content; and lesson reflection focused more on practice. These findings suggest there is a relationship between activity and content which supports the findings in the literature (Marchant & Brodie, 2016; Rowland, 2012; Hindin, Morocco, Mott & Aguilar, 2007). The results have also shown that there were changes in the foci of teachers’ conversations for some activities from 2012 to 2013, for example during error analysis in 2012 teachers focused more on learner understanding because they regarded it as the main contributor to learner errors but after learning about how learner errors occur they started to realise how their practice contributes to these errors. As a result they shifted their focus from learner understanding to practice. This means that changes in foci over time may indicate teacher professional growth. In relation to depth, Level 2 conversations were found to be prominent across all the activities which means that there is not enough evidence in this study to suggest that there is a relationship between activity and depth in teachers’ talk, which supports Eskelson’s (2012) finding. However, there were some increases and decreases in levels of depth in some activities which shows that the depth of teachers’ conversations did shift over time. These shifts in depth may be related to the change of facilitator from university-based in 2012 to school-based in 2013. From the literature reviewed in this paper and the analysis that we have done, we suggest that both the activity-content and activity-depth relationships require further study in different communities or in larger samples of coded sessions.

References

Teacher perceptions of the successes and challenges of a mathematics homework drive for primary learners

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In this paper I argue for the importance of foregrounding homework as a practice that can support student learning, especially in poorer performing schools where learners lag behind with key foundational knowledge. A socio-constructivist perspective of learning informs this argument. Furthermore this paper is guided by the assumption that developing productive learning dispositions is key to supporting learning. Data from teacher questionnaires repeated annually over a two-year period provide an empirical basis to support the argument. This data emerges from 5 years of research and development work of the South African Numeracy Chair Project with twelve schools in the broader Grahamstown area. The data points to strong take-up by teachers of the homework drive project that was introduced and enabled by the provision of learner take-home workbooks. The data indicates a range of positive benefits for learners as noted by participating teachers.

Introduction, Context and Rationale

Mathematics education in South Africa is struggling according to a wide range of regional, national and international assessments (see Fleisch, 2008; Reddy al., 2015; DBE, 2014). Finding ways forward to the many challenges that contribute to poor learning and performance in this learning area is essential. A wide range of research points to critical need for addressing the challenges of mathematics education especially in the primary years where the majority of learners already fall two grades behind expectation by the intermediate phase (e.g. Taylor, 2015). These include addressing mathematics knowledge for teaching (Adler, 2005); improving teaching pedagogies that foreground sense-making (Venkat & Naidoo, 2012; Hoadley, 2012), running after school mathematics clubs aimed at extension and remediation (Graven & Stott, 2012; Stott & Graven, 2013), increasing teaching time and the opportunity to learn within schools (Carnoy et al., 2011) and so forth. All of these are important and I would argue that a combination of these strategies and related intervention projects should work together if we are to progress in turning this crisis around. However the aspect that I choose to focus on in this paper is that of extending students’ opportunity to learn beyond the school day through building mathematics homework into the everyday practices of teachers and learners.

My reason for the focus on homework in this paper relates firstly to my broader research work within the South African Numeracy Chair Project (SANCP) that points towards weaknesses in primary mathematics student learning dispositions which stand in contrast to the requirements of the current Curriculum and Assessment Policy (CAPS) curriculum (DBE, 2011). Additionally I have argued that learning dispositions are a largely unexplored area of South African mathematics education research and that learning dispositions are possibly a key contributing factor to our poor comparable performance on regional studies such as Southern and East African Consortium for Monitoring Educational Quality (SACMEQ). Other Southern African countries participating in SACMEQ have similar levels of poverty, health issues such as HIV and AIDS, low parental literacy levels and language challenges and many spend far less on education than South Africa. Yet the learners in these countries outperform our learners on comparative studies in mathematics. I have thus argued that perhaps greater attention must be given to repairing the passive learning dispositions and the views that mathematics is not for all, promoted under apartheid. See Graven & Heyd-Metzuyanim (2014) and Graven (2014) for elaboration on the possible role of dispositions in our low levels of mathematical learning.
Within a range of literature defining key learning dispositions generally (e.g. Carr & Claxton, 2002), and productive mathematical learning dispositions more specifically (Kilpatrick, Swafford & Findell, 2001), the notion of steady effort and/or developing resilience and independence are foregrounded. Yet when our project began working with teachers and schools in the broader Grahamstown area few of them gave homework on a daily basis suggesting a wide range of reasons for this. This resonates with Spaull’s (2013) findings from the SACMEQ111 results for Grade 6 South African learners that only 49.9% to 56.1% of quintile 1 and quintile 4 schools respectively give homework ‘most days of the week’. Furthermore he found that:

The only common factor in the mathematics regression which is not common in the reading regressions is the dummy variable ‘received homework most days of the week.’ Compared to students who never receive homework, any homework frequency is positively associated with mathematics performance in poorer schools. (Spaull, 2013, 443)

Aside from supporting performance, homework can have motivational benefits for learners and help learners develop strategies for coping with mistakes and difficulties (Bempechat, 2004) and skills in managing tasks independently (Corno & Xu, 2004). Furthermore homework can increase time spent on written learning activities where learners work independently at their own pace. At the start of the project, analysis of a sample of a range of learner books across schools pointed to low levels of written learner activity by the end of each year (see also Hoadley, 2012) and the echo of what Brombacher refers to as the 4 sums a day practice to enable teachers to comply with the regulation of marking all learner work (Graven, submitted). In this respect I felt it important that opportunities for learners to do mathematics increased. Additionally I wanted to increase learner opportunities for working independently, at their own pace and for consolidating and developing fluency in relation to what was learnt in class. Thus in June 2012 the ‘homework drive’ was introduced to all teachers participating in the Numeracy Inquiry Community of Leader Educators (NICLE) of the SANCP. This project is explained further below.

SANCP: Intervention projects and research methods

NICLE began in 2011 as the key intervention project of the SANCP at Rhodes University in the Eastern Cape. SANCP researches sustainable ways forward to the challenges in mathematics education through partnering researchers with schools catering for learners from predominantly low Socio-economic Status (SES backgrounds) in the broader Grahamstown area. The Eastern Cape is one of the poorest provinces in South Africa and has amongst the lowest ANA results. The SANCP team consists of post-graduate primary mathematics researchers, supervised by the Chair (author), who simultaneously conduct research and development projects aimed at improving primary mathematics learning in Eastern Cape schools. The SANC is one of six mathematics education Chairs in South Africa, which are funded by private foundations and the DST while administered by the NRF. As such these chairs differ from other Chairs in the SA Chairs Initiative as they are tasked with merging research and development objectives through partnering with a cluster of at least ten schools serving learners from predominantly low SES backgrounds.

NICLE focuses on the critical transition from Foundation to Intermediate phase (i.e. Grade 3 and 4). It runs as a professional community of practice, which has met on a regular basis over the past five years. NICLE is constituted by the SANCP team of researchers, occasional invited education ‘experts’ (local, national and international) and about 40 regularly participating teachers, principals
and district officials who engage each year in workshops interrogating and implementing research informed ideas for strengthening primary mathematics teaching and learning in their schools. Workshop activities focus on ways to remediate and enable learner progression from predominantly concrete forms of calculation that tend to dominate the local primary landscape (Hoadley, 2012; Schollar, 2008). SANCP team members bring up to date research based resources for teaching and remediating mathematics learning to the community while teachers contribute critical classroom teaching experiences and knowledge of learners. Sessions promote increasing classroom participation and connectionist teaching (Askew, Brown, Rhodes, Johnson & William, 1997) in ways that foreground sense-making rather than ritual participation (Heyd-Metzuyanim & Graven, 2015).

In the second year of NICLE (i.e. 2012) teachers were increasingly willing to share their ideas, methods and opinions and some NICLE teachers chose to further their studies. Thus there is some overlap between the research community of practice (COP) within SANCP and the NICLE COP and several teachers have taken the lead in running sessions or aspects of sessions. We developed the ‘agreement’ with teachers that receiving any resource comes with the commitment of trying it in one’s class and providing feedback in subsequent sessions on this experience. This worked well to increase teacher input and enables us to gauge the ‘take-up’ of workshop ideas. A key development in the NICLE program in 2012 was the introduction of the homework drive.

This drive provides teachers with homework resource materials for all Grade 2, 3 and 4 learners (and is based on teachers’ commitment to use them for homework purposes). The design principles for each of the homework books are that: activities are relatively easy to access with simple instructions/language accompanied by examples (they should not need mediation); activities are progressive and structured to encourage development of increasingly efficient strategies; activities encourage practice of ‘basic facts’ (Askew, 2012); across activities there is connection between concepts through the use of multiple representations such as number lines, hundred charts and so forth, and finally, learners are encouraged to make up problems of their own to solve enabling learner extension and some meta-analysis of question/activity types. The homework books are workbooks with place for working. Workbooks are printed for learners in English, Afrikaans and isi-Xhosa and are provided to teachers in the languages required by their learners.

Teachers get the next set of homework books for their class once a sample of their learners’ completed homework books are shown to our project administrator. The reason for requesting only a sample of complete learner books related to initial teacher comments that they did not give homework because not all children did all their homework. We agreed that rather than not give any homework as a result it was important to allow learners who were willing to work hard and put in the steady independent effort required by homework the opportunity to do so. I shared my experience of providing homework books to learners in the first Grade 3 maths club I ran and that the majority of learners relished the opportunity to do regular homework. Half of the learners in this club completed the 48 page books I gave them in the first week even though I only suggested they do one page a day. Thus while it was important to encourage all students to do their homework I emphasised that we did not expect 100% learner compliance. Additionally we expected learners to work through the books at differential paces and indeed this was an advantage as it is often difficult to enable differential working in whole class
activities. However if a learner wanted the next book they would have to show their teacher that they had completed the previous homework book.

All Grade 2, 3 and 4 NICLE teachers participated in the homework drive in 2012 and 2013 and all provided samples of learner books, as required in order to receive the next set of books. The homework drive continues to date. While we acknowledge that there is not 100% buy in from learners in terms of always doing their homework, all Grade 2-4 teachers in NICLE in 2012 and 2013 were using the books for the allocation of at least some of the homework given to learners. At the end of 2012 and 2013, as part of the end year NICLE questionnaire, teachers were asked to provide feedback on their experiences of the homework drive. The responses of the Grade 2-4 NICLE teachers on these questions provide the empirical data informing this paper.

**Research frame and methodology**

SANCP draws on socio-cultural and socio-constructivist perspectives of learning for both research and development. Wenger’s (1998) community of practice perspective of learning informs both the design of NICLE and the workshop activities. Also research into the nature of teacher learning within NICLE draws on this perspective (see for example Pausigere & Graven, 2014). Within this perspective, learning involves four central interconnected and mutually defining components of learning namely: meaning (learning as experience); identity (learning as becoming); community (learning as belonging) and practice (learning by doing).

Focusing on the nature of mathematics learning and how learners develop mathematical proficiency the project draws primarily on a socio-constructivist perspective. Thus learning mathematical concepts requires learners to actively construct and build concepts on existing knowledge. The hierarchical nature of mathematics requires that learners progressively develop this knowledge through interaction with a range of learning resources including peers and more knowledgeable others. In respect to the latter a willingness to engage with others in mathematical communication is important and this relates to the importance of developing a productive disposition.

Our project team has researched the nature of teacher and student learning, across the five years of the project (2011-2015) through collecting a wide range of quantitative and qualitative data in partner schools. These include our own annual mathematics learner assessments and a mathematics learning disposition questionnaire across all grade 3 and 4 learners in 11 schools (an average of approximately 1200 learners per year). Additionally teacher questionnaires, interviews and classroom observations have been conducted across the 5-year period.

Teacher questionnaires are given annually to teachers, which gather data on teacher experiences of their participation in NICLE and the various intervention projects attached to SANCP. Teachers participating in NICLE come from a range of project schools in the broader Grahamstown area and include a farm school, ex House of Representatives (HoR) schools, township schools and ex model C (formerly White only) schools. Data, and published research, points to many successes in terms of increased teacher confidence and commitment to practices that foreground sense-making and conceptual understanding, as well as data that shows overall improved learner performance on a range of assessments from 2011 to 2014 (SANCP, 2015; Graven, in press). However, here the focus is only on one aspect of the NICLE project – namely teacher experiences of the homework drive. Thus I
draw on teacher comments on the homework drive in the annual (end year) NICLE questionnaires of 2012 (end of the first year it was introduced mid year) and 2013 (the end of the second year in which it ran for a full year). The empirical data shared is thus the written teacher responses of the Grade 2, 3 and 4 teachers on the homework drive in the NICLE 2011 and 2012 questionnaires. NICLE provides the empirical field for this research into teacher experiences of the homework drive and as such the sample of teachers is an opportunity sample.

The homework drive and books focused on Grade 2-4 foundational mathematics concepts as they were deemed too difficult for Grade 1 learners and too easy for Grade 5-6 learners although some of these teachers did use the books for extension or remediation for some learners. In 2013, 23 of the 35 NICLE teachers were Grade 2, 3, or 4 teachers. Due to some changes in teachers in participating schools only 21 of the 23 Grade 2-4 teachers participated in NICLE in both 2012 and 2013. This paper thus reports on the written responses of those 21 Grade 2, 3 and 4 teachers who participated in NICLE across 2012 and 2013. All Grade 2 - 4 NICLE teachers elected to participate in the homework drive. These 21 teachers come from 8 different schools including from three township schools (7 teachers) and four ex HOR schools (13 teachers) and one ex model C school (1 teacher). Two teachers taught Grade 2, 13 taught Grade 3 and 6 taught Grade 4.

The questions relating to the homework drive project in the annual questionnaires were stated as follows:

- Do you give homework to learners? Say whether this is seldom, often or always.
- What are your experiences of the homework drive? Have you found it useful and to what extent have learners completed homework regularly?

The questions were phrased in the same way in 2012 and 2013. In 2012, 23 of the 44 NICLE participants were Grade 2, 3 or 4 teachers and thus had the opportunity to participate in the homework drive.

Thematic analysis was conducted on teacher responses reported in the findings below.

**Findings and discussion**

The first question simply enquired as to whether teachers gave homework and, if so, the regularity of it. All teachers answered ‘Yes’ to the question in both 2012 and 2013. In terms of the regularity of this in 2012 one third (7/21) said often while almost two thirds (12/21) said always. One teacher did not state the frequency and simply answered yes. Similar responses were evident in 2013 where one third said often and almost two thirds said always while two teachers did not state the frequency but instead wrote:

- Yes. It improves their mathematical skills, children enjoy homework – especially NICLE homework books! Children make their own homework, they love it.
- Yes. The homework drive has done so much for us. The different levels at which the activities has been set is so helpful.
The issue of enjoyment of homework by learners was similarly noted in several teacher responses who said they gave homework always because learners enjoyed it. Of interest this differs from the extent to which NICLE teachers said they gave homework at the start of NICLE (i.e. March 2011) – one fifth of these teachers indicated that they either did not give homework or only gave homework sometimes and several cited reasons of learners not doing homework and or problems with parents ranging from parents being unable to support homework or parents doing the homework for learners (SANCP, Indicator Report 2015).

The questions that focused on teacher experiences of the homework drive, included:

What are your experiences of the homework drive? Have you found it useful and to what extent have learners completed homework regularly? Despite the limitations of gathering data in questionnaire format, analysis of teacher responses gave rise to several interesting themes as to the aspects teachers valued in this homework drive and their experiences of it. The absence of certain themes, that I might have expected given my own motivation for the homework drive, was similarly of interest.

Following a thematic analysis of all twenty teachers’ responses across the two years the following themes emerged:

**Learner enjoyment**

Six of the 21 teachers in 2012 commented on how children enjoy, love or are excited by the homework drive. For example:

- They loved the homework book but did not want to only complete the given pages. Therefore I have allowed those to complete as many pages as they want to.
- Learners enjoyed homework activities as a result they were asking for more activities.
- Learners were excited and some completed the books on their own before they were told to.

The above points to homework providing some learners with increased agency to go beyond what is merely requested of them. Allowing these learners opportunities to extend themselves and practice more than is required by teachers is an important aspect of enabling learners’ ownership and independence in relation to their afterschool learning.

**Steady effort (or regularity of work)**

While a key part of the rationale for introducing the homework drive was to develop ‘habits’ of working regularly and independently on mathematics this aspect was only noted by two teachers in the 2012 responses. For example one teacher wrote:

- The drive supported learners to do their homework regularly.

**Supporting mathematical learning (practice and strategies)**
In the 2012 responses only one teacher comment related to the value of homework in terms of enabling learners to practice maths (which relates to the above category) while another commented on the value for improving calculation strategies:

It is useful because they are getting a lot of practice.

Their confidence improved a lot and their calculation strategies too.

*Learner confidence*

In 2012 two teachers commented that homework supported the development of learner’s’ mathematical confidence (as seen in the quote above). The second teacher noted:

And learners feel so proud that nobody is helping at home-homeworks it improves their confidence

*Comments in relation to parent support or absence of it*

Several (4) teacher comments related positively to parental support for the homework drive. For example:

And it has also brought the parents and children closer to complete their homework

Parents were more aware of learners’ progress

Balancing these comments on the positive aspects of parental involvement were four negative comments relating to the challenges of parental involvement and/or often the lack of it.

It is only 2-3 learners who don’t do homework because they don’t have parents at home to support them.

One problem is that parents are not able to guide homework, because some of them are working hard and others are not literate (most of them).

I found that more often learners don’t do homework because of lack of help at home.

Sometimes parents write homework themselves instead of helping their learners and as an educator you have to educate parents first about the importance of homework.

The latter comment is important and points to the importance of teacher parent meetings in order to strengthen such initiatives.

Several teachers simply wrote that the homework drive was useful because learners did their homework. Such responses while indicating acknowledgement of the usefulness did not provide information as to why teachers find homework useful.

Similarly to 2013, the greatest frequency of teacher comments on homework was on the theme of learner enjoyment (7/21 teachers) and again there were several comments about learners being eager
to go beyond the prescribed amount. Other themes discussed above similarly emerged in the 2013 (i.e. at the end of the second year of the homework drive). For example relating to the *mathematical* value of homework *per se* one teacher wrote:

The homework book is used as a baseline tool. It helps secure basic knowledge and skill for Grade 4.

Of interest, while there were again positive comments about parental involvement the negative comments seen in 2012 about issues with parental involvement were no longer present. Some teachers who had stated problems with parents shifted their views. For example one teacher who wrote about the need to educate parents about homework (quoted above) now wrote:

Even parents can participate by helping their learners with their homework.

The above indicates some shift from seeing parents as a possible obstacle to parents as a resource.

A new theme that emerged from one teacher related to the importance of learners working on their own and at their own pace. So for example she wrote:

Good for learners to do homework on their own. Fast learners complete tasks quickly. Slow learners with the necessary encouragement are also able to do the homework.

**Concluding remarks**

While the buy in of teachers and learners in the homework drive is a positive finding it is useful to reflect on some of the reasons teachers give for this. Similarly it is useful to reflect on how these compare with my reasons for establishing the homework drive. The homework drive was established partly because I saw it as important that learners develop independent habits of steady effort and resilience in mathematics through doing homework (two key aspects of a productive disposition). Additionally homework should allow for the consolidation of essential foundational concepts and allow learners to work at differential paces. This would hopefully improve learner motivation; enable stronger mathematical confidence, increased enjoyment of mathematics (some homework activities were oral and dice games) and increased written participation in mathematics (an aspect noted as being low in primary classrooms as discussed in the introduction).

Of interest, the most frequently occurring theme in relation to teacher comments was how much learners enjoyed the homework. While ‘enjoyment’ or ‘love’ of mathematics is not a key aspect of Kilpatrick et al.’s (2001) definition of a productive disposition, it is emphasised as a key aspect of dispositions in SANCP work (discussed above) and has been emphasised in my research writing (e.g. Graven & Schafer, 2014). The notion of developing confidence was noted by some teachers too. Similarly, several teachers noted the issue of homework enabling consolidation, practice and different pacing for learners (and many teachers wrote how several learners went ahead of the homework given).

On the other hand one might have expected more comments as to the *mathematical* value of: developing foundational knowledge (and basic facts), progression towards increasingly efficient
calculation strategies and supporting connected understanding of multiple representations used in class (such as number lines and 100 charts). These were key design principles in the selection of activities and the way they were structured in the homework books (discussed above). Similarly one may have expected more comments relating to developing in learners the habit of steady effort and independent hard work (i.e. learning without the teacher), as this was a key motivation for the homework drive. However, only three teachers in their comments noted this.

Perhaps these absences are due to the limitations of the use of questionnaires and the way in which the questions were phrased. Interviewing may have yielded a wider range of findings and comments. On the other hand, it is interesting to note what teachers foreground and further research could explore the extent to which teachers’ motivation for and experiences of homework change as learners move up the grades and from primary into high school. It is possible that in higher grades the emphasis on independence and a steady independent work ethic could be greater.

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The Potential and Challenges of Using GeoGebra to Teach Geometrical Constructions in Botswana Junior Secondary Schools: The Case of Gaborone-West Schools

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This study identified the challenges of integrating technology in mathematics instruction using freely available dynamic software, GeoGebra. A case study method to gauge teachers’ experiences on using the software to geometrical constructions was employed. The research design was underpinned by the constructive framework and utilised qualitative data collection methods whose data collection tools were interviews and observations. The study population comprised of junior secondary schools mathematics teachers in Gaborone West public schools. Purposive sampling was employed to select four mathematics teachers with two female and two male mathematics teachers observed teaching “Geometrical constructions” to their respective form one classes. Dey’s framework of analysis was used to analyse the data collected. Results show GeoGebra’s potential to support teachers’ work if utilised effectively. The premise was that a technology based teaching/learning environment provides the possibility to work on mathematical concepts in a broader way compared to purely-centred classroom session. Using GeoGebra helps teachers to communicate and express mathematical concepts in different representations to students, but its introduction and integration was challenging to teachers with inadequate knowledge and lack of competence in technology use. The study provided evidence that GeoGebra has a potential in enhancing teachers, mathematics instructional practices.

Introduction

The study investigated the potential and challenges of using” GeoGebra” for mathematics instruction in the backdrop of declining grades in both national examinations and international and comparative studies (BEC 2011; TIMSS 2007). The decline is due to persistent teacher-centred pedagogy; inadequate and inappropriate use of resources; lack of interest and negative attitudes; failure to link mathematics to real life; the absence of problem-solving, Discovery and investigation activities, and the incompetence of teachers in mathematical Pedagogical Content Knowledge (PCK) (Taole and Chakalisa,1995). The Ministry of Education and Skills Development (MoESD) resolved to infuse technology in instructional practices (RNPE,1994) to make subjects easier to understand, interesting to learn and applicable to real life. Despite these efforts, traditional methods still dominate classroom instruction, contributing to poor performance in mathematics. In 2005 Botswana joined the Strengthening of Mathematics and Science in Secondary Education in Western, Eastern, Central and Southern Africa (SMASSE-WESCA), an in-service association of mathematics and science educators in twenty-nine (29) Sub-Saharan African Countries established to motivate both teachers and students.

Government recommended MS Excel in the Junior Certificate (JC) mathematics syllabus, leaving out the freely available software used worldwide, including GeoGebra and Geometer Sketchpad which...
address a variety of mathematics topics such as geometry, the most challenging topic at JCE level in Botswana (TIMSS 2007).

**Theoretical Framework**

The constructivist paradigm and discovery learning theory (Omar, 2009) were used to highlight and structure the approaches and methods to investigate the research questions. Constructivism is the belief that knowledge is constructed by individuals based on a unique set of experiences with their environment (Crotty, 1998). The assumption was for students to discover mathematical concepts through GeoGebra as a result of constructing new ideas, concepts, and connections based on their experiences.

Here, epistemological gains result from creating, constructing, discovering and negotiating rather than being told or given. The discovery learning theory is the belief that humans acquire meaning through engaging interpreting the world, offering individuals the desire to know, which motivates them to solve problems (Surif, 2002). The theory challenges high achievers through open-ended problems mostly not offered in regular classroom sessions, while average achievers learn difficult concepts in a simpler way by experimenting and comparing the results of their work. The emphasis is on doing activities instead of relying on text books, which increases knowledge retention.

Castranova (2009) condemned traditional instructional methods for not creating the employee for today’s businesses. Technology availability requires new research to consider the effectiveness of technology-based discovery learning compared to using technology through traditional approaches. Students explore and solve problems to create; integrate and generalize knowledge through student-driven, interest-based activities that encourage integration of new knowledge (Holmes and Hoffman, 2000). Using GeoGebra in geometry allows students to construct meanings and discover new knowledge; hence the influence of constructivist and discovery learning paradigms this study.

**Literature Review**

Mathematics education is one of the earlier fields to introduce technology as an assistant tool in classrooms (Sangwin, 2007). The dynamic and symbolic nature of computer environments allows students to generalise, formalise and make links between their initiatives, notions of mathematics and some formal aspects of mathematical knowledge. Technology has forced educators to re-evaluate the mathematics that students need and determine the best methods for attaining good results and positive mathematical attitudes.

Technology allows students to focus more on applications and less on computational aspects. Rojano (2008) posits that when technology is used appropriately students can learn more mathematics at a deeper level. They gain the opportunity of owning the mathematics being taught, the chance to model and conceptualise ideas, generate multiple representations of solutions, get instant feedback and have the chance to solve problems without the inconvenience or restriction of using pencil and paper. Students develop critical thinking, problem solving ability, individual initiative, interpersonal and study skills as well as desirable attitudes and values towards mathematics and mathematics based professions. However the use of technology in instruction brings with it a great challenge for teachers and they must be ready for it (Clements, 2003).
Technology tools address students’ learning preferences, pace, motivation, allowing hands-on activities, cooperative learning and verbalisation of thinking as students work as individuals and as groups to construct knowledge (Giamatti, 1995).

GeoGebra is “a dynamic construction and exploration tool that adds a powerful dimension to the study of mathematics” (Key Curriculum Press, 2007) and can be introduced into the mathematics classroom at many levels, from basic Geometry, Algebra, to Calculus. It has elements of dynamic geometry software (DGS) and Computer Algebra Systems (CAS) (NCTM, 2010) and is a tool for Presentation; modelling and Authoring.

Figure 1: GeoGebra window- Algebra, Geometry and Graphic views

It enables students to visualise geometrical shapes and view the connected algebraic part while they can also access the spreadsheet. This can be fascinating and motivating to students as they explore more without the hassle of moving from spreadsheet to word.

It demonstrates the close connection between geometry and algebra and is becoming a recognized part of mathematical knowledge (Hohenwarter and Preiner, 2007; Lu, 2009), that acquire knew knowledge through analysis, synthesis and giving them the platform to exercise critical thinking (Ogwel, 2009). The inconvenience of using tangible instruments (protractor, compass, etc.) mostly unavailable, easier to make mistakes with and may contribute to untidiness is eliminated. However, systematic enquiries into the effectiveness of GeoGebra in mathematics instruction are limited, worse still in the African context.

Study Methodology

Paradigm and Design

The research design was underpinned by the constructive framework and utilised qualitative data collection methods based on a case study whose data collection tools were interviews and observations. The research focused on bringing personal values, addressing the “why” and “how” aspects and the case study approach helped in examining the particularity and complexity of using GeoGebra in mathematics instruction (Creswell, 2007).
There is a rapid growth in technology usage in secondary schools worldwide, but little or no research on GeoGebra uses in Botswana to guide this investigation and the researchers assumed that case study explorations with some descriptive and explanatory elements, a deeper understanding on how to adopt it for mathematics teachers could be attained (Yin, 2003).

**Study Population and sampling**

The study population comprised of junior secondary schools mathematics teachers in Gaborone West public schools, Gaborone being the capital city of Botswana. Out of six junior secondary schools in Gaborone west, one school with eighteen streams was purposively selected for easy access as one of the researchers was based at the same school.

Purposive sampling was employed to select four mathematics teachers with two female and two male mathematics teachers observed teaching “Geometrical constructions” to their respective form one classes in a government aided Junior Secondary School. None of the participants received formal training on using GeoGebra to teach mathematics, however, all learned GeoGebra on-line and through practice and sharing of ideas and developments.

**Data Collection Instruments and Methods**

Interviews and observations were conducted during class sessions with field notes taken to maximise information gathering techniques and to provide insightful and targeted evidence directly on the case study topic.

Following governments’ requirements on research protocol, permission to conduct research was obtained from relevant authorities. Data collected through interviews were documented as teachers shared their views on GeoGebra and the technical problems experienced while using the software. Informal interviews were conducted through chatting with teachers to obtain a more holistic sense of the way they used GeoGebra.

**Validity and Reliability of Instruments**

The researchers recorded all conversations, allowing their contributions to be identified and enabling more careful analysis of participants’ responses to be carried out which helped reduce data due to selective memory, thereby improving reliability of the study. Similar wording of open-ended questions were for every participant to improve reliability of the interviews. A pilot study was conducted on non-participating teachers to check both validity and reliability and their comments and views were used for further clarifications and explanations on the instruments.

**Ethical Considerations**

Participants’ ethical perspectives; social ethics, protocol and authority in position were observed. Permission was sought from the department of research and evaluation, the school-head of research site; the relevant senior teacher and the research participants. The contents of the interviews were treated in stringent confidentiality.

**Data Analysis Procedures**
Data analysis used a framework adapted from Dey (1993) focusing on teachers’ perspectives on technology use to ensure compatibility. The researchers transcribed, explored and described individual cases to get more insightful information. The following predetermined themes were used as a framework for the analysis.

**Theme 1: Teaching Background**; qualification, years of teaching, experience using technology.


**Theme 3: Software Evaluation**; strengths and weaknesses of GeoGebra compared to other software.

**Theme 4: GeoGebra Usage**; supporting materials and the reasons for the chosen topics.

These themes gave proper direction to the data analysis protocol by helping the researchers identify and categorise related data for coherent presentation and interpretation.

**Presentation and Discussions of Findings**

The study is grounded on discovery learning based on constructivism supported by Kant’s conceptual framework of idealism that informed the case study design carried out through qualitative methods. Dey’s framework for data analysis was used to discuss each case pertaining to the four themes using pseudonyms of the participants for confidentiality.

**Case 1: Kemoeng**

**Teaching Background**

Kemoeng has studied computer studies and has three years mathematics teaching experience at junior secondary school level. He teaches all forms (Form Ones, Twos and Threes) with great interest in incorporating technology in the teaching/learning of mathematics.

**Conceptions of GeoGebra**

Kemoeng has a year’s experience with Geogebra, found it helpful in exploring geometry than algebra, and often used the computer laboratory for mathematics lessons. GeoGebra helped him speed up preparing students for examinations and they learned ahead without the hassle of a pen or pencil, but had to master drawing as they are examined on this perspective rather than on technology.

His students realised GeoGebra as interactive, intuitive, helping them share and discuss ideas, explore and investigate certain areas of mathematics; encouraging cooperation and interaction among them. Since GeoGebra is relatively new, he waits to see how it develops and how he can develop his career in relation to software.

**Software Evaluation**

Kemoeng believes that students can use GeoGebra at home, and that it can be used in any platform. He said; “Though I have done a course on computer studies, I feel I need to be resourced on how to effectively use GeoGebra to teach mathematics so that I can be confident with it and really master it. This will help my GeoGebra lessons to be more effective.”
GeoGebra usage

He used GeoGebra for demonstrations, saving time when drawing shapes and angles, enabling students to visualize parallel lines, make angle bisectors, draw and measure different angles, realize the linkage between properties of shapes, angles and their characteristics. The dynamic software facilities are limited and require improvement. Students need more access to the computer laboratory fully equipped, to benefit from this software. Computer sharing limited students to explore the software at their own pace.

Case 2: Lebogang

Teaching Background

Lebogang did computer studies as a minor course during teacher training and taught mathematics for six years at junior secondary school level. The training helped her develop advanced skills using mathematical software (Excel and GeoGebra), already installed in the school computer laboratory.

Conceptions of GeoGebra

She has a positive attitude towards GeoGebra, believes it is a convenient tool arousing students’ interest in visualisation and checking ones’ work. She stated; “I like the software as it allows me to draw graphs, solve equations and calculate. It has a lot of capabilities that other software like the recommended Excel do not have. I am happy about the software as it links geometry with algebra; it makes mathematics to be alive rather than the abstractness that is always perceived when the subject is mentioned.”

She observed that teachers and students use computers for games or for the internet. Most teachers are unaware of GeoGebra because of challenges using computers. The computer cannot do the logical and deductive thinking for students and teachers, so GeoGebra helps strengthen and motivate students to learn, but cannot explain why the concepts are right.

She is discouraged by the current ill-equipped computer laboratories with most computers not working and students have to share. Prohibiting students entering the computer laboratory without teachers limits them exploring the dynamic software on their own. Although GeoGebra is limited since human brains are the ones doing the logical thinking, it provides quality functionalities that encourage her to use the software in teaching mathematics.

Software Evaluation

“I am rather impressed by the features and capabilities that GeoGebra has (e.g. algebra)”, and GeoGebra combines geometry, algebra and Excel itself and has other parts like tangent lines helping students explore more on geometry.

GeoGebra Usage

She used GeoGebra mostly in teaching geometry through demonstrations, emphasising key points, checking students’ work, testing, verifying thinking and sometimes for research. Her skilfulness at
geometrical constructions is apparent, and used GeoGebra for presentation purposes in her classrooms, while being led by a text-book.

**Case 3: Tumiso**

*Teaching Background*

Tumiso had sixteen years teaching experience at all levels, had acquired technology skills while at University of Botswana, has particular enthusiasm for new technologies and likes trying a combination of open-source software to teach mathematics. She is HOD for Mathematics and Sciences department, and encourages others to incorporate technology in teaching as stipulated in the syllabus.

*Conceptions of GeoGebra*

She believes teachers are generally afraid of teaching with computers which is different from using Microsoft Word for typing. She observed students as passive when using computers to learn, with some falling asleep during lessons, suggesting they lack interest as they view a computer as a tool for playing games, surfing the internet, chatting, etc. as Lebogang noted.

She views GeoGebra as very useful in rescuing one in times of difficulty instead of using the chalkboard. It’s easier for students to understand a particular concept when dragging the points to see the effect of motion of another point. She believes with proper training GeoGebra is user-friendly and can be used for all mathematics topics.

*Software Evaluation*

GeoGebra has a great potential on mathematics education, in terms of speed and availability. “This software is very relevant to mathematics and I believe that if teachers can be trained on using it to teach mathematics, good results can be attained. I think SMASSE; a programme for teaching mathematics can go hand in hand with GeoGebra. Teachers may even be able to finish the syllabus as the software can help link the topics more easily”, she said.

*GeoGebra Usage*

She used GeoGebra on geometry and it changed her teaching strategies. She emphasise step by step explanations for students to understand the concept and view the software as friendly. She comments the animation feature in GeoGebra which attracts students’ attention and can motivate students to learn on their own. “Mathematics teachers should take students to the mathematics laboratory to investigate, explore and even manipulate objects to bring life to the subject and kill abstractness that is generally associated with it. This may even help in bringing better results and more mathematical orientated career aspirations by students at the end of the year”, she said.

**Case 4: Matthew**

*Teaching Background*
Matthew had eight years teaching experience in different areas of Botswana and understands students from different backgrounds. Despite no formal training on IT, he gained particular interest in technology through workshops and is really integrating technology in mathematics instruction.

**Conceptions of GeoGebra**

GeoGebra is very good for teaching/learning and it can arouse students’ interest to learn mathematics. “It may be very useful to low and high achievers to see and explore more on the relationship between shapes, lines and angles. Students can really benefit from it and see the connection of mathematics topics as well as their relevance in real life”. GeoGebra helped him to bring life to mathematics and was excited; “ I believe that if I was well trained on using this software I could really make a great beneficial difference in mathematics classroom teaching. My students will also appreciate mathematics and be able to see the fascination and beauty of the subject”.

**Software Evaluation**

Matthew claims that GeoGebra outperforms MS Excel as it covers geometrical topics, algebra and Excel itself. It is more relevant to mathematics and government should encourage its use and/or workshop mathematics teachers to become competent to use it. He stressed that its use can kill the spirit of boredom that most students associate with mathematics.

**GeoGebra Usage**

Matthew uses GeoGebra for demonstrations during lessons and sometimes allows students to explore and investigate concepts. However, he believes that students need to master drawing shapes and lines using pencil and paper; and gives time to practice on that for examinations.

**Cross-Case Analysis**

**Emerging Issues in Relation to the Use of GeoGebra**

From the cases discussed above there are common themes among individual teachers which the researchers have extracted for cross-case analysis. There are addressed by assigning some categories for a constant comparative analysis adopted from Glaser and Strauss, (1967).

Most teachers mentioned the environment and the unavailability of facilities as concerns and believe that using GeoGebra in teaching/learning mathematics call for availability and/or improvement of technological facilities in schools. They also believe that with proper GeoGebra training they can completely use the software for the greater benefit of the students. Thirdly, most teachers view GeoGebra as a tool for demonstrations during class sessions. The last issue identified was that of mathematics topics that GeoGebra can address effectively. The following are categories used for cross-case analysis adapted from Dey’s framework for cross-case analyzing which emerged from the interviews and observations made. They include: environment/infrastructure suitable for application of technology in mathematics teaching/learning; Teacher training on technology use for teaching; GeoGebra as a tool for teaching/learning and mathematics topics that teachers believe GeoGebra can effectively be applied to enhance teaching and learning.

**The Environment (Infrastructure and Resources).**
Lebogang views GeoGebra as a friendly environment for mathematics teaching/learning, but is discouraged by the current educational environment where computer laboratories are ill-equipped for teaching-learning sessions. Most computers are not working and students have to share during class sessions. Restricting students entry to the computer laboratory without teachers, greatly limits them to study on their own and explore the dynamic software.

Tumiso believes that GeoGebra provides an environment through which mathematics teachers and students can investigate explore and manipulate objects to bring life to the subject and kill the abstractness generally associated with it. This may yield better results and encourage students to aspire for mathematical or science based careers.

The syllabus expects teachers to teach certain concepts using technology, but with no provision of material to foster this implantation. The computer laboratories in all junior secondary schools throughout the country are impractical due to too many mathematics classes and computer awareness lessons take precedence. This is a great challenge to teachers (see Clements, 2003) who then resort not to bother using the laboratory at all.

According to the findings, mathematics teachers advocate for a conducive environment in terms of well-equipped laboratories which may foster GeoGebra use in teaching and learning. It is evident that they would prefer separate, well equipped laboratories to allow students to investigate, explore and experiment their mathematical ideas.

**Mathematics Teacher Training on Technology (GeoGebra).**

All study participants believe it is one thing to use GeoGebra to learn and another to teach mathematics. They stressed the need to assimilate GeoGebra in the teaching/learning of mathematics compared to MS Excel, on condition that teachers be trained on using the software. Since most participants learnt GeoGebra through the internet, sharing ideas with each other and frequent use on their own, they were not competent and confident enough to thoroughly engage students during lessons, but mainly used it for demonstrations and presentations.

Tumiso believes GeoGebra could be used to teach all mathematics topics, but stressed that proper training is essential for the software to be beneficial to students and teachers. Kemoeng needed to be resourced on mastering using GeoGebra to teach mathematics and believed this would help him to successfully apply it in lessons. He felt they were certainly other areas of GeoGebra he had not explored and was underdeveloped in his capacity. Lebogang said most mathematics teachers were not aware of this software because it was a challenge to use computers for instructional purposes. The data suggests that teachers could be categorised into two groups; those with and those without formal training in computers education. However, since the software is free, both categories of teachers have access to GeoGebra online materials from the internet for their classroom practices.

Policies that govern a country have a great influence in curriculum development, and Botswana is not an exception to this. Government recommended the infusion of technology teaching/learning and the JCE mathematics syllabus was tailor made to teach certain topics using MS Excel. However, it is evident from the research that there is still a crisis among mathematics teachers concerning the issue if implementation.
The study shows teachers’ lack of proper training for the integration of technology in instructional practices. Teachers argue that MS Excel is not relevant to mathematics teaching compared to GeoGebra. There was eagerness to learn GeoGebra, which shows the commitment and zeal to improve and develop teaching through the use of this technology. This suggests that mathematics teachers, given formal in-service training on technology use for teaching, can make a big difference in mathematics instruction. Teacher educators should consider teaching pre-service mathematics teacher trainees on how to incorporate technology in instruction.

**GeoGebra as an Educational Tool.**

Almost all participants viewed GeoGebra as a relevant educational tool for students to practice mathematics concepts and ideas. To distinguish technology in general and GeoGebra in particular, a comparative analysis across the cases and across the themes was applied and the findings are that GeoGebra is generally identified as an educational tool for classroom activities, investigations, demonstrations, presentations and visualisations. It is also used for geometrical activities and proofs as well as for creating teaching materials, getting immediate feedback, reflective checking and for research purposes.

Kemoeng believes using GeoGebra in mathematics instruction can speed up preparing students for examinations without hassle of using pen and pencil. He pointed out that GeoGebra enabled his students to visualise parallel lines; make angle bisectors; draw and measure different angles; and realised the linkage between properties of shapes, angles and their characteristics. Kemoeng found GeoGebra to be useful and convenient in the teaching process. He did not engage his students to learn using GeoGebra because he still needed to be trained on how to appropriately use the software for instructional practices.

Lebogang viewed GeoGebra as convenient in arousing students’ interest through visualisation, demonstrations and checking one’s work. She used it to emphasise key points, testing, verifying thinking and sometimes for research. Her skillfulness at geometrical constructions was apparent, but she mainly used GeoGebra for presentation purposes. Just like Kemoeng, Lebogang did not engage her students in using GeoGebra to learn, but mainly for verifying thinking, while allowing visualisation during her presentations.

Tumiso viewed GeoGebra as useful for displaying and demonstrating rather than on the chalkboard. She stressed that GeoGebra makes it easier for students to understand mathematical concepts, but teaching using the software needs to be effectively addressed. She found GeoGebra good for mathematics explorations, investigations and manipulations and advocates for building mathematics laboratories in schools. She stressed students need to see mathematics being applied practically to experience its beauty and relevance. Matthew commends GeoGebra as very good for instruction as it can be used for arousing the interest of students to learn mathematics. It may be very useful for low and high achievers to see and explore more relationships between shapes, lines and angles; makes it easier for students to understand and can be used to teach almost all mathematics topics. Teachers value the bidirectional capability of GeoGebra as a key feature which includes both the drag mode as well as the inverse way of changeability in the algebraic window. Most participants valued GeoGebra as relevant for teaching Mathematics compared to MS Excel because it allows one to teach geometry, algebra and has an Excel window as well.
The findings suggest that teacher conceptions appear to play a significant role in affecting instructional decisions and behaviour. Most participants gave negative reflections about general technology integration, especially with regard to MS Excel, but were enthusiastic about GeoGebra in mathematics instruction. Integration of technology in mathematics instruction evokes many factors that interact with teachers’ conceptions, decisions and behaviour. These include their choices of mathematical software and pedagogical issues linking mathematical content knowledge and technology implementation. All the teachers believe that GeoGebra outperforms the MS Excel recommended for the JCE syllabus and to them it is a treasure found at last!

Mathematics Topics Addressed by GeoGebra.

The participants used GeoGebra to teach geometrical constructions, though Lebogang had experimented on algebra. Matthew believed that GeoGebra could be used to teach almost all mathematics topics. Kemoeng and Matthew warn that though teachers are encouraged to incorporate technology in the teaching/learning of mathematics, students write their examinations using pencil and paper, not computers. Tumiso felt that the software is very relevant to mathematics and if teachers could be trained to use it for teaching, good results could be attained. She suggested that SMASSE could be implemented extensively with GeoGebra to achieve better mathematics results. The data shows that teachers have the willingness to further explore the potentials of GeoGebra to teach topics than geometrical constructions. It is evident that if well trained, teachers will be competent enough to use it extensively in other areas of mathematics.

Conclusion and Recommendations

Conclusion

This research study investigated the potentials of using GeoGebra in teaching geometrical constructions and the challenges that teachers encounter while using the software at junior secondary school level in Botswana.

Discovery learning theory as supported by Kant’s critical idealism provided a platform to guide teachers towards using technology to help arouse students; interest to learn. GeoGebra help students to discover, investigate, explore, discuss and experience, hence become confident in mathematics as well as developing positive attitudes towards the subject and realise its applications in real life. According to Algaic (2003), teaching mathematics using technology requires teachers who can actually teach technology. Teachers tend to teach mathematics the way they have been taught a students and it is high time for a change to properly assimilate global trends that are unavoidable in contemporary society. The purpose of this study was not to rank teachers, nor criticize them or the software but rather to explore their conceptions and practices regarding GeoGebra such that researchers could make suggestions pertaining to the implementation of technology in teaching and learning mathematics. The Botswana government recommended the infusion of technology in the curriculum, but the researchers believe it is the mathematics teachers’ responsibility, as professionals in their area to explore relevant software to that area and suggests it for implementation.

The findings show teachers’ practical elaborations of GeoGebra as interrelated within four dimensions namely: proper environment; training of teachers on the use of technology; understanding
GeoGebra as an educational tool and the mathematics topics that can be effectively taught through technology. The findings of the study revealed that teachers’ conceptions of GeoGebra are strongly based on the provision of enough equipment to foster their mathematical instructional practices. Teachers advocate for a mathematics computer equipped classrooms for students to really appreciate mathematics and be able to practice, explore, investigate and even experiment on their ideas for learning and development through the use of technology. Despite using GeoGebra for geometrical topics, teachers believe it can be used for other topics if they are properly trained. Most of the participants used GeoGebra mainly for demonstrations and presentations in their lessons, but stated their lack of expertise to teach students to use it as they are still learning the potential of the software. They believe that with proper training they would gain confidence to create materials and allow students to explore, investigate and experiment mathematics ideas and concepts using the software.

The study shows that GeoGebra could be used more than merely as a tool, but there is need for an environment where teachers and students collaborate for the creation of complete pieces of mathematical work. Implementation of GeoGebra use in classroom practices can effectively result in sharing of mathematical ideas, thoughts, conjectures and investigations (Hawkridge, 2009) and students and teachers should try it even if they have never used technology before in their classroom practices.

**Recommendations**

The research findings evoked a better understanding of teachers’ potentials and challenges that they experienced while using GeoGebra to teach geometrical constructions, shedding some light on aspects that suggests further research; like teachers’ readiness to integrate technology in the teaching/learning of mathematics with regard to training and availability of resources. The researchers strongly believe that the pedagogy of GeoGebra should go beyond demonstrations and contribute to exploring the challenges and potentials of its implementation. The researchers recommend that the MOESD should recognise mathematical software such as GeoGebra and provide an in-service training on how to teach mathematics using technology. Pre-service teachers should be well trained in the integration of technology in teaching mathematics to be well equipped to teach using technology. Internet services should be enhanced in schools to help teachers keep abreast with the use and application of technology in the teaching and learning mathematics. This can also help share ideas on how to teach using technology in terms of chatting, e-mails and others for both teachers and students. To augment this, government should consider the provision if mathematics laboratories equipped with modern technology. The encroachment of smart boards in senior secondary school classrooms is a positive development that could be extended to other levels.

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Exploring motivational factors and self-regulated learning strategies as predictors of students’ anxiety in mathematics learning

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Learning is a complex process that involves interaction of factors too numerous to count. The purpose of this study is to determine whether motivational factors and self-regulated learning strategies are significant predictors of students’ mathematics anxiety in secondary schools in Malawi. The subscales for the motivation investigated in this study were intrinsic goal orientation, extrinsic goal orientation, task value, control of learning beliefs, self-efficacy for learning and anxiety; while the subscales for the self-regulated learning strategies scale are rehearsal, elaboration, organization, critical thinking, self-regulation, time and study environment management, effort regulation, peer learning, and help-seeking. The study group was comprised of 184 secondary school students. It was found that students’ motivational factors and self-regulated learning strategies are significant predictors of students’ mathematics anxiety. The findings are useful to educators in the research areas of mathematics education. It is hopeful that the proposed model will become a useful reference for further investigations of factors influencing mathematics anxiety.

Keywords: Education, Mathematics, students’ motivational factors, learning strategies, math anxiety

Introduction

Research indicates that there are many factors influencing self-regulated learning strategies (Pintrich, 2004; Shores & Shannon, 2007; Garcia, & Pintrich, 1996). A review of literature on mathematics self-concept, mathematics self-efficacy, beliefs toward mathematics and affective toward mathematics has shown that these variables are closely related to mathematics self-regulated learning strategies (Zimmerman, 2003; 2002). However, the inter-relationships of these variables and their causal effects on each other are still unclear. Much recent research has focused on the various aspects of teaching and investigated how the motivational factors and self-regulated learning strategies influence students achievement in mathematics (Wolters, 2003; Kurman, 2006). However, there are very few studies on students’ predictors of learning behaviours such as mathematics anxiety.

Self-regulated learning strategies, motivational factors and anxiety are all interrelated and are likely to affect academic self-regulated learning strategies (Eccles, & Wigfield, 2002). It is argued that these factors form a complex network that brings about changes in mathematics self-regulated learning strategies (Pintrich, 2004; Garcia, & Pintrich, 1996). Therefore, the focus of this study is to clarify the directions and magnitude of the relationships between these variables among students of secondary mathematics. In doing so, a path model is created to explain the relationships between motivational factors, self-regulated learning strategies and mathematics anxiety.

Motivational factors are more complex than the additive effects of student ability, perceived competence and self-regulated learning strategies desire, even though they significantly contribute to the students’ desire to successfully participate in mathematical activities and to do well in
mathematics. Kurman (2006), however, adopted a somehow different position. He argued that “only when students perceive that self-regulated learning strategies will lead to rewards they value and, further, believe that their own hard work will result in self-regulated learning strategies will their engagement in mathematics learning increase.

The importance of motivational factors, self-regulated learning strategies and mathematics anxiety in mathematics courses, and the apparent differences between boys and girls’ views has been demonstrated by Watt’s argument that boys maintain higher intrinsic value for mathematics and higher mathematics related self-perceptions than girls throughout adolescence (Kurman, 2006). However, it is important to understand how it is that boys come to be more interested and like mathematics more than girls; and also why girls perceive themselves as having less talent, even when they perform similarly well (Pajares, 2002). Finding from the Program of International Student Assessment (2003) study relating to girls’ confidence in mathematics indicated that females appear to be less engaged, more anxious and less confident in mathematics than males. Mathematical confidence, which is related to anxiety, is an affective dimension closely associated with mathematics self-regulated learning strategies.

Fear and anxiety are the cornerstones of low self-esteem in mathematics. Those who suffer from low self-esteem experience extreme fear and anxiety frequently. Believing that there is something innately wrong with themselves, these low self-esteem sufferers experience self-esteem attacks (often called panic attacks) when they do something they deem to have been stupid, something they think others have noticed, and something that confirms their own feelings of inadequacy, incompetence, being undeserving or unlovable. During these attacks they may attack or withdraw and isolate while feeling embarrassed, humiliated, devastated, depressed, even despairing. Depending on how seriously they perceive their "mistake" they may not recover for minutes, hours, days, or longer. They are often too fearful to ask for help, thinking that needing help is an admission of inadequacy. This state of mind often accounts for low achievement in mathematics.

**Aims of the study**

The aim of this study is to determine whether motivational factors and self-regulated learning strategies are predictors of students' mathematics anxiety among secondary school students. In this respect, the following questions are answered in this study:

- Are motivational factors significant predictors of students' mathematics anxiety?
- Are self-regulated learning strategies significant predictors of college students' mathematics anxiety?
- Is there any correlation between motivational factors and self-regulated learning strategies?

**Significance of the study**

The motivational factors of students are of particular significance and importance because of their potential influence on their future beliefs and actions related to learning mathematics. Motivational factors contribute to students’ performance in mathematics. It is highly undesirable for those who have unfavourable feelings about mathematics to employ appropriate strategies for learning mathematics in school. Furthermore, lack of motivation coupled with inappropriate learning strategies may lead to anxiety and frustration. Thus, it seems reasonable to assess the relationships
among motivational factors; self-regulated strategies and mathematics anxiety. Therefore, the study is practically significant to the curriculum designers to cater for the motivational factors; self-regulated strategies and reduced math anxiety among students by some interventions. It is also of policy significant, in long term, to set up appropriate selection criteria for admission to secondary schools and revise the mathematics curriculum for secondary schools, to improve the quality of learning mathematics for students in secondary school.

Furthermore, the study is theoretically significant to find out to what extent the motivational factors influence their self-regulated learning strategies, and in turn, the effect on anxiety in mathematics. In particular, the model proposed is able to explain the interrelationship of motivational factors, self-regulated learning strategies and anxiety. The strength of the factors and the relations within and between the motivational factors, the self-regulated learning strategies and anxiety can also be found through stepwise linear regression analysis modelling. As a result, the findings of the study may form the basis for future intervention programmes which aim at improving students’ motivation and self-regulated learning strategies in mathematics.

**Literature review**

Understanding mathematics is key for most career opportunities. Moreover, it is possible to make use of mathematics strategies in certain areas of science, like economics, politics, social studies, genetics and medicine (Roman, 2004). Mathematics skills, used in many fields, are composed of computation skills and problem-solving skills (Schunk, 2000). There are some questions the students should ask themselves in order to gain these skills. The answers for these questions focus on the concepts of motivational factors (Eccles & Wigfield, 2002; Linnenbrink & Pintrich, 2002; Metallidou & Vlachou, 2007; Pintrich, 2004) self-regulation (Zimmerman, 2002) and mathematics anxiety.

**Theoretical framework for the study**

The literature suggests that when students possess motivational factors and use self-regulated learning strategies for mathematics learning, their successes increase (Camahalan, 2006; Dresel, & Haugwitz, 2005; Malmivuori, 2006; Metallidou & Vlachou, 2007; Yukselturk & Bulut, 2007). On the other hand, if they do not use these factors and strategies effectively, their failure and anxiety may increase (Kurman, 2006). Students must organize their motivational factors and self-regulated learning strategies to decrease their mathematics anxiety and become successful in mathematics. In other words, examining motivational factors and self-regulated learning strategies can serve as a clue for reasons of mathematics success or failure (mathematics anxiety). The proposed theoretical framework for analysing students’ motivation is useful in investigating the relationship among motivational factors, learning strategies and mathematics anxiety. The framework is useful in clarifying students’ notion of what it might mean to be motivated to learn mathematics, what strategies learners use and whether these two influence math anxiety. Figure 1 provides a summary of my understanding of how the three aspects of mathematics learning are linked together.

Bandura (1997) emphasizes the importance of individuals' motivational processes and he further states that individuals should shape their beliefs about their abilities, set negative and positive outcomes, and anticipate different pursuits and goals for themselves. He points out that self-efficacy and belief have a significant role in regulation of motivation in addition to these. On the other hand, Linnenbrink and Pintrich (2002) dwell upon a different dimension of motivation and define it as an academic enabler. They state that self-efficacy, attributions, intrinsic motivation, and goals are significant for students' motivation. Pintrich (2004) emphasizes the importance of motivational factors in the learning process and underlines the fact that motivational factors - goal orientation, self-
efficacy, perceptions of task difficulty, task value beliefs, and personal interest in the task - should be regulated by the students to be effective in learning process.

![Figure 1: the relationship among motivational factors, learning strategies and mathematics anxiety](image)

For students to become successful in mathematics, they should have not only motivational factors but also employ appropriate self-regulated learning strategies. A learning strategy is a person’s approach to learning and using information. Students use learning strategies to help them understand information and solve problems. Students who do not know or use good learning strategies often learn passively and ultimately fail in school. Learning strategy instruction focuses on making students more active learners by teaching them how to learn and how to use what they have learned to be successful.

Self-regulated learning materializes with both students' motivational factors and self-regulated learning strategies. Self-regulated learning requires a process which, according to Schunk and Zimmerman (2002), has three major levels: self-observation, self-judgment, and self-reaction. In this process, planning, managing time, attending to and concentrating on instruction, using cognitive self-regulated learning strategies, building a productive study environment, and making use of social sources are crucial. In addition to these, strategies for evaluating motivational processes like setting performance goals and outcomes, holding a positive attitude about one's capabilities, and evaluating learning, its outcomes, and positive experiences that can affect learning have a considerable role. As Boekaerts and Corno (2005) point out, students can gain skills in the areas of decision-making, problem-solving, and resource management in education, assessing teaching, and completing the intervention required, depending on the assessment results, based on a certain process and program. Students' success increases when these motivational factors are supported with self-regulated strategies. Eccles and Wigfield (2002) state that such motivational factors as task value, expectancies and values are important for student success in mathematics. As Pintrich (2004) states, this importance is based on general assumptions of the self-regulated learning such as active, constructive and potential for control assumption, goal and criterion for learning. As Wolters (2003) points out, in models of self-regulated learning, students become more effective when they take a purposeful task.
Furthermore, students' motivational factors and self regulated learning strategies contribute most to the students to carry out any learning task. Cleary and Zimmerman (2004) make it clear that highly self-regulated learners approach learning tasks with self confidence (reduced anxiety), proactively set goals, and develop a plan to realize their own learning and reach their learning goals. Whether self-regulated learners are aware of the ability they have or not is a predictor of their success or failure. Self-regulated learners search information themselves and they do the necessities to improve the information they have reached. Zimmerman and Campillio (2003) state learners should have the characteristics of self-generated thoughts (self confidence), feelings (motivational factors), and actions (strategies) cyclically planned to reach their personal targets. At the same time, these characteristics should be backed up with cognitive and metacognitive strategies and effort. This support, as Pintrich (2000) states, is achieved with the self-determined and active process of planning, executing, monitoring, and controlling of strategic learning.

Mathematics anxiety is a stress and anxiety situation related to students' negative experiences with mathematical concepts and procedures. Although many studies have shown that mathematics anxiety is related to such variables like age, sex, self-efficacy, mathematics attitudes (Cates & Rhymer, 2003), Oberlin (1982) indicates that teaching techniques lead to mathematics anxiety. Jackson and Leffingwell (1999) note that mathematics anxiety can occur if students have negative experiences at elementary and secondary schools, and they state that having a hostile or intensive attitude towards the students, treating students prejudicially because of their gender, demonstrating an uncaring attitude, expressing anger, having unrealistic expectations, embarrassing students in front of peers, communication and language barriers, quality of instruction, evaluation methods, and difficulty of material are among the behaviors and attitudes of mathematics teachers that can cause mathematics anxiety. Likewise, Furner and Duffy (2002) indicate that the school system, gender, socioeconomic status, and parental background may affect mathematics anxiety, too. However, little is known whether what drive students hold towards learning mathematics (motivation) and what they do when learning mathematics (learning strategies) are a reflection of their mathematics anxiety. I perceive that the theoretical framework as an analytical tool captured the complexity and the richness of the students’ motivation in detail, and the tool made it possible for me to present detailed descriptions of the students’ motivation for learning mathematics.

**Research methods**

In this study, a quantitative method was used. The quantitative data helped determine whether significant associations exist between independent variables and dependent variables. Motivational factors and self-regulated learning strategies were independent variables for the study, while mathematics anxiety was the dependent variable. In this study, the extent to which motivational factors and self-regulated learning strategies served as predictors of mathematics anxiety was analyzed. Participants of this study were 184 students taking a general mathematics course in selected secondary schools in Malawi. The study group was formed from form 3 students. The group consisted of a total of 184 students - 93 (50.5%) girls and 91 (49.5%) boys. The schools were conveniently sampled because our student teachers were conducting their teaching practices in these schools. Form
three classes were purposively selected because these were non examination classes who had stayed in secondary school long enough to provide appropriate information from experience

**Research Instrument**
A questionnaire was used to collect data for this study. The questionnaire contained the sections on personal background and motivational factors and possible self-regulated learning strategies (Dunn, K. E., Lo, W. J., Mulvenon, S. W., & Sutcliffe, 2012). The self-regulated learning strategies in mathematics adapted from the “Study Process Questionnaire” (SPQ) developed by Biggs (1992) was used to measure the self-regulated learning strategies of students in this study (Hendricks, Ekici, & Bulut, 2000; Karadeniz, Büyükoztürk, Akgün, Kılıç-Çakmak, & Demirel, 2008). This instrument consisted of 64 items on a five-point scale. In the questionnaire, the latent variable was measured through observed indicators in terms of items in the questionnaire. The questionnaire was designed using Likert scale responses on five-point continuum from 1 (definitely false) to 5 (definitely true). The ordered categories are simply scored with successive integers and a students’ response is taken as the sum of the scores of all statements of the instruments. The reliability estimates of affective towards learning mathematics were reliable as the reported coefficient alpha was .92 (Duncan & McKeachie, 2005).

**Data collection Procedure**
The quantitative data were obtained from a survey questionnaire administered to 184 respondents. The sample consisted of form 3 students in 5 secondary schools in Malawi. The questionnaires were self-administered and collected immediately after they were completed. In this way, the participants completed the questionnaires without consulting each other and 100% of the questionnaires were collected.

**Data Analysis**
SPSS for Windows 16.0 was used to produce the frequencies and percentages for the scales of constructs and mathematics self-regulated learning strategies. After performing descriptive statistical analysis, reliability analysis was carried out for all the scales of the instruments. The reliability was measured by the internal consistency coefficient and assessed by calculating the coefficient alpha.

Next, the questionnaire items were initially subjected to a Spearman Correlation Coefficient analysis. Given that the structure could vary, two factor analyses of the possible correlation between the motivational factors and self-regulated learning strategies were performed in order to investigate possible correlation between the two sets of factors. Finally, stepwise linear regression analysis was used. In stepwise linear regression analysis, the relationship between the predictor variables, students' motivational factors, and learning strategies, and the dependent variable, math anxiety, were tested. Data were analyzed using SPSS 16.0 software.

**Results**

**Demographic information**
The sample consisted of 184 form three students drawn from five government secondary schools. There were 93 (50.5%) girls and 91 (49.5%) boys. The gender representation was fairly equal in this study. All the schools were coeducation except one which was girls only school run by Catholic
Church. Table 2 show the age distribution of the students involved in this study. The majority of participants were of the ages between 14 and 18 with very few of ages 13, 20 and 25 years.

Table 2: Age distribution of the sample

<table>
<thead>
<tr>
<th>Ages (Years)</th>
<th>Frequency</th>
<th>Percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>4</td>
<td>2.2</td>
</tr>
<tr>
<td>14</td>
<td>21</td>
<td>11.4</td>
</tr>
<tr>
<td>15</td>
<td>36</td>
<td>19.6</td>
</tr>
<tr>
<td>16</td>
<td>54</td>
<td>29.3</td>
</tr>
<tr>
<td>17</td>
<td>37</td>
<td>20.1</td>
</tr>
<tr>
<td>18</td>
<td>24</td>
<td>13.0</td>
</tr>
<tr>
<td>19</td>
<td>6</td>
<td>3.3</td>
</tr>
<tr>
<td>20</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>25</td>
<td>1</td>
<td>0.5</td>
</tr>
</tbody>
</table>

The frequency distribution of the students responses regarding their self-regulated learning strategies towards mathematics learning is presented in Table 2 (Scores of 4 = agree and 5 = strongly agree have been combined as agree whereas the scores of 1 = strongly agree and 2 = disagree as disagree. Scores for not sure formed the third category).

Table 3: The average percentages of frequencies students’ ratings of the motivational factors

<table>
<thead>
<tr>
<th>Motivational factors</th>
<th>Agreement</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>F</td>
<td>ALL</td>
</tr>
<tr>
<td>Valuing math</td>
<td>90.25</td>
<td>79.75</td>
<td>86.51</td>
</tr>
<tr>
<td>Willingness to do math</td>
<td>76.25</td>
<td>74.25</td>
<td>75.11</td>
</tr>
<tr>
<td>Diligence</td>
<td>74.43</td>
<td>69.29</td>
<td>71.24</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>66.50</td>
<td>60.67</td>
<td>63.05</td>
</tr>
<tr>
<td>Confidences</td>
<td>64.00</td>
<td>44.67</td>
<td>55.54</td>
</tr>
<tr>
<td>Reward for effort</td>
<td>61.00</td>
<td>48.00</td>
<td>47.49</td>
</tr>
<tr>
<td>Interest</td>
<td>52.20</td>
<td>43.80</td>
<td>47.43</td>
</tr>
<tr>
<td>Intellectual inspiration</td>
<td>44.33</td>
<td>48.00</td>
<td>45.51</td>
</tr>
<tr>
<td>Self-regulated learning strategies</td>
<td>42.60</td>
<td>38.00</td>
<td>40.79</td>
</tr>
<tr>
<td>Mathematics Anxiety</td>
<td>20.80</td>
<td>20.00</td>
<td>20.53</td>
</tr>
</tbody>
</table>

The average percentages of frequencies students’ ratings of the motivational factors are presented in Table 3 for easy comparison. When motivational factors are compared, students seem to be very assertive about value of learning mathematics, willingness to do mathematics, diligence, enjoyment and talent, confidence and self-efficacy in learning mathematics. However, they seem not seeing much reward for their effort in learning mathematics. They are also less interested with weak intellectual stimulation. They are not sure about their approaches to mathematics learning but disagree that mathematics learning causes anxiety among students. Table 4 shows that the majority of the students employ communication strategies in learning mathematics. At the bottom of the list is use of time and study environment to enhance concentration during mathematics learning. This implied that discussing and talking about mathematics is more valuable than silently organizing and working out mathematics problems.
Table 4: Students’ mathematics self-regulated learning strategies

<table>
<thead>
<tr>
<th>Students self-regulated learning strategies</th>
<th>Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
</tr>
<tr>
<td>Communication Behavior</td>
<td>75.00</td>
</tr>
<tr>
<td>Self-regulation</td>
<td>74.73</td>
</tr>
<tr>
<td>Critical Thinking</td>
<td>74.19</td>
</tr>
<tr>
<td>Rehearsal</td>
<td>70.43</td>
</tr>
<tr>
<td>Exploratory Behavior</td>
<td>69.36</td>
</tr>
<tr>
<td>Elaboration</td>
<td>69.23</td>
</tr>
<tr>
<td>Peer-learning</td>
<td>69.18</td>
</tr>
<tr>
<td>Help-seeking</td>
<td>67.18</td>
</tr>
<tr>
<td>Organization</td>
<td>66.49</td>
</tr>
<tr>
<td>Effort Management</td>
<td>65.38</td>
</tr>
<tr>
<td>Time and Study Environment</td>
<td>62.10</td>
</tr>
</tbody>
</table>

The results in Table 5 show that self efficacy, math anxiety and math enjoyment are all significantly correlated to all self-regulated learning strategies in mathematics whereas the rest of the motivational factors are correlated significantly to at least six self-regulated learning strategies at 0.01 level of significance. All self-regulated learning strategies are positively correlated to motivational factors except critical thinking which is negatively correlated to interest, intellectual stimulation and approaches to mathematics learning.

Table 5: Correlation analysis

<table>
<thead>
<tr>
<th></th>
<th>Self efficacy</th>
<th>Anxiety</th>
<th>Interest</th>
<th>Enjoyment</th>
<th>Intellectual stimulation</th>
<th>for Rewards of effort</th>
<th>Diligence</th>
<th>Valuing math learning</th>
<th>to Willingness to learn math</th>
<th>Approaches to math learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rehearsal</td>
<td>0.24</td>
<td>0.48</td>
<td>0.41</td>
<td>0.39</td>
<td>0.49</td>
<td>0.31</td>
<td>0.73</td>
<td>0.52</td>
<td>0.49</td>
<td>0.69</td>
</tr>
<tr>
<td>Elaboration</td>
<td>0.61</td>
<td>0.28</td>
<td>0.22</td>
<td>0.32</td>
<td>0.28</td>
<td>0.13</td>
<td>0.16</td>
<td>0.32</td>
<td>0.09</td>
<td>0.16</td>
</tr>
<tr>
<td>Organization</td>
<td>0.89</td>
<td>0.37</td>
<td>0.27</td>
<td>0.29</td>
<td>0.28</td>
<td>0.14</td>
<td>0.25</td>
<td>0.24</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>Critical thinking</td>
<td>0.52</td>
<td>0.26</td>
<td>-0.03</td>
<td>0.38</td>
<td>-0.02</td>
<td>0.08</td>
<td>0.02</td>
<td>0.24</td>
<td>0.03</td>
<td>-0.01</td>
</tr>
<tr>
<td>Self regulation</td>
<td>0.53</td>
<td>0.23</td>
<td>0.11</td>
<td>0.29</td>
<td>0.29</td>
<td>0.25</td>
<td>0.16</td>
<td>0.32</td>
<td>0.23</td>
<td>0.22</td>
</tr>
<tr>
<td>Effort management</td>
<td>0.34</td>
<td>0.25</td>
<td>0.01</td>
<td>0.30</td>
<td>0.21</td>
<td>0.15</td>
<td>0.19</td>
<td>0.31</td>
<td>0.15</td>
<td>0.18</td>
</tr>
<tr>
<td>Study environment</td>
<td>0.62</td>
<td>0.34</td>
<td>0.25</td>
<td>0.33</td>
<td>0.42</td>
<td>0.28</td>
<td>0.35</td>
<td>0.44</td>
<td>0.39</td>
<td>0.43</td>
</tr>
<tr>
<td>Peer learning</td>
<td>0.54</td>
<td>0.36</td>
<td>0.20</td>
<td>0.22</td>
<td>0.23</td>
<td>0.22</td>
<td>0.28</td>
<td>0.29</td>
<td>0.35</td>
<td>0.43</td>
</tr>
<tr>
<td>Help seeking</td>
<td>0.44</td>
<td>0.47</td>
<td>0.23</td>
<td>0.33</td>
<td>0.36</td>
<td>0.24</td>
<td>0.42</td>
<td>0.44</td>
<td>0.43</td>
<td>0.47</td>
</tr>
<tr>
<td>Exploratory behaviour</td>
<td>0.39</td>
<td>0.27</td>
<td>0.13</td>
<td>0.28</td>
<td>0.31</td>
<td>0.15</td>
<td>0.32</td>
<td>0.28</td>
<td>0.23</td>
<td>0.24</td>
</tr>
<tr>
<td>Communication behaviour</td>
<td>0.40</td>
<td>0.32</td>
<td>0.20</td>
<td>0.44</td>
<td>0.18</td>
<td>0.22</td>
<td>0.20</td>
<td>0.50</td>
<td>0.32</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Participants in this study were asked to rate their opinions on mathematics anxiety items and their responses are summarized in Table 6. The results show that the majority of students experienced anxiety when the thought of the consequences of failing mathematics. This makes them remember most tasks that they failed to answer previously. The fears are likely result of personal experience about mathematics learning. However, students become less nervous and continue to fight.

Table 6: Mathematics anxiety
Mathematics Anxiety: when taking exams,  

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>I always think about the consequence of failing.</td>
<td>118</td>
<td>63.0</td>
</tr>
<tr>
<td>I keep thinking of the questions that I failed to answer in previous exams.</td>
<td>104</td>
<td>56.6</td>
</tr>
<tr>
<td>I feel nervous and worry.</td>
<td>67</td>
<td>36.4</td>
</tr>
<tr>
<td>My heart beat faster.</td>
<td>57</td>
<td>31.0</td>
</tr>
<tr>
<td>Before taking math exam, I am too wary to take a good sleep.</td>
<td>48</td>
<td>26.1</td>
</tr>
<tr>
<td>I feel inferior to other classmates</td>
<td>47</td>
<td>20.2</td>
</tr>
<tr>
<td>I am totally blank and can not remember what I learned before.</td>
<td>33</td>
<td>17.9</td>
</tr>
</tbody>
</table>

**Stepwise linear regression analysis models**

Three stepwise linear regression analyses were conducted. First, a stepwise regression analysis method was used to determine whether affective factors are predictors of students' mathematics motivational factors. Findings from stepwise regression analysis are summarized in Table 7. It appears from the results that there a very weak relationship (r = 0.077) between motivational factors and mathematics anxiety. According to the findings of the study (Table 7), motivational factors are not significant predictors of students' mathematics anxiety (p<.05). About 7.7% of the variance in mathematics anxiety was explained by motivational factors.

Table 7: Summary of stepwise regression analysis between motivational factors and mathematics anxiety.

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>T</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
</tr>
<tr>
<td>1 (Constant)</td>
<td>3.654</td>
<td>.375</td>
<td></td>
<td>9.739</td>
</tr>
<tr>
<td>Affective factors</td>
<td>.085</td>
<td>.096</td>
<td>.077</td>
<td>.892</td>
</tr>
</tbody>
</table>

Second, a stepwise regression analysis method was used to determine whether motivational factors are predictors of students' mathematics anxiety. Findings from stepwise regression analysis are summarized in Table 8. It appears from the results that there a very weak relationship (r = 0.057) between motivational factors and mathematics anxiety. According to the findings of the study (Table 8), motivational factors are not significant predictors of students' mathematics anxiety (p<.05). About 5.7% of the variance in mathematics anxiety was explained by motivational factors.

Table 8: Summary of stepwise regression analysis between motivational factors and mathematics anxiety
Second, the stepwise regression analysis method was used to determine whether affective factors are predictors of students' mathematics anxiety. Findings from stepwise regression analysis are summarized in Table 9.

Table 9: Summary of stepwise regression analysis between affective and motivational factors

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td>T</td>
</tr>
<tr>
<td>(Constant)</td>
<td>3.408</td>
<td>.376</td>
<td>9.056</td>
<td>.000</td>
</tr>
<tr>
<td>Motivational factors</td>
<td>.061</td>
<td>.093</td>
<td>.057</td>
<td>.656</td>
</tr>
</tbody>
</table>

Third, the model derived from the analysis of the data is $y = 0.74x + 0.80$. Considering that $r = 0.617$, there is a strong relationship between affective factors and mathematics anxiety. According to these results, affective factors were found to be significant predictors of students' mathematics anxiety ($p<.01$). About 62% (61.7%) of the variance in mathematics anxiety was explained by affective factors.

The stepwise regression analysis method was used to determine whether self-regulated learning strategies are predictors of students' mathematics anxiety. Findings from stepwise regression analysis are summarized in Table 10.

Table 10: Summary of stepwise regression analysis between learning strategies and mathematics anxiety

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td>T</td>
</tr>
<tr>
<td>(Constant)</td>
<td>.798</td>
<td>.319</td>
<td>2.500</td>
<td>.014</td>
</tr>
<tr>
<td>Affective factors</td>
<td>.735</td>
<td>.081</td>
<td>.617</td>
<td>9.042</td>
</tr>
<tr>
<td>Model</td>
<td>Unstandardized Coefficients</td>
<td>Standardized Coefficients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------------------</td>
<td>---------------------------</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td>t</td>
</tr>
<tr>
<td>1 (Constant)</td>
<td>2.134</td>
<td>.360</td>
<td></td>
<td>5.933</td>
</tr>
<tr>
<td>Learning strategies</td>
<td>.452</td>
<td>.106</td>
<td>.347</td>
<td>4.273</td>
</tr>
</tbody>
</table>

According to these results, the relationship between learning strategies and mathematics anxiety is weak \((r = 0.347)\). A model derived from the analysis of the data is \(y= 0.45x + 0.213\). This shows that learning strategies were found to be significant predictors of students' mathematics anxiety \((p<.01)\). About 35% \((34.7\%)\) of the variance in mathematics anxiety was explained by learning strategies.

**Discussion**

Based on the findings of this study, motivational factors are not significant predictors for mathematics anxiety. The strong negative correlations between mathematics anxiety and motivational factors in mathematics provide considerable support for the findings of this study \((Ashcraft, 2002)\). The findings support the views that mathematics anxiety is a subscale of motivational factors though in the negative.

Almost all self-regulated learning strategies are positively correlated to motivational factors except critical thinking which is negatively correlated to interest, intellectual stimulation and approaches to mathematics learning. Students' motivational factors should be increased and they should gain self-regulated learning strategies for being successful in mathematics or coping with mathematics anxiety. In a study in which the correlations between the goal orientations of the students, motivational factors, and self-regulated learning, adopting a learning goal orientation, and a relative ability are examined, goal orientation results in a generally positive pattern of motivational factors, including adaptive levels of task value, self-efficacy, and anxiety, as well as cognition, including higher levels of cognitive strategy use, self-regulation, and academic performance \((Shores & Shannon, 2007; Wolters & Yu, 1996)\). To become successful, students should determine their individual beliefs about how well they will do in upcoming tasks, specific, proximal, and divergent goals, and values, motivational factors and learning strategies, such as cognitive and metacognitive strategies, and they should behave in a planned way, according to these factors and strategies \((Eccles & Wigfield, 2002)\).

Besides having high motivational factors, students should be aware of their self-regulated learning strategies and they should use these strategies effectively in mathematics to cope with mathematics anxiety. Most important, students should take responsibility for their learning. Related with the awareness of self-regulated learning, Zimmerman \((2002)\) states that self-regulated learners are aware of regulating the learning process, learning responses, and learning outcomes, and they use these strategies to reach their academic goals. In addition to self-regulated learning strategies, other strategies like self-evaluation, organization, transformation, goal setting and planning, information seeking, record keeping, self-monitoring, environmental structuring, giving self-consequence,
rehearsing and memorizing, seeking social assistance, and reviewing should be used (Zimmerman, 2002). For effectiveness of self-regulated learning, individuals should engage in self-monitoring in order to ignore the obstacles in using cognitive learning strategies and the conflicts that occur while gaining a learning objective (Zimmerman, 2002).

**Conclusion**

In conclusion, motivational factors and self-regulated learning strategies influence each other as well influence cognitive activities in the learning process and subsequently mathematics anxiety. Stepwise linear regression analysis model starts from a conceptually derived model specifying the relationships among a set of variables. Theory based on the literature and pilot studies provides the centrepiece for structural equation methodologies designed for use with substantive interests in understanding complex patterns of interrelationships among variables. Cause and effect in the structural equation model are totally dependent on the way in which the relationships are specified and the results at best indicate to plausibility about the relationships. However, the strength and conviction with which the researcher can assume causation between two variables lies not in the analytical methods chosen but in the theoretical justification provided to support the analysis. The result also shows that affective factors and learning strategies act as the mediator of mathematics anxiety. The finding proves useful to educators in the research areas of affective domain of mathematics.

**References**


Exploring the relationships between student affective constructs and their learning strategies in mathematics

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The aim of this study is to investigate the relationship between students’ affective constructs and learning strategies in mathematics. A sample 184 students in five secondary schools are used to build a hypothesised model to investigate how affective towards mathematics influence the mathematics learning strategies. Descriptive statistics, correlation analyses and stepwise linear regression analysis were employed in analyzing data and developing models. The result shows that affective factors act as the mediator of mathematics learning strategies. The finding proves useful to educators in the research areas of affective domain of mathematics. It is hopeful that the proposed model becomes a useful reference for further investigations on affective domain of mathematics.

Keywords: Education, Mathematics, students’ affective factors, learning strategies

Introduction

Research on mathematics education has shown that there are many factors influencing learning strategies in mathematics and that affective factors which are all interrelated are likely to affect learning strategies (Philippou, 1998). Brown (1994: 135) defined the affective domain as “the emotional side of human behaviour.” By analogy, the cognitive domain could be defined as the mental side of human behaviour. These seemingly clear-cut definitions for the two most important domains of learning, might suggest a division between cognition and affection, when indeed they are two sides of the same coin. Generally, affective factors are emotional factors which influence learning. They can have a negative or positive effect. Negative affective factors are called affective filters and are an important idea in theories about mathematics learning strategies. According to Hall (2009:1), a “Learning Strategy is a person’s approach to learning and using information. Students use Learning Strategies to help them understand information and solve problems. Students who do not know or use good learning strategies often learn passively and ultimately fail in school. Learning Strategy instruction focuses on making students more active learners by teaching them how to learn and how to use what they have learned to be successful.”

Therefore, implementation of appropriate learning strategies is related to student's self regulation behavior which in turn should be encouraged by pedagogical designs. A learner's attitude to Mathematics, to the teacher, to other learners in the group and to herself are all affective factors and have impact on how well she learns. In the classroom, affective factors may be as important for successful mathematics learning, if not more so, than ability to learn. It is argued that in mathematics, these factors form a complex network that brings about changes in mathematics learning strategies. Learning strategies are more complex than the additive effects of student ability, perceived competence and learning strategies desire, even though they significantly contribute to the students’ desire to successfully participate in mathematical activities and to do well in mathematics. The finding from the Program of International Student Assessment (2003) study relating to girls’ confidence in
mathematics: “females appear to be less engaged, more anxious and less confident in mathematics than males. Mathematical confidence is an affective dimension closely associated with mathematics learning strategies. Therefore, the focus of this study is to investigate the relationships between affective factors and mathematics learning strategies among students of secondary mathematics.

Statement of the problem

Mathematics is a compulsory subject in many national school curricula world wide. Student are expected not only to study mathematics, but more importantly to achieve high grades in mathematics examinations. Yet many learners find mathematics learning quite challenging. Consequently, to survive in mathematics lessons, students resort to use of varied learning strategies which largely may depend on whether, they enjoy or hate mathematics. Some strategies are adopted out of panic whereas others are used out of pleasure. Whether students like or dislike mathematics is a question of affective domain. They type of affective domain dominant in an individual learner is likely to influence the learning strategies. Is teachers establish the association of affective factors with particular learning strategies, it is possible to plan and deliver mathematics lessons that would help students learning mathematics effectively. Therefore, this study is designed to investigate how affective factors relate to the learning strategies that secondary school learners employ when learning mathematics.

Aims of the study

The aim of the study was to investigate the interrelationship between the students’ mathematics affective constructs and mathematics learning strategies among secondary school students. The objectives of the study were to investigate:

- the kind of affective factors that students demonstrate toward the learning of mathematics
- learning strategies that students employ in mathematics learning,
- The relationship between the students affective factors and mathematics learning strategies

Rationale

The affective factors of students are of particular importance because of their potential influence on the learning strategies in mathematics. Positive students’ affective contribute to their performance in mathematics formation of positive affective. Students’ quality of learning includes students’ affective factors towards mathematics. It is highly undesirable for those who have unfavourable feelings about mathematics to learn mathematics in school. Thus, it seems reasonable to assess the relationships of students’ affective factors and strategies employed by students in learning mathematics. Therefore, the study is practically significant to the curriculum designers to cater for the affective characteristics of students by some interventions, and it is also policy significant, in long term, to revise the curriculum of mathematics for secondary schools, so as to improve the quality of learning mathematics for students in secondary school. Finally, the findings of the study may form the basis for future intervention programmes which aim at improving students’ mathematics learning strategies

Literature review
According to Bloom (1956), there are three types of learning: cognitive skills, affective and psychomotor. This taxonomy of learning behaviors can be thought of as “the goals of the learning process.” That is, after a learning episode, the learner should have acquired new skills, knowledge, and/or affective. This study is concerned with affective domain.

The affective domain (from the Latin affectus, meaning "feelings") includes a host of constructs, such as affective, values, beliefs, opinions, interests, and learning strategies. The affective domain describes learning objectives that emphasize a feeling tone, an emotion, or a degree of acceptance or rejection. Affective objectives vary from simple attention to selected phenomena to complex but internally consistent qualities of character and conscience. There are numerous such objectives in the literature expressed as interests, affective, appreciations, values, and emotional sets or biases.

**Theoretical framework**
The theoretical framework of this study is based on the work by Relich, et al. (1994) and summarized in Figure 1. The affective domain (Relich, et al., 1994) includes the manner in which people deal with things emotionally, such as feelings, values, appreciation, enthusiasms, learning strategies, and affective. The five major categories are listed from the simplest behavior to the most complex receiving, responding, valuing, organizing and characterizing.

![Diagram](image)

Figure 1: General theoretical model of the relationship between students’ affective factors and learning strategies

Receiving is being aware of or sensitive to the existence of certain ideas, material, or phenomena and being willing to tolerate them. This category of affective domain includes awareness, willingness to hear and selected attention. For example, learning is characterized by listening to others with respect. Listening attentively for and remembering the mathematical concepts are the goal of the learning process. Examples include: to differentiate, to accept, to listen (for), and to respond to.

Responding is committed in some small measure to the ideas, materials, or phenomena involved by actively responding to them. This category of affective domain includes active participation on the part of the learners. For example, learning mathematics implies attending and reacting to a particular mathematics experience. Learning outcomes may emphasize compliance in responding, willingness to respond, or satisfaction in responding (learning strategies). Students should participate in class
discussions; give a presentation, questions new ideas, concepts and models in order to fully understand them. They should know the mathematical rules and practices them. Examples are: to comply with, to follow, to commend, to volunteer, to spend leisure time in, to acclaim.

Valuing is willing to be perceived by others as valuing certain ideas, materials, or phenomena. This is the worth or value a person attaches to a particular mathematics learning. This ranges from simple acceptance to the more complex state of commitment. Valuing is based on the internalisation of a set of specified values, while clues to these values are expressed in the learner's overt behavior and are often identifiable. For example, students may demonstrate belief in the mathematical process. It is sensitive towards individual and cultural differences in mathematics ability (value diversity). Valuing is showing the ability to solve problems. Proposes a plan to solving mathematical problem and follows through with commitment. Valuing informs individual on mathematical matters that one feels strongly about. Examples include: to increase measured proficiency in, to relinquish, to subsidise, and to support, to debate.

Organisation is to relate the value to those already held and bring it into a harmonious and internally consistent philosophy. This implies organising values into priorities by contrasting different values, resolving conflicts between them, and creating a unique value system. The emphasis is on comparing, relating, and synthesising values. For example, organisation recognises the need for balance between freedom and responsible behavior; accepts responsibility for one's behavior; explains the role of systematic planning in solving mathematical problems; accepts professional ethical standards; creates a life plan in harmony with abilities, interests, and beliefs; and prioritises time effectively to meet the needs of the organisation, family, and self. Examples are: to discuss, to theorise, to formulate, to balance, and to examine.

Characterisation by value or value set is to act consistently in accordance with the values he or she has internalised. This refers to the value system that controls their behavior. The behavior is pervasive, consistent, predictable, and most importantly, characteristic of the learner. Instructional objectives are concerned with the student's general patterns of adjustment (personal, social, emotional). For examples, internalising values means showing self-reliance when working independently. It means cooperating in group activities (displays teamwork); using an objective approach in problem solving; displaying a professional commitment to ethical practice on a daily basis; revising judgments and changes behavior in light of new evidence; and values people for what they are, not how they look. Examples include: to revise, to require, being rated high in the value, to avoid, resisting, managing and to resolve.

On the other hand, according to Karadeniz, Buyukozturk, Akgun, Cakmak, & Demirel (2008), learning strategies consist of two components: Cognitive and meta-cognitive strategies, and resource management. The component of cognitive and meta-cognitive strategies contains five elements: Rehearsal, elaboration, organization, critical thinking, and meta-cognitive self-regulation. Rehearsal strategies involve reciting or naming the learning materials. Elaboration strategies include summarizing, generative note-taking, or paraphrasing. Organization strategies include clustering, or outlining. Critical thinking refers to the strategies to make purposeful or reflective judgment or decisions by analyzing the information observed. Meta-cognitive self-regulation strategies contain planning, monitoring and regulating. The component of resource management includes four elements: time and study environment, effort regulation, Peer learning, and help
seeking. Time and study environment strategies include scheduling, planning and managing one’s time. Effort regulation reflects the commitment to completing one’s goal. Peer learning refers to the strategies to cooperate with others to complete the task. Help seeking refers to the strategies to manage and use the support from others.

**The relevance of the affective domain in mathematics learning**

When teaching mathematics, teachers tend emphasise the cognitive domain in their teaching. The majority of the teacher’s efforts typically go into the cognitive aspects of the teaching and learning and most of the classroom time is designed for cognitive outcomes. Yet the affective domain can significantly enhance, inhibit or even prevent student learning. However, teachers can increase their effectiveness by considering the affective domain in planning and delivering lesson activities, and also assessing student learning. Thus, there is significant value in realising the potential to increase student learning by tapping into the affective domain. According to Relich, et al. (1994), students should be encouraged to not just receive information at the bottom of the affective hierarchy. Students should respond to what they learn to value it, to organise it and maybe even to characterise themselves as mathematics students. Finally, it must be emphasised that students may experience affective roadblocks to learning that can neither be recognised nor solved when using a purely cognitive approach (Alsop & Watts, 2003; McLeod, 1992).

**Research methods**

**Research Design**

This research is an ex-post facto design in the sense that the researcher does not have direct control over independent variables because their manifestations have already occurred or because they are inherently not manipulable. A questionnaire survey was used to gather data on students’ strategies for mathematics learning. These students were selected from a sample of five secondary schools in Malawi conveniently selected as they were being used for students teaching practicum as well as due to time and cost restraints. For each of the five selected schools, all form 3 students participated in this survey. Students filled the survey questionnaire after classes. The final sample of the survey consisted of 184 students from the 5 secondary schools.

**Research Instrument**

The instruments consisted of two questionnaires. In the first questionnaire, students’ affective towards mathematics learning was measured by 60 items in the “Affective towards mathematics learning” scale developed by Relich, et al. (1994). This sub-scale measured students’ affective towards learning mathematics. The questionnaire contained the sections on personal background and factors influencing students’ feelings and confidence, plus latent variables respectively: mathematics beliefs, mathematics self-concept, mathematics-learning affective, self-efficacy, and learning approach.

Second, learning strategies in mathematics from the “Study Process Questionnaire” (SPQ) developed by Biggs (1992) was used to measure the learning strategies of students in this study. The second questionnaire contained sections on possible learning strategies. This instrument consisted of 64 items on a five-point scale. In both questionnaires the latent variable was measured through observed indicators in terms of items in the questionnaire. All the instruments were designed using Likert scale. The ordered categories are simply scored with successive integers and a students’ response is taken
as the sum of the scores of all statements of the instruments. The use of Likert Scale is appropriate for this study because it is simple and it focuses directly on a person’s affective.

**Data collection Procedure**

The quantitative data were obtained from a survey questionnaire administered to 184 respondents. The sample consisted of form 3 students in 5 secondary schools in Malawi. The questionnaires were self-administered and collected immediately after they were completed. In this way, the participants completed the questionnaires without consulting each other and 100% of the questionnaires were collected.

**Data analysis procedure**

Descriptive statistics by SPSS for Windows 16.0 was used to produce the means and standard errors for the scales of constructs and mathematics learning strategies. After performing descriptive statistical analysis, reliability analysis was carried out for all the scales of the instruments. The reliability was measured by the internal consistency coefficient and assessed by calculating the coefficient alpha.

The data from the students learning strategies questionnaire and the students’ affective factors were analysed using the statistical software SPSS for Windows. Part I of the questionnaire contained personal data. The data from Parts II to V of the questionnaire were initially analysed for internal consistency reliability using scale from SPSS for Windows. Then, for the affective factors (self efficacy, anxiety, interest, enjoyment, intellectual stimulation, reward for effort, diligence, valuing mathematics learning, willingness to learn mathematics and approaches to mathematics learning) and the learning strategies (rehearsal, elaboration, organization, critical thinking, self regulation, effort management, time and study environment, peer learning, help seeing, exploratory behaviour and communication behaviour) were considered as seven latent variables.

**Spearman Correlation Coefficient Analysis**

The questionnaire items were initially subjected to a Spearman Correlation Coefficient analysis. Given that the structure could vary, two factor analyses of the possible correlation between the affective factors and learning strategies were performed in order to investigate possible correlation between the two sets of factors.

**Constructing a Stepwise linear regression Model**

Stepwise linear regression is a method of regressing multiple variables while simultaneously removing those that aren't important. Stepwise regression essentially does multiple regressions a number of times, each time removing the weakest correlated variable. At the end you are left with the variables that explain the distribution best. The only requirements are that the data is normally distributed (or rather, that the residuals are), and that there is no correlation between the independent variables (known as collinearity).

**Testing the goodness-of-fit of the model**
SPSS for Windows provides a number of goodness-of-fit measures to judge how well a proposed model fits the data obtained in the study, a Chi-Square index was applied. A value of .90 or greater is commonly recommended in the judgment of the proposed model fits the data. However, Hart et al (1993) also pointed out that measure of goodness-of-fit are sensitive to the number of items in the model. They suggested that values of close to .80 or above could be considered acceptable for models having more than thirty items.

Results

Demographic information
The sample consisted of 184 form three students drawn from five government secondary schools. There were 93 (50.5%) girls and 91 (49.5%) boys. The gender representation was fairly equal in this study. All the schools were coeducation except one which was girls only school run by Catholic Church.

Table 1 show the age distribution of the students involved in this study. The majority of participants were of the ages between 14 and 18 with very few of ages 13, 20 and 25 years.

Table 1: Age distribution of the sample

<table>
<thead>
<tr>
<th>Ages (Years)</th>
<th>Frequency</th>
<th>Percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>4</td>
<td>2.2</td>
</tr>
<tr>
<td>14</td>
<td>21</td>
<td>11.4</td>
</tr>
<tr>
<td>15</td>
<td>36</td>
<td>19.6</td>
</tr>
<tr>
<td>16</td>
<td>54</td>
<td>29.3</td>
</tr>
<tr>
<td>17</td>
<td>37</td>
<td>20.1</td>
</tr>
<tr>
<td>18</td>
<td>24</td>
<td>13.0</td>
</tr>
<tr>
<td>19</td>
<td>6</td>
<td>3.3</td>
</tr>
<tr>
<td>20</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>25</td>
<td>1</td>
<td>0.5</td>
</tr>
</tbody>
</table>

The frequency distribution of the students responses regarding their learning strategies towards mathematics learning is presented in Table 1 (Scores of 4 = agree and 5 = strongly agree have been combined as agree whereas the scores of 1 = strongly agree and 2 = disagree as disagree and also scores for not sure form the third category).

Affective factors in mathematics learning
The average percentages of frequencies students’ ratings of the affective factors are presented in Table 2 for easy comparison.

Table 2: Frequencies of students’ ratings of affective factors

<table>
<thead>
<tr>
<th>Affective factors</th>
<th>Male</th>
<th>Female</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valuing math</td>
<td>90.25</td>
<td>79.75</td>
<td>86.51</td>
</tr>
<tr>
<td>Willingness to do math</td>
<td>76.25</td>
<td>74.25</td>
<td>75.11</td>
</tr>
</tbody>
</table>
When affective factors are compared, students seem to very assertive about value of learning mathematics, willingness to do mathematics, diligence, enjoyment and talent, confidence and self efficacy in learning mathematics. However, they seem not seeing much reward for their effort in learning mathematics, they are less interested with weak intellectual stimulation. They are not sure about their approaches to mathematics learning but disagree that mathematics learning causes anxiety among students.

The distribution of the frequency percentages across the affective factors displayed in Figure 2 show that there was steady decrease of frequency from valuing mathematics with the lowest for mathematics anxiety. This implies that there are some affective factors that are clearly felt by student more than other factors and these may account for the learning of mathematics.

![Figure 2: The spread of the frequency distribution across students’ affective factors](image)

Table 3 shows that the majority of the students employ communication strategies in learning mathematics. At the bottom of the list is use of time and study environment to enhance concentration during mathematics learning.
Table 3: A study of students’ mathematics learning strategies

<table>
<thead>
<tr>
<th>Students strategies in mathematics learning</th>
<th>Male</th>
<th>Female</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication Behavior</td>
<td>75.00</td>
<td>70.33</td>
<td>72.39</td>
</tr>
<tr>
<td>Self-regulation</td>
<td>74.73</td>
<td>68.99</td>
<td>71.02</td>
</tr>
<tr>
<td>Critical Thinking</td>
<td>74.19</td>
<td>67.03</td>
<td>70.65</td>
</tr>
<tr>
<td>Rehearsal</td>
<td>70.43</td>
<td>59.89</td>
<td>65.22</td>
</tr>
<tr>
<td>Exploratory Behavior</td>
<td>69.36</td>
<td>60.44</td>
<td>65.49</td>
</tr>
<tr>
<td>Elaboration</td>
<td>69.23</td>
<td>61.36</td>
<td>76.46</td>
</tr>
<tr>
<td>Peer-learning</td>
<td>69.18</td>
<td>65.75</td>
<td>67.44</td>
</tr>
<tr>
<td>Help-seeking</td>
<td>67.18</td>
<td>62.09</td>
<td>64.68</td>
</tr>
<tr>
<td>Organization</td>
<td>66.49</td>
<td>54.40</td>
<td>60.51</td>
</tr>
<tr>
<td>Effort Management</td>
<td>65.38</td>
<td>73.63</td>
<td>69.46</td>
</tr>
<tr>
<td>Time and Study Environment</td>
<td>62.10</td>
<td>59.89</td>
<td>67.75</td>
</tr>
</tbody>
</table>

This implied that discussing and talking about mathematics is more valuable than silently organizing and working out mathematics problems.

The distribution of the frequency percentages across the affective factors displayed in Figure 3 show that the frequency percentages are steadily the same ie between 50% and 75%. To these students, all the learning strategies appear to be equally important.

![Figure 3: The spread of the frequency distribution across students’ affective factors](image)

Correlations among affective and learning strategies

The results in Table 4.3 show that all learning strategies are positively correlated to affective factors except critical thinking which is negatively correlated to intellectual stimulation. There is significant Correlation coefficient between affective factors and learning strategies ($r=0.404$) at 0.001 level of significance.
Table 4: Correlational analysis between affective constructs and learning strategies

<table>
<thead>
<tr>
<th></th>
<th>Self Eff</th>
<th>Anxiety</th>
<th>Interest</th>
<th>Enjoyment</th>
<th>Intellectual stimuli</th>
<th>Reward</th>
<th>Diligence</th>
<th>Valuing</th>
<th>Willingness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rehearsal</td>
<td>.269**</td>
<td>.385**</td>
<td>.365**</td>
<td>.305**</td>
<td>.460**</td>
<td>.249**</td>
<td>.683**</td>
<td>.489**</td>
<td>.494**</td>
</tr>
<tr>
<td>Elaboration</td>
<td>.462**</td>
<td>.211*</td>
<td>.122</td>
<td>.274**</td>
<td>.168</td>
<td>.119</td>
<td>.034</td>
<td>.312**</td>
<td>.063</td>
</tr>
<tr>
<td>Organisation</td>
<td>.688**</td>
<td>.285**</td>
<td>.289**</td>
<td>.224**</td>
<td>.323**</td>
<td>.133</td>
<td>.189*</td>
<td>.397**</td>
<td>.361**</td>
</tr>
<tr>
<td>Critical Thinking</td>
<td>.468**</td>
<td>.203*</td>
<td>.067</td>
<td>.265**</td>
<td>-.016</td>
<td>.018</td>
<td>-.020</td>
<td>.239**</td>
<td>.033</td>
</tr>
<tr>
<td>Self Regulation</td>
<td>.429**</td>
<td>.271**</td>
<td>.060</td>
<td>.285**</td>
<td>.236**</td>
<td>.203*</td>
<td>.099</td>
<td>.261**</td>
<td>.191*</td>
</tr>
<tr>
<td>Effort Management</td>
<td>.269**</td>
<td>.206*</td>
<td>.010</td>
<td>.157</td>
<td>.095</td>
<td>.121</td>
<td>.105</td>
<td>.209*</td>
<td>.083</td>
</tr>
<tr>
<td>Study Environment</td>
<td>.485**</td>
<td>.278**</td>
<td>.228**</td>
<td>.277**</td>
<td>.400**</td>
<td>.252**</td>
<td>.225**</td>
<td>.396**</td>
<td>.287**</td>
</tr>
<tr>
<td>Peer Learning</td>
<td>.397**</td>
<td>.202*</td>
<td>.177*</td>
<td>.131</td>
<td>.136</td>
<td>.158</td>
<td>.231**</td>
<td>.289**</td>
<td>.321**</td>
</tr>
<tr>
<td>Help Seeking</td>
<td>.313**</td>
<td>.288**</td>
<td>.169</td>
<td>.179*</td>
<td>.341**</td>
<td>.245**</td>
<td>.297**</td>
<td>.401**</td>
<td>.297**</td>
</tr>
<tr>
<td>Exploratory Behaviour</td>
<td>.291**</td>
<td>.216*</td>
<td>.076</td>
<td>.162</td>
<td>.266**</td>
<td>.164</td>
<td>.188*</td>
<td>.196*</td>
<td>.169*</td>
</tr>
<tr>
<td>Communication Behaviour</td>
<td>.330**</td>
<td>.269**</td>
<td>.179*</td>
<td>.376**</td>
<td>.165</td>
<td>.183*</td>
<td>.094</td>
<td>.415**</td>
<td>.265**</td>
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</table>

However, there is very weak correlation between motivational factors and learning strategies and also between motivational factors and affective factors. Furthermore, reward was only significantly correlated to three learning strategies (help seeking, rehearsal, and managing study environment) out of 11 strategies. Those students who possessed diligence were likely to learn by rehearsal, managing study environment, peer learning and help seeking but negatively correlated to critical thinking.

It can be seen that in Table 4, rehearsal, study environment and help seeking are significantly correlated with all motivational factors. Motivational factor of self-efficacy was highly positively correlated with organization (r = .688) and also diligence was highly correlated with rehearsal (r = .683). On the other hand it is negatively related to surface approach (r = .02) but positively correlated with deep approach (r = .60). Hence the results show that affective factors take the mediator role with mathematics learning strategies. It is these correlations that lead to the influences of the affective constructs on leaning strategies in mathematics.

**Linear regression analysis model**
The primary purpose of this study is to determine the extent of the students’ affective factors contribution to learning strategies. When SPSS was used to compute stepwise linear regression, dependent (learning strategies) and independent (affective factors) variables were picked. This allows you to generate several statistics. This shows various statistics for each "model". The models are composed of different sets of the variables. These models are the combinations of variables that best explain the dependent variable. The affective factors were found to be significantly associated with overall learning strategies with \( r = 0.414, t = 5.238, p < 0.05 \) which indicates that the affective factor contributing to learning strategies.

Table 5. Multiple regression result between affective factors and learning strategies

<table>
<thead>
<tr>
<th></th>
<th>R</th>
<th>R²</th>
<th>Adjusted R²</th>
<th>Std. Error Est.</th>
<th>F</th>
<th>P</th>
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<tbody>
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<td></td>
<td>0.414</td>
<td>0.171</td>
<td>0.165</td>
<td>0.48</td>
<td>27.432</td>
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Model of affective factors and learning strategies

The result of this study showed that the relationship between affective factors and learning strategies is positive and significant \( t = 5.238, p < 0.05 \). This means that as the affective increases, the level of learning strategies also increases. The formula below shows the model of the present study. The model summary gave details of the overall correlation between the variables left in the models and the dependent variable. There the linear regression equation coefficients for the various model variables were obtained. The 0.38 value was the coefficients for which the variable's data should be multiplied by in the final linear equation we might use to predict long term learning strategy. The constant of 1.89 is the intercept equivalent in the equation \( y = 1.89 + .38x \). Therefore, learning strategies \( = 1.887 + 0.378 \) affective factors + e. When an analyst attempts to fit a statistical model to observed data, he or she may wonder how well the model actually reflects the data. How "close" are the observed values to those which would be expected under the fitted model? One statistical test that addresses this issue is the chi-square goodness of fit test. This test is commonly used to test association of variables in two-way tables), where the assumed model of independence is evaluated against the observed data. In general, the chi-square test statistic is of the form

\[
X^2 = \sum \frac{(\text{observed} - \text{expected})^2}{\text{expected}}
\]
If the computed test statistic is large, then the observed and expected values are not close and the model is a poor fit to the data. The goodness-of-fit index for the final model is 69.9 with degree of freedom 287 indicating that the hypothesis that the fitted residuals are different from zero can be rejected. The results also indicate that the data fit the final model very well and this is reflected by the root mean square error approximation less than .05. The goodness-of-fit index, adjusted goodness-of-fit index and comparative goodness-of-fit indices exceed or close to .90 provide further support for the final model and its explanation of the relationships between affective and learning strategies.

The final model

This model satisfies a number of criteria and thus it was selected as the final model. First, the final model is consistent with substantial theory in the literature. Second, this goodness-of-fit can be improved upon compared with competing models. Thirdly, the final model is based on and consistent with the results in the pilot study. The model confirms that affective and learning-approach constructs are interrelated A significant relationship among the individual variables within these domains can be investigated further and the influence of one variable on another variable can be quantified with the path coefficients. The significance is based on the existence of correlations between the variables and the path coefficients that are greater than .10 and the p-value are less than .05. As shown in Table 5, the model claims that a student with a high self-concept exerts a negative impact on learning strategies. Moreover, the model asserts that the higher the students’ mathematics self-concept the higher would be their mathematics learning self-efficacy as there is a strong positively direct effect of strength of .83 from mathematics self-concept on mathematics learning self-efficacy.

Furthermore, the model also indicates that the students with positive beliefs about mathematics tend to have high mathematics learning self-efficacy as the path coefficient from mathematics beliefs to mathematics learning self-efficacy is positive to the magnitude strength of .28. Moreover, the model claims that affective factors have influence on mathematics learning strategies, as there is also a direct path of strength .33 linking enjoyment in mathematics learning and the learning strategies used. However, the model also claims that indirectly influences mathematics learning strategies to learning because self-efficacy exerts a positive impact of strength of .60 on communication behaviour and .26 on surface approach to learning. Hence, it claims that students’ mathematics learning self-efficacy influences their approach to learning and the higher the efficacy they held, the higher the likelihood they would choose a deep approach to learning. This result informs practice that student-training educators should put more emphasis on enhancing students’ self-efficacy and encouraging deep approaches to learning. Statistically, the above model is feasible as the SPSS program converges with all parameter estimates falling into the acceptable. However, only the final model fits the data well in terms of the parsimony principle, goodness-of-fit indices and literature support. The result of correlations among constructs, the direct and indirect effects of influences of independent variables on dependent variables and the goodness-of-fit indices for the final model are reported in the following section.

Conclusion

In conclusion, students’ mathematics self-concept, mathematics learning self-efficacy, beliefs and attitudes towards mathematics influence cognitive activities in the learning process. The result also shows that mathematics learning self-efficacy acts as the mediator of affective factors and learning
strategies. The finding proves useful to educators in the research areas of affective domain of mathematics and learning strategies. Educators should focus on understanding affective factors predominant in individual learners and students should be motivated to understand that the subject could be studied using different strategies just like other subjects, and to appreciate that it is an essential tool and a prerequisite for further education in many vocations.

References


Yaratan, H., & Kasapoglu, L. (2012). Eight grade student's attitude, anxiety, and achievement pertaining to mathematics lessons. Procedia-Social and Behav
Relationships among perceived difficulty of a mathematics problem, confidence in problem solving and achievement in mathematics of First Year Mathematics Students at the University of Malawi-The Polytechnic

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The aim of this study was to examine the degree of correlation among students perceived level of difficulty, level of confidence and their performance in a trigonometry test among the first year students’ taking a mathematics course. Considering that most of the first year students were selected to university partly because they scored high grades at secondary school level, it is expected that they would perceive trigonometry tests as easy as well as with confidence. In this study of first year mathematics undergraduate class of 116 at the Polytechnic of the University of Malawi, we investigated students’ perception of difficulty of mathematics and their confidence in mathematics. Student achievement was compared to two variables. Fifty-seven male and fifty-nine female students participated in this study. Data was collected through a class test administered as part of the continuous assessment of the course. The test consisted of 25 items grouped into ten questions drawn from a topic on logic, sets and functions. The results show that there is no correlation between student perception of level of difficulty and their performance as well as student perception of confidence and their performance in trigonometry test. However, there is a strong negative correlation between students’ perception of level of difficulty and their perceived confidence. The results also show that there is no correlation among all the three variables among male students whereas there was strong correlation between students’ perceived difficulty and confidence among female students. The findings have implications on what and how teachers and lecturers of mathematics should do to enhance confidence and reduce fear of mathematics among students of different sex.

Introduction
The aim of this study was to investigate the relationship among students' perceptions of the levels of difficulties of the trigonometry test items, the perception of the level their confidence in getting the answers correct and their level of achievement. Perceiving something being difficult and have confidence in finding solution is a matter of emotions. Perception of something being difficult tends to influence the amount of efforts in solving the problem. For some people, perceiving something as difficult meant that they resign from trying to find solutions. For others, perceiving some level of difficult provides an impetus to try hard and find solution. Confidence, which has generally been accepted as a belief about one's competence in mathematics, has been identified as one of the most important affective variables influencing the students' approach to new mathematics including a determining factor of their persistence. The student will persist if confident of finding a solution or eventually gaining understanding; likewise, a confident student is more likely to participate in mathematical courses at a higher level.

Problem statement
It is human nature for people to spend more time doing the things they enjoy. People embrace things that they are good at. Likewise, people avoid those things that cause them anguish. Thus, if students begin to feel they do not understand mathematics, they will begin to lose confidence and avoid math
whenever and however possible. Those students who struggle with math in their early elementary years begin to develop an, "I'm no good at math" attitude. This attitude perpetuates as math becomes more and more complicated.

On the other hand, there are students who are successful in math and get good scores on tests. The majority of successful math students claim to enjoy math. They are confident in their mathematical abilities. However, some students are unable to explain how or why mathematical operations work. While they have likely been shown how they can work out a mathematical problem, they most likely have never had to explain that to someone else. All they needed to know is how to do it so they can get the right answer on a test. Eventually this confidence can begin to diminish. Students who have enjoyed much success by memorizing rules and procedures with little to no conceptual understanding of the math involved will likely "hit a wall” at some point in their education.

When students get to university, they are expected to do more complex mathematics such as trigonometry. Although it may be easy for some lecturers to explain some basic concepts of trigonometry, it is extremely difficult to get students to understand, for example, why $(\sin x)^2$ is not $\sin^2 x$ but $\sin 2x$. This is an example of the "crack” that university student’s fall through when the focus of instruction is procedural. Time constraints often force teachers to teach and students to learn math in the most efficient way in order to pass tests. This can become problematic for students who are not good at memorizing math procedures in a short period of time. The result becomes poor difficulty and a loss of confidence that can stick with students for the rest of their lives. Teachers expect their students to be able to not only get high grades in mathematics, but to develop confidence and find mathematics easy. Students should learn mathematics with ease and confidence if they are to succeed in the subject. If students begin to develop this conceptual understanding of mathematics, their difficulty about math, their confidence in understanding math, and their subsequent achievement should improve.

**Purpose statement**

The purpose of my study is to investigate the relationship between students’ perception of the level of difficulty and confidence in trigonometry and their achievement in a trigonometry test. For example, is it possible for students who lack confidence in math to have high achievement? Conversely, are there students who have high confidence in their abilities, but still fall behind in their level of achievement? Are there differences between male and female students in level of difficulty and confidence in solving problems on trigonometry? During this project, I investigated the following questions:

1. What is the relationship between students' perception of the level of difficulty and their achievement in the trigonometry test?
2. What is the relationship between students' perception of the level of confidence and their achievement in the trigonometry test?
3. What is the relationship between level of student confidence and their perception of the level of difficulty?
4. Are there differences in the students’ perception of the levels of difficulty and confidence in a trigonometry test?
The findings of this study will be useful to the lecturers/teachers of mathematics at all levels of education in that they will be able to plan and deliver their lessons in a manner that would address issues of increasing confidence while reducing fears of mathematics.

**Literature review**

One problem of mathematics teaching was the preconceived notions students have about what mathematics is and whether or not they can be successful in mathematics. A student’s perception of mathematics may be formed from a number of sources. One powerful influence on student difficulty is the classroom teacher. In a study of fourth, seventh, and ninth graders from both rural and urban schools, Haladyna, Shaughnessy, and Shaughnessy (1996) identified a strong relationship between teacher quality and positive difficulty toward math. The authors also noted that this relationship may be more significant for grade lower grades than higher ones. Similar teacher influence was found by Turner, Meyer, Midgley, and Patrick (2003) who studied two teachers with different communication styles. They found that teacher interaction with students had an impact on student confidence and difficulty toward math. In a three-year study of elementary students' difficulty and beliefs about mathematics, Kloosterman, Raymond, and Emenaker (1991) found that students develop confidence and positive feelings about difficulty when students work. However, confidence and difficulty seemed to change in upper classes when they begin to solve problem independently. This change in attitude toward doing problems as a group seemed to be a reflection of the difference in teacher difficulty (Kloosterman, Raymond, and Emenaker).

Student difficulty was also found to be shaped by a student’s level of success. In a study of college-aged men and women, Ross and Broah (2000) investigated factors that influence achievement. Specifically, they looked at self-esteem and personal control as attribution of success and failure. One of their findings suggested that future academic achievement is earlier academic achievement. The more success a student had in mathematics, the more positive their attitude toward it (Stodolsky, Salk, and Glaessner, 1991). While this seemed to make sense on a logical level, it also implied that teachers needed to find ways for those students who experienced dismal success in the past to feel great success.

This study explores three concepts as they influence students’ achievement in mathematics: difficult and confidence in mathematics. Difficult implies that considerable mental effort or physical skill is required, or that obstacles are to be overcome which call for sagacity and skill in the doer; as, a difficult task. The definition of difficult is something that is hard to understand or do.

- Requiring considerable effort or skill; not easy to do or accomplish.
- Not easy to endure; full of hardship or trouble; trying
- Not easy to comprehend, solve, or explain: a difficult puzzle.
- Not easy to please, satisfy, or manage: a difficult child.

Difficulty may arise from fear of failure. The feelings of inferiority and outright fear that many students feel when they confront mathematics severely inhibit students’ natural intelligence and creativity. It is as though every mathematical subject, and every concept within a subject, is surrounded by a kind of “force field” that radiates fear, a feeling of “this is not for you”, “You aren’t
smart enough!"). The origin of this force field may be early experiences in a family in which, say, a father had always been good at mathematics, and had made it clear he expected his children to likewise be good at the subject. In the case of women, the origin might be subtle messages sent by teachers throughout the primary and secondary school years — perhaps without conscious intention — that technical subjects are too hard for girls. Or, it might be the atmosphere that surrounds mathematics and indeed all technical subjects in the nation’s most prestigious schools, in which the question is not, Can you learn it?, but Can you learn it the way it is taught and at the pace that those in charge demand?. Are you engineering or scientific or mathematics-professor material, yes or no? In short, are you a winner or a loser?

Confidence in mathematics is a feeling that you think you are capable of doing mathematics. It may make you optimistic and pleasing about mathematics and thereby enjoy doing mathematics. In this study, confidence is understood to have an influence on success in mathematics. Confidence is one of the critical factors for your success in mathematics. However, most of students are not confident enough to tackle mathematical problems and their efforts in mathematics don’t make sense. Confidence does not mean being better than others or being successful. Confidence is a feeling that you think you will do better after your efforts, a feeling that you can know more after your time, a feeling that you come from the environment so you can change yourself to adapt to the environment. Confidence concerns clam, attitude, and mind. First thing of confidence is being calm and make a analysis of yourself to know what is your weakness, what is your strongpoint. As you know, psychological diathesis always has important influence on success. So confidence should make you being strong in psychological diathesis. Purpose and use of confidence is to maximize your actual ability and future potential.

It is generally assumed that there is a link between students’ confidence and difficulty in mathematics. However, few studies seem to confirm this relationship. A feeling of difficult is related to a feeling of confidence in the sense that persistent feeling that something is difficult tend to erode confidence in a learner and consequently failure. This relationship can be modelled as follows:

![Figure 1. A model for generation of mathematical beliefs.](image-url)
Figure 1 illustrates that when the level of difficulty in a learner increases, the level of confidence decreases leading to failure in mathematics. However, when the level of difficulty in a learner decreases, the level of confidence increases, leading to high achievement in mathematics.

A student's attitude and confidence could be difficult to change. This could be good if a student had a good attitude, but could be very problematic when a student's attitude and confidence are negative. In a three-year study of students' difficulty and beliefs about mathematics, Kloosterman, Raymond, and Emenaker (1996) found that about 60% of student difficulty and confidence remained constant from year to year. Those students who reported a change in their level of confidence changed only from one level to the next; a student with low confidence never moved to high confidence and vice versa. Kloosterman, Raymond, and Emenaker (1996) also found the relationship between confidence and achievement varied with age. While there was little relationship between these two variables as students’ progress through grades, there existed a strong positive correlation between a student’s confidence in their mathematical ability and their achievement. Hackett and Betz (1989), who studied college aged men and women, found a weak positive relationship between student self-efficacy and performance.

In a study on attitudes, confidence, and achievement of high-ability fifth grade math students, Piper (2008) found that most students had strong correlations between their confidence levels and achievement. However, some students were over or under-confident in their abilities compared to their achievement. It was not clear whether confidence promotes achievement or vice versa. Lloyd, Walsh, and Yailagh (2005) suggested that confidence did not directly affect achievement but rather what students attributed their success and failure to. In their study of fourth and seventh grade boys and girls in Canada, Lloyd, Walsh and Yailagh found that both boys and girls were more likely to attribute their success to internal factors such as ability and effort and less likely to attribute success to external factors such as the teacher. They made the connection between how students attributed success and failure to self-efficacy. Ross and Broh (2000) suggested that while academic achievement enhanced student self-efficacy, the extent to which students felt a sense of personal control over their success is actually what impacted achievement. The implication was that understanding how students thought of their success and failure in math might have been more important than their confidence level as teachers plan how to increase student achievement.

How students attributed success and failure in school and their confidence levels may have had an impact on students as they progressed through level of education. Scott and Fensham (2006) points out that level of difficulty in mathematics are relative to the grade level. For example, the first year students are likely to experience lots of difficulties with college mathematics as compared to those in the second year classes because of the various school backgrounds still fresh in them. It was not surprising that students would bring old feelings with them to a new class. Those feelings might have been positive and rooted in a history of success, or could have been negative stemming from a lack of academic success. Wong, Lam and Wong (2002) pointed out that learning difficulties occurred when they could not solve problems. Students began to face learning difficulties late primary classes when they started feeling the pressure of work. In a study of upper elementary students in urban area of the USA, Mason and Stipek (1989) found that students carry a briefcase feelings and perceptions to new classrooms that may weaken teachers' efforts to increase student's skills. Therefore, it became
important for a teacher to make efforts to assess students' difficulty and confidence early in a school year in order to address "hidden" issues that might have been impacting student achievement.

Teachers also contribute to the student perception of the difficulty in mathematics. Teachers too quickly assume that students struggle with mathematics because they just have not been exposed to the right teaching method. If a student struggled in the classroom as a result of how he or she attributed success and failures in class, then the "right" teaching method might very well have been one that addressed how the student felt about his or her own ability rather than a particular teaching tool. As Mason and Stipek (1989) stated, "Once teachers ascertain which students possess these negative self-perceptions and emotions, they much develop strategies to assist students in overcoming the cognitive and emotional obstacles that may interfere with successful performance" (p. 66). Age and grade level might also affect how a student attributed success and failure. Because of their more direct role in student learning, younger students might be more likely to attribute their success and failure to their teacher rather than their own efforts or abilities (Lloyd, Walsh, and Yailagh, 2005). Lloyd, Walsh, and Yailagh found that students were more likely to attribute success and failures to internal factors than were younger students. Craig (2006) the factors that appear to affect student perception of the difficulty level of a word problem are familiarity, context and visual representation in that order of mathematics content. Thus, student’s difficulty and beliefs are shaped by a number of factors some of which a teacher can be controlled by a teacher and others cannot be easily controlled. However, there is little attention paid towards exploring how some of these factors influence each other. For example, how does students’ confidence, difficulty and performance in mathematics relate to each other?

Students’ perception of the levels of difficulty and confidence in a mathematics tests can also be explained through mathematics anxiety. Cahill (2005) points out that the brain is responsible for interpreting something as a dangerous, and therefore warns and prepares the body for action. This message depicts itself as anxiety. According to Scientists have shown for the first time how brain function differs in people who have math anxiety from those who don’t. A series of scans conducted while second- and third-grade students did addition and subtraction revealed that those who feel panicky about doing math had increased activity in brain regions associated with fear, which caused decreased activity in parts of the brain involved in problem-solving.

In another study, Menon (2012) performed functional magnetic resonance imaging brain scans on 46 second- and third-grade students with low and high math anxiety. Outside the scanner, the children were assessed for math anxiety with a modified version of a standardized questionnaire for adults, and also received standard intelligence and cognitive tests. Therefore, it is possible that students’ perceptions of the levels of difficulty and confidence in solving mathematical problem could be explained biologically

Methods

The survey was carried out at the Polytechnic. A sample for this study consisted of students the math class of studying environmental health, environmental science and technology and business education at the Polytechnic of the University of Malawi. The subject of this research project consisted of 116
students (57 male and 59 female). Data for this study was collected in March 2011. The students were taught during the normal time and they were given a test constructed by their lecturer based on the concepts of trigonometry which included:

(a) Angular measure (Convert between degrees and radians)
(b) Trigonometric functions (evaluate trigonometric ratios of right angled triangles)
(c) Graphs of trigonometric functions
d) Addition and double angle formulae
e) Application to triangles etc
(f) Product and Factor Formulae
g) The solution of trigonometric equations
(h) Inverse trigonometric functions

The test was part of the continuous assessment requirement for their courses. Students were told about the test. The test consisted of 25 items grouped into ten major questions each focusing on a major concept in trigonometry. Students were asked to work out the answers to all the questions and write down their answers on the answer sheet provided. Then indicate whether the question was easy or difficult using a number scale of 1=easy, 2=average and 3=difficult. In addition, students were asked to also indicate whether they were confident that they would get all the marks for the questions by using a scale number of 1=very confident, 2=average and 3=least confident. The test lasted for 2 hours.

Quantitative data were recorded and analysed. SPSS was used to compute frequencies, produce scatter graphs. Further analyses were done to explore patterns based on gender differences. The results are presented in four sections. In each section, a scatter graph is presented to illustrate the patterns being observed. Furthermore, Pearson correlational analysis was conducted using SPSS. Finally, run stepwise regression analyses

**Results**

**Student confidence level versus performance**

Figure 1 shows a scatter diagram for the overall performance against overall confidence level. It is evident from the scatter diagram that there is a weak correlation between overall difficult levels and overall confidence level.
This means that there is weak association between students’ performance and the level of confidence. When the level of confidence was correlated to overall performance in the test, the Pearson correlation was 0.215 which was not significant at $p<0.01$ level of two tailed. This Pearson correlation coefficient indicates that there is weak positive correlation between overall performance and overall perceived level of confidence in solving problems in trigonometry test.

**Student performance versus difficult level**

Figure 2 shows a scatter diagram for the overall difficult level against overall confidence level. It is evident from the scatter diagram that there is a weak correlation between overall difficult levels and overall confidence level. This means that the students’ perception of level of difficult of the test was not associated with their level of confidence.
Furthermore, a correlational analysis shows that the correlation between levels of difficult and performance ($r = 0.188$) also is not significant at $p<0.05$ level. The results from the statistical tests suggest that the perception of level of difficult of the question items was not associated with the student achievement in trigonometry. Thus, students performance in the test was not associated with their perception of the level of difficulty of the question items.

**Student confidence level versus difficult level**

Figure 3 shows a scatter diagram for the overall difficult level against overall confidence level. It is evident from the scatter diagram that there is a negative correlation between overall difficult levels and overall confidence level. This means that there is some degree of association between the students’ perception of the level of difficulty of mathematical questions and their level of confidence.

When the overall level of difficult was correlated to the overall level of confidence was test using Pearson Correlation ($r = -0.600$) was found to be significant at $p<0.01$ level of two-tailed test. This statistical test shows that there was negative correlation between level of confidence and levels of difficult in a trigonometry test. The findings suggest that the high level of confidence is associated with the low level of difficult in solving mathematical questions.

**Correlation between perceived levels of confidence and difficulty by gender**

Figure 4 shows a scatter diagram for the overall difficult level against overall confidence level for male and female students. It is evident from the scatter diagram that there is no correlation for male and a negative correlation for female students between overall difficult levels and overall confidence level.
This means that there is gender difference in association between the level of difficult and the level of confidence in a mathematics test. The findings suggest that female students are more accurate with their ability in mathematics than are male students.

When the level of difficult was correlated to the level of confidence, the Pearson correlation for male is -0.358 and for female is -0.80. These correlation indices indicate that there is negative correlation for both male and female and that there is stronger correlation for female than for male. The findings suggest that for female, levels of confidence in solving mathematical questions are more likely to be associated with their perception of the level of difficulty of the questions than it is for male. For male students, the level of difficult of a question does not put them off; but keep trying with the hope that they will get it right. The stepwise regression analysis model for male was -0.72x +25.364 whereas for female student was -0.117x + 54.336. In both cases, it is evident that there is fair level of difficult as a predictor of confidence level in mathematics rests.

Figure 5 shows a scatter diagram for the overall confidence level against overall performance in mathematics test for male and female students. It is evident from the scatter diagram that there is little correlation for male and a negative correlation for female students between overall difficult levels and overall confidence level. This means that there is gender difference in association between the level of difficult and the level of confidence in a mathematics test. The findings suggest that female students are more accurate with their ability in mathematics than are male students.
When the level of confidence was correlated to the performance, the Pearson correlation for male is 0.502 and for female is 0.242. These correlation indices indicate that there is positive correlation for both male and female and that there is stronger correlation for male than for female. The findings suggest that for female, levels of confidence in solving mathematical questions are less likely to be associated with their perception of the level of difficulty of the questions than it is for male. For male students, the level of difficult of a question does not put them off; but keep trying with the hope that they will get it right. The stepwise regression analysis model for male was $0.502x + 18.341$ whereas for female student was $0.214x + 26.532$ in both cases, it is evident that there is fair confidence level as a predictor of students performance in mathematics rests.

Figure 5 shows a scatter diagram for the overall confidence level against overall performance in mathematics test for male and female students. It is evident from the scatter diagram that there is no correlation for male and a negative correlation for female students between overall difficult levels and overall confidence level. This means that there is gender difference in association between the level of difficult and the level of confidence in a mathematics test. The findings suggest that female students are more accurate with their ability in mathematics than are male students.
When the level of difficult was correlated to the performance, the Pearson correlation for male is 0.426 and for female is 0.14. These correlation indices indicate that there is positive correlation for both male and female and that there is stronger correlation for male than for female. The findings suggest that for female, performance in solving mathematical questions are less likely to be associated with their perception of the level of difficulty of the questions than it is for male. Again, for male students, the level of difficult of a question does not put them off; but keep trying with the hope that they will get it right. The stepwise regression analysis model for male was $0.851x + 17.973$ whereas for female student was $0.182x + 32.068$ in both cases, it is evident that there is fair confidence level as a predictor of students performance in mathematics rests.

**Discussion**

The results of this study indicate that the student perception of the level of difficulty and their level of confidence in a trigonometry test had weak association on their performance. However, there is gender difference in perceptions of levels of difficult and of confidence solving mathematics questions. Despite higher performance, male students were also more likely to indicate that the test items were difficult than female students. Furthermore, the difference between male and female students in their perceived levels of difficult and level of confidence students were not significant.

The study has also revealed that unlike male students, female students demonstrated strong correlation between perceived level of difficult and level of confidence in a test. Although the study did not attempt to investigate the cause for confidence, previous studies have explored the biological explanations (Digitale, 2012). For example, in female, if the amygdala section of the brain kicks in, it increases response to intense emotions such as fear, depression or shame. The cortex shuts down and no critical thinking occurring. Rationalising with a female whose amygdala is sky high would be pointless. Males may have similar experience, though not as intense because, unlike in male, amygdala is more developed at a younger age in females and is more responsive to key emotions as fear. This means that male students are not marred by the question being difficult and their confidence comes about as a result of trying out to answer the question. This is contrary to female students who are afraid of attempting to answer a question once they perceive it as difficult. Unlike male student, female students quickly give up when are confronted by challenging question. The findings of this study have implications on how to teach mathematics. There is a strong suggestion that male student respond differently from female students to mathematical questions. This means that when presenting or assessing students, caution should be made to student sex. For male students, perceiving mathematical questions as challenging has little effect on their level of confidence in finding solution. On the other hand, female students tend to have confidence in finding solution to mathematical questions when they perceive them as easy. The findings of this study provides an insight into why there is a gender difference in achievement in a mathematics test; it is a question of levels of confidence arising from the perception of level of difficulty of the mathematics test. Female students are more likely to be afraid of failure and ridicule whereas male students are likely proud of succeeding when confronted with a difficult mathematics question.

The stepwise regression analysis models produced models which show varying degree of predictability. There are strong predictability among levels of difficulty, levels of confidence and
performances in mathematics among male students than among female students. However, when the correlation analyses are considered, it appears that the correlational ratios are so weak that suggest that the models are inconclusive; that is, there need for further research in this area where large sample of students will be considered.

**Conclusion**
The above result gave a clear picture of how student perception of the level of difficulty and their level of confidence relate to their performance in mathematics. Generally, there is little relationship between students’ perceptions of difficulty and confidence and their performance in mathematics. However, there is a significant relationship in students’ perceptions of difficulty and confidence and their performance in mathematics among female than among male students.

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Adaptation of mathematical knowledge for teaching for number concepts and operations measures for use in Malawi

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This paper describes what is entailed in the adaptation process of mathematical knowledge for teaching for number concept and operations (MKT-NCOP) measures for assessing mathematical knowledge for teaching (MKT) among pre-service teachers in Malawi. We describe the adaptation process with all the steps from stem/item selection to modification of items from their original form. A conceptual framework for adaptation derived from literature is presented and findings from its implementation are shared. Results show that, while language and content remain the same, the adaptations of the U.S. measures for use in Malawi significantly modifies the context of the stems and items.

Introduction

In a comparative study between South Africa and Malawi, Kazima, Pillay and Adler (2008) observed the lack of understanding of mathematical knowledge for teaching. According to Kazima, et. al., the two teachers they observed failed to restructure a lesson when an activity they had planned for their students gave different results from what they expected. The observation about teacher’s dogmatism made by Kazima, et. al. may not be unique to this particular Malawian teacher but possibly a representation of the practice among Malawian teachers. Chitera (2011, pp 1010), reports that “student teachers [in Malawi] are prepared to perform only mathematical procedures without justification on why they have used a particular procedure for a given problem”. Based on these observations by Kazima et. al. and Chitera, we ask ourselves the following questions: Are primary school teachers able to handle mathematics teaching and learning in a way that reflects their versatility in and command of the subject? How well are primary school student teachers prepared to teach mathematics in terms of subject knowledge and knowledge for teaching? Can we develop or adapt diagnostic measures to successfully assess primary school student teachers’ mathematical knowledge for teaching? We feel compelled to asked these questions because we are of the view that mathematical knowledge for teaching is vital to teachers as it demands beyond content knowledge and procedures (Adler, 2005, Ball, Hill, & Bass, 2005; Ball, Thames, & Phelps, 2008).

Over the years studies have been carried out to assess teachers’ knowledge for teaching mathematics by developing or adapting diagnostic measures. However, we have not come across any such studies reporting findings from Malawi. In this paper we report on the process we followed to adapt U.S. MKT measures for number concepts and operations. The aim for examining and detailing the entire adaptation process in this paper is to emphasise the importance of adaptation process which, most often, receives less attention compared to pilot studies and psychometric analysis of the measures. With this key objective in mind, this paper explains how the adaptation process was implemented, aspects of the instruments that were subject to modification, and issues encountered during the
adaptation process. To address this objective, we answer the following research question: What does adaptation of U.S. developed measures entail in the context of Malawi?

**Related Literature**

Researchers seem to agree that teaching mathematics depends, among other factors, on a specialized body of knowledge specifically for teaching mathematics (Adler, 2005; Ball et al., 2008; Kwon, Thames, & Pang, 2012). While the link between ordinary subject content a teacher has and students’ achievement remains blurred (Ball, Lubienski, & Mewborn, 2001; Monk, 1994), there is strong evidence that links teachers’ mathematical knowledge for teaching to classroom instruction and students’ achievement (Ball et al., 2005; Baumert et al., 2010; Hill, Rowan & Ball, 2005; Mewborn, 2003). Shulman (1986) first studied this body of knowledge. Shulman’s initial classification of the knowledge for teaching included seven categories, namely: knowledge of content, knowledge for curriculum, pedagogical content knowledge, knowledge of pedagogy, knowledge of learners and learning, knowledge of context, and knowledge of educational philosophies and objectives. Before and immediately after Shulman’s initial work, different terminologies were used to describe the body of knowledge required for teaching. For instance, the terms content knowledge and pedagogical content knowledge were widely use. Ball, Thames, and Phelps (2008) and Manson (2008) argue that differences in the understanding of, and use of, the terms to describe this body of knowledge caused a lot of ambiguities and limitation in its use. Grossman (1990), a member of Shulman’s research team improved Shulman’s categorization of the body of knowledge for teaching. She reduced Shulman’s seven categories into four main categories. These categories were subject-matter knowledge, general pedagogical knowledge, knowledge of context and pedagogical content knowledge. The major contribution through Grossman’s categorization and definition of the knowledge for teaching was that she included beliefs as part of the pedagogical knowledge.

Further research (Fennema & Franke, 1992; Marks, 1990) followed these initial efforts to define and understand knowledge for teaching mathematics. However, these efforts were mainly disjointed and used Shulman’s work to defined subject matter knowledge for teaching from a qualitative focus (Ma, 1999). Ball, Thames and Phelps (2008) developed a practice-focused framework for teachers’ mathematical knowledge for teaching whose aspects have been experimentally verified. In their work, Ball, Thames and Phelps analysed literature that was available on mathematical knowledge for teaching and isolated from the literature important components of mathematical knowledge for teaching. These components have been subjected to empirical studies by studying teaching of mathematics and not teachers (Ball et al., 2008; Hill et al., 2005). Ball and her research team derived the term Mathematical Knowledge for Teaching (MKT) to represent the special type of knowledge required only for teaching mathematics.

Ball et al. (2008) mathematical knowledge for teaching framework has two major domains namely: subject matter knowledge (SMK) and pedagogical content knowledge (PCK). For them, subject matter knowledge comprises common content knowledge (CCK), specialized content knowledge (SCK), and horizon content knowledge. Horizon content knowledge represents knowledge about mathematics that is outside the curriculum being taught, and how such knowledge is important in orienting and navigating in the classroom (Jakobsen, Thames, Ribeiro, 2013). Hill, Ball, and Schilling (2008) refer to this sub-domain as knowledge at the mathematical horizon. Pedagogical knowledge is made up of knowledge of content and students (KCS), knowledge of content and teaching (KCT),
and knowledge of content and curriculum (KCC). The common content knowledge sub-domain of subject matter knowledge is knowledge that is not unique to teachers. Rather it consists of mathematical knowledge and skills that are required in, for instance, solving mathematics problems or performing a mathematical procedure and defining a mathematical concept. This therefore encompasses all the knowledge and skills necessary to use mathematics in general as required by both teaching and non-teaching professionals. The specialized content knowledge is “mathematical knowledge not typically needed for purposes other than teaching” (Ball et al., 2008, p. 400). For Hill et al. (2008, p. 378), this is the “knowledge that allows teachers to engage in a particular teaching task, including how to accurately represent mathematical ideas, provide explanations for common rules and procedures, and examine and understand unusual solution methods to problems”. They argue that this knowledge differs significantly from Shulman’s (1986) original conceptualization of subject matter knowledge which in their view is common content knowledge. Teachers require this specialized knowledge to among other things identify error patterns in students and assess whether a nonstandard approach is generalisable.

Another apparent sub-domain of mathematical knowledge for teaching is knowledge of content and students which calls for “mathematical understanding and familiarity with students and their mathematical thinking” and given content (Ball, et al., 2008, p. 401). For Hill et al. (2008, p. 378), knowledge of content and students entails “teachers’ understanding of how students learn particular content”. The last sub-domain identified by Ball and her colleagues is knowledge of content and teaching. This involves knowing about teaching and knowing about mathematics simultaneously. It involves teachers’ knowledge to make instructional choices as they decide

…which examples to start with and which examples to use to take students deeper into the content. Teachers evaluate the instructional advantages and disadvantages of representations used to teach a specific idea and identify what different methods and procedures afford instructionally. (Ball et al., 2008, p. 401)

The two sub-domains classified under pedagogical content knowledge (PCK) in this theoretical conceptualization match with Shulman’s (1986) features of pedagogical content knowledge. Ball and her colleagues placed Shulman’s third category, curricular knowledge, under their pedagogical content knowledge domain.

Research has ably demonstrated that teaching mathematics requires mathematical understanding beyond content knowledge necessary for practicing mathematics in general sense (Ball et al., 2005; Hill et al., 2005; Ball & Schilling 2008; Shechtman, Roschelle, Haertel, & Knudsen, 2012). Furthermore, studies have shown that having strong subject matter content knowledge is inadequate for the mathematical knowledge necessary for teaching. However, the fact remains that we do not have an all-inclusive understanding of what mathematical knowledge is necessary for teaching across contexts and the extent to which other factors impact mathematical knowledge for teaching in teachers (Silverman & Thompson, 2008). Further research is therefore required to expand the conceptualization of mathematical knowledge for teaching by considering different contexts and how mathematical knowledge for teaching develops in these differing context as suggested by Silverman and Thompson.

While there has been different mathematical knowledge for teaching models due to researchers’ differing conceptions and beliefs about what mathematical knowledge is required for effective teaching, there appears to be a common understanding that teachers’ mathematical knowledge for
teaching and practice are interactive and dynamic. Another important and common understanding among the different mathematical knowledge for teaching models available is context. All the models seem to suggest that teachers’ mathematical knowledge for teaching is not context free as it will be affected by locality, resources, background, and other factors (Thompson, 1992; Silverman & Thompson, 2008; Andrews, 2011; Delaney, 2012). We therefore observe that our current work is a means for extending the discussion and conceptualization of mathematical knowledge for teaching to a different context.

Adaptation methodology

This study is guided by literature and lessons drawn from similar studies that adapted MKT measures. Malda, Vijver, Srinivasan, Transler, Sukumar, and Rao (2008) worry about fairness of adapted measures and urge researchers to guarantee it in all procedures leading to adaptation. For them, fairness is lack of bias, equitable treatment in testing procedure, equality in outcomes of testing, or equality in opportunities to learn. They argue therefore that “it is unfair to assess intelligence of children from Africa with a test that has been validated in a Western culture…, with a population of children exposed to very different educational and material environments at home and school” (p. 452). It is therefore equally unfair to assess Malawian teachers’ knowledge using measures developed and validated for a cultural context different from Malawi. We agree with Delaney, Ball, Hill, Schilling, and Zopf (2008), Delaney (2012), and Mosvold, Fauskanger, and Jakobsen (2009) that use of unsuitable measures can be biased due to cultural inappropriateness.

Guided by Hambleton (2005) and Delaney et al. (2008) adaptation frameworks, we applied an iterative framework for our adaptation processes. Our first task was to decide whether to adopt (use unchanged), adapt (use with some modifications) or assemble (develop entirely new measures) (Hambleton, 2005). We examined the existing U.S. developed measures and instruments in terms of structure, differences and similarities in context and content between the U.S. as depicted in the measures and Malawi as perceived by ourselves. We were also privileged that one of us had previously stayed in the U.S. and adapted the measures for use in Norway. Consequently, as a team, we were familiar with the measures, the source culture (U.S.), and target culture (Malawi). This familiarity compelled us to opt for adaptation as we noted insignificant differences between the two cultures. Furthermore, we noted that apart from the measures being previously adapted for use in European and Asian contexts, Cole (2009; 2012) suggests that the measures can be adapted and be used in an African context with a considerable degree of validity. Borsa, Damasio, and Bandeira (2012), and Delaney et al. (2008) argue that there are considerable advantages to adapting over assembling measures. It is observed that by adapting an instrument, the researcher is able to compare data from different samples and from different backgrounds, which enables greater fairness in the evaluation because the same instrument assesses the construct based on the same theoretical and methodological perspective…(with) …greater ability to generalize and …increasingly diverse population. (Borsa et al., 2012, p. 424)

Considering the above, we concluded that it was feasible to use the U.S. developed measures and instruments in Malawi after some modifications. Hence our decision to adapt measures. Adaptation is generally understood as a “procedure in which an instrument that is developed for one cultural group is transferred for usage in another cultural group” (Malda et al., 2008, p.453). The adaptation procedure must therefore safeguard cultural appropriateness in the target population. Since our aim is to assess mathematical knowledge for teaching number concept and operations (MKT-NCOP)
among student teachers in Malawi, we intend to come up with MKT-NCOP measures that are suitable to Malawian contexts and draw lessons from the adaptation process that could be applied in similar process. In the sections that follow, we describe the adaptation process within a framework of adaptation as suggested by Hambleton (2005).

First Stage
The first stage in Hambleton’s adaptation framework involves linguistic translation of the instrument/s from a source language into a target language. We decided not to translate from English to local languages because English is the official language of instruction in Malawi from the fifth year of primary school onwards. Consequently, our target sample of student teachers had used English in school and examinations for at least 8 years through their upper primary and secondary school education. Nevertheless, instead of labouring with translation, we had the task of selecting instruments from a pool of instruments at our exposure for adaptation. A total of ten NCOP forms were available. These are three 2001 NCOP-CK forms (A, B and C), three 2001 NCOP-KCS forms (A, B and C), two 2002 NCOP-CK forms, and two 2004 NCOP-CK forms. While there were some common stems/items or repetition of stems/items from 2001 forms to 2004 forms, we notice that the developers of the items modified some stems/items with time. The changes made were mainly linguistic in nature and varying of response items. However, most of the stems remained unchanged. They were also a few new stems that were developed and added over the period. In order to select the forms for adaptation, we aligned the items in each form to the Malawi’s Initial Primary Teacher Education (IPTE) mathematics syllabus/content. We observed that items from Form A of 2001 were reasonably spread across the subject areas. For this reason, we decided to use this form and the corresponding Form B. Form C of 2001 was not considered because it did not cover as many areas in the syllabus as Form B. At this stage, we decided not to repeat items so that we could pilot as many items as possible for our final instruments. Consequently, common items B3, B6, B11, B12 and B14 in the original Form B of 2001 were replaced by similar items from the remaining forms. We further added two new stems to Form A to cover the concepts of division, multiples and factors which were not covered by the original form A. After these initial structural amendments, Form A has 25 stems with a total of 46 items while Form B has 24 stems with a total of 42 items. Originally, the forms had 23 and 24 items respectively.

Second Stage
Having created our working instruments for possible piloting, the adaptation processes entered a second stage which involved more cultural cognitive lens for judging evidence of adequacy of modifications (Malda et al., 2008). Our primary effort was towards contextualizing the stems and items, hence the instruments. In this respect and in line with Delaney et al.’s (2008, p. 182) “changes related to the general cultural context”, we changed names of places, people and objects from the source (U.S) context to names recognized in the target (Malawi) context by considering equivalence in commonality of the name if it is a person or equivalence in familiarity if it is a place (Hambleton, 2005) and conceptual equivalence (Borsa et al., 2012). When changing names to Malawian context, we noted that while it is not common for teachers to be addressed as Miss, Ms, Mrs. or Mr. but rather as ‘Madam’ and ‘Sir’ for female and male teachers respectively regardless of one’s marital status, their use is not official. We therefore used the official titles followed by surnames to refer to teachers throughout the instruments. Examples of the changes made with reference to general contextualization are presented in Table 1.
Third Stage

The third stage required that we considered modifying the content of each individual stem and its corresponding items so that they could reflect the IPTE curriculum, syllabus and textbooks. This addressed the two forms of changes suggested by Delaney et al. (2008): “changes related to school cultural context” and “changes related to mathematical substance” (p. 182). This stage therefore helped to establish experiential and conceptual equivalences. Experience equivalence refers to “noting whether a particular item is applicable in the new curriculum and, if not, replacing it with an equivalent item” while conceptual equivalence involves establishing whether a particular “term or expression … assesses the same aspect in different cultures” (Borsa et al., 2012, p. 425). We noted that some terms may have different meanings in Malawi from their original meanings in U.S. For instance, the term quiz in Malawi is synonymous with quiz competition between schools and not a test taken by individual students.

We examined the IPTE curriculum, and reviewed lectures’ guides, students’ textbooks and teaching syllabus to identify the differences in content and school context. Once we made initial changes based on text books and our lived experiences, we sought input, through semi-structured interviews: from two primary school teachers, a primary education advisor (PEA) and a primary school teacher educator. The two primary school teachers were identified based on previous working relationship and their teaching experience. Both of them have been teaching primary mathematics for at least fifteen years and were well placed to comment on how well the stems and items represented primary school mathematics from a perspective of practice. As an advisory officer, the PEA was expected to comment on the instruments, mainly, from a policy point of view. Although the two of us are mathematics educators and practicing in Malawi, we are not directly involved in the IPTE programme. This necessitated us to involve a deputy principal of one of the teacher education colleges. The deputy principal has five years secondary school mathematics teaching experience and nine years of primary school teacher education. These four additional individuals therefore provided a critical insight that we as a team could not have as they are more familiar with primary school and teacher education curriculum, culture, and context. Their feedback to the initially modified items informed the adaptation process further about the relevance of the content, representations, notations, wording of the stems and items, and general authenticity of the stems and items.

In summary, when adapting the measures we saw to it to preserve equivalence between the source (U.S.) and target (Malawi) by ensuring that: (a) terms and words used had same interpretation and free from ambiguities (semantic equivalence), (b) each stem/item measured same concepts (conceptual equivalence), (c) the symbols and notations used were relevant to the IPTE and primary mathematics curricula in Malawi (experiential equivalence), (d) non-metric units of measures were replaced by metric units used in Malawi (experiential equivalence), (e) all contexts were modified to Malawi (experiential equivalence), (f) all mathematical terms used reflected Malawian school curriculum, and (g) the level of difficulty of the items were the same (Borsa et al., 2012).

While the MKT-NCOP measures were not developed and validated for use in Malawi, we are of the strong view that having gone through the three stages discussed above, we have endeavoured to achieve near equivalence of the measures. Therefore, the adapted MKT-NCOP measures and instruments are ready for piloting.
Results and discussion

In this section we discuss the findings by focusing on issues that emerged in the implementation of the adaptation framework. In this study, three main categories of issues arose as a result of the adaptation process; linguistic issues, contextual issues, and issues in item characteristics as depicted in Figure 1. This is against a background that most adaptation studies identify four categories with content issues being the forth. For the content-related modifications, IPTE teaching syllabus and textbooks (MoE, 2005, MIE, 2008) were analysed for common expressions and correct terminologies. In our case, NCOP content was not an issue we grappled with because NCOP content covered by the original MKT measures we adapted was similar to the content covered in Malawi’s IPTE programme.

Our main focus was therefore dealing with context related issues. An example from this is an item which is about money. The item begins with an assumption that the respondents have $1.25 and then double it to buy a piece of cake. The context of this item is money in terms of currency unit and magnitude. First we had to replace the U.S. Dollar ($) with Malawi Kwacha (K). Replacing $ with K but keeping the numerical value unchanged raised the issue of meaningfulness of money magnitude/value. K1.25 in Malawi is almost nothing and cannot buy anything let alone a piece of cake. Therefore we used the monetary value of K1,250.00 so that it makes sense as a cost of a piece of cake. After replacing all the names, acronyms were also changed accordingly. Table 1 shows examples of changes we made to the measures.

<table>
<thead>
<tr>
<th>Category of change</th>
<th>Source (U.S.) culture</th>
<th>Target (Malawi) culture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Context: General</td>
<td>Mr. Lopez</td>
<td>Mr. Lunda</td>
</tr>
<tr>
<td></td>
<td>Timo</td>
<td>Timothy</td>
</tr>
<tr>
<td></td>
<td>Taffy</td>
<td>Sweets</td>
</tr>
<tr>
<td></td>
<td>Pizza</td>
<td>Nsima</td>
</tr>
<tr>
<td></td>
<td>$1.25</td>
<td>K1,250</td>
</tr>
<tr>
<td>School</td>
<td>Quiz</td>
<td>Test</td>
</tr>
<tr>
<td></td>
<td>Student papers</td>
<td>Student notebooks</td>
</tr>
<tr>
<td></td>
<td>Practice state exam</td>
<td>Mock exam</td>
</tr>
</tbody>
</table>

Figure 1: Adaptation framework showing change categories that informed it

Table 1: Examples of changes made.
The consultations with the two teachers, the PEA, and the deputy principal of a teacher education college were mainly school and content-related. We also sought their comments on the degree to which response options differed. Furthermore they commented on the face validity of the items and clarity of the statements. One of the items in the original MKT instruments was about trapezoids. Through these consultations we were able to establish that the use of the term trapezoids is not common in primary school and in IPTE mathematics curriculum as a means of teaching number and operations. Hence the stem was excluded from the final adapted instrument.

Adaptation practices are widely recognized in research and have a great prominence in achieving success in cross-cultural studies in order to maintain the equivalence between source and target culture. The U.S. MKT-NCOP measures have been adapted in other languages and cultures by researchers before. They were adapted in Ireland (Delaney et al., 2008; Delaney, 2012), Ghana (Cole, 2009, 2012), South Korea (Kwon, 2009; Kwon et al., 2012), Indonesia (Ng, 2012; Ng, Mosvold, & Fauskanger, 2012), and Norway (Mosvold & Fauskanger, 2009; Mosvold, Fauskanger, Jakobsen, & Melhus, 2009; Ng, Mosvold, et al., 2012). In their adaptation study, Delaney and colleagues introduced a framework for categorizing changes in the adaptation process. The framework was then extended by Kwon and colleagues and by Ng and colleagues in 2012. Since the adaptation process was within the English, translation aspects were not a major concern for the Ireland study just as the case in our present study. In addition to translation, Mosvold et al. (2009) (see also Ng, Mosvold, et al., 2012) considered changes that were motivated by political directives as a new category. Teachers’ work is another category of changes suggested by Kwon et al. (2012). Both of these categories were not considered by Delaney and colleague. We have also not come across these additional categories in our study. In this study, we combined Hambleton (2005) and Delaney et al. (2008) adaptation frameworks to make modifications to the MKT-NCOP measures. The accomplishment of the adaptation process is pivotal to the success of the following steps in our study: validation of the instruments through a pilot study and use of the instrument in the Malawi in our main study. We have endeavoured to address the issues that affect the different aspects of equivalence as suggested by the frameworks we followed so that we can proceed to piloting the instruments for purposes of using the measures and not comparing the results to those of U.S.
We now turn to the design of study and discuss what we have learnt. Initially, we had to decide whether to adapt measures or not, based on differences and similarities between the source (U.S.) culture and target (Malawi) culture and equivalence of the latent we intend to assess and its dependence on context (Hambleton, 2002). Although differences between U.S. and Malawi are inevitable, we noted through IPTE syllabus and textbooks that significant and fundamental similarities existed between Malawi and the U.S. Similar observation was made between Ghana and the U.S. (Cole, 2012). For her, Ghana and the U.S. are very different countries, but “there are some fundamental similarities in each of the country contexts such as the nature of mathematics knowledge that children are expected to know” (p. 417). The similarities between the two cultures provided an excellent platform for adaptation. Moreover, as Cole posits, mathematics in general and the number concept and operations in our case can be interpreted in similar ways in U.S. and Africa with minute inconsistencies on the content coverage. While, teaching and teacher education are culturally informed (Delaney, 2012; Mosvold, Fauskanger, Jakobsen, & Melhus, 2009), our backgrounds, and consultations with teachers and educators who had a better understanding of primary teacher education helped in the adaptation process. The familiarity of the source (U.S.) context and the original MKT measures by one of us made decision making less cumbersome and the process more realistic. In summary, we noted that the differences between the U.S. and Malawi cultural context were manageable and therefore acceptable to implement an adaptation.

Conclusion

While it is not our objective to conduct U.S.-Malawi comparisons, we, in order to guard against issues that may affect source-target equivalence, have employed a stern framework that guided us through tested best practices of the adaptation process. We observe that the frameworks we followed alone are not enough to guarantee the equivalence as suggested by Hambleton (2005), Delaney et al. (2008), and Borsa, et al. (2012) between the original and adapted versions of the MKT-NCOP measures. We need to pilot the measures and subject the data to statistical analysis in order to establish item characteristics, validity and reliability which we cannot define just by describing the adaptation process. Our objective in this paper was to describe adaptation process and highlight what we modified in the instruments as we plan to carry out statistical analysis of pilot data.

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Teaching for the test or setting up students for failure: A case study of a linear algebra class in Zimbabwe

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Students expect that by attending a revision session where the lecturer presents solutions of examination type questions they will improve their performance in the examination. In this study we set out to investigate whether this assumption was valid with a group of 107 in-service mathematics teachers who were attending a university course on Linear Algebra. The purpose of this study was to reflect on the effectiveness of the revision session that was held as part of the in-service course for practising teachers. The study took the form of a document analysis of the teachers’ written responses to particular items which appeared in a test they wrote previously, that were covered in the revision session and appeared again in the examinations. The teachers worked under unrealistic conditions, and this may have impacted on the low levels of improvement for many students. It is recommended that university authorities should carefully consider the demands placed on the teachers when timetables with tough timelines are designed and should consider instead how opportunities for engagement with the concepts could be optimised.

Introduction

Many educators assume that an efficient way of preparing for an examination is to have the instructor revise solutions of problems that students struggle with. In South Africa for example many interventions to improve the mathematics results at Grade 12 level take on the form of teachers presenting solutions of problems to students. As the matric examinations get closer, many learners sign up for revision sessions. However the issue of whether such revision sessions can have a greater impact than learners engaged in meaningful studies on their own, has not been established.

Teaching and learning are dualistic processes and the point at which the two intersect most is during assessment. In addition to providing feedback to students about how well they are coping with the content, assessments provide the opportunity for instructors to identify what students know and can do and what they do not know and cannot do yet (Carr, Mcgee, Jones, Mckinley, Bell, Barr &Simpson, 2004). Hence the design of the assessment instrument is a specialised task that can be used to elicit the information required by the instructor. Equally important to the design of an assessment is the need to provide quality feedback to students. Feedback that an instructor provides to students on completion of their assessment tasks is an important tool to improve students’ learning (Carr et al., 2004). In addition to helping students identify their mistakes or shortcomings, effective feedback must provide information on what the appropriate response (or correct solution) was as well as providing information on what they need to do to improve their results (Bansilal, James & Naidoo, 2010).

This study was carried out with a group of 107 in-service mathematics teachers who were enrolled for a course in Linear Algebra at a university in Zimbabwe. The course was delivered under tight timeframes. The teachers attended lectures for 2 weeks and then wrote a test in December. They then went back to their work place, returned in April for two weeks when they were taught new concepts. It was during this session that the revision session for the test was carried out. The teachers returned
in June to write the examination which included many of the items (with minimal changes) from the original test which was revised in April. The purpose of this study is to reflect on the effectiveness of the revision session that was held as part of the in-service course for practising teachers. It is hoped that some of the findings from this study will help lecturers, researchers and educators in general to interrogate practices for helping students in their preparation for examinations and assessments in general.

**Literature Review**

Matrix algebra is one of the fundamental topics of linear algebra which needs to be understood (Bogomolny, 2007). Understanding matrix algebra concepts is more than performing calculations. It is being aware of how procedures work, developing an intuitive expectation of the result without actually performing all the calculations, being able to work with variations of algorithms, being able to notice connections and organise experiences (Bogomolny, 2007).

In addition, Stewart and Thomas (2009), Possani, Trigueros, Preciado and Lazano (2010), Wawro (2011), and Ozdag and Aygor (2012) also conducted studies on students understanding of linear algebra. Their findings show that many students have difficulties in developing conceptual understanding of linear algebra because of its abstractness. The nature of students’ previous knowledge in mathematics structures and set theory does not facilitate the construction of new knowledge (Dogan, 2011). Holding up the point, Carrizales (2011) states that students struggle to understand, explain and relate the theory learnt. This implies that some linear algebra concepts are so complex and invisible that students have difficulties in understanding them.

Some difficulties in understanding linear algebra are related to misconceptions. Misconceptions are systematic conceptual errors caused by beliefs and principles in the cognitive structure. Engelbrecht, Harding and Potgieter (2005) investigated first year calculus students’ confidence in handling conceptual and procedural problems and also compared students’ conceptual procedural skills. Their study indicated that these students do not perform better in procedural problems than in conceptual problems. Again the study indicated that students do not have more misconceptions about conceptual mathematics than about procedural issues. Furthermore, Aygor and Ozdag (2012) carried out a study to investigate misconceptions by undergraduate students while solving problems on matrices and determinants. Their results revealed many misconceptions which are related to confusion between matrices and the determinant of matrices. For example, some students took the relationship $\det A = -\det B$ (that is determinant of matrix $A$ equal to minus one times determinant of matrix $B$) to relation $A = -B$ (that is, matrix $A$ equals minus one times matrix $B$). Some student also took the relationship $\det A = k \det B$ (that is determinant of matrix $A$ equal to $k$ times determinant of matrix $B$) to mean $A = kB$ (that is matrix $A$ equals $k$ times matrix $B$). Again some students took the relationship $\det A + \det B$ (determinant of matrix $A$ plus determinant of matrix $B$) to mean $A + B$ (matrix $A$ plus matrix $B$).

Furthermore, constructivist perspectives imply that new knowledge is built on prior understandings and APOS theory refers to the construction of an object understanding of a concept as an encapsulation of the object (Dubinsky, 1997). Bansilal (2013) carried out a study to identify and explain how non-encapsulation related to addition and subtraction number bonds hampered a student’s efforts in attaining fluency in the multiplication tables. The findings suggest that the participant’s struggles were due to a non-encapsulation of the various number bond strings, which did not allow the participant to see patterns in addition by seven. She pointed out that many students struggle to make the transition from addition and subtraction to multiplication and division, which hampers further progress in mathematics. This might imply that lack of adequate schema for integers can work against the development of fluency in carrying out the appropriate operations on matrices. Uncertainty in addition and subtraction of integers might result in incorrect entries of matrices since most students struggle to reach the kind of fluency that could make their calculations less
burdensome. It is therefore important for any study to take into consideration the prior concepts that support the development of the new concept.

In trying to support students’ construction of knowledge, an important component is the feedback that students receive from their teachers about their learning. Formative assessment “provides feedback to the teacher and to the student about present understanding and skill development in order to determine a way forward” (Carr, et al., 2004, p.6). The gap between actual development and potential development, that is, between what a student can do unaided by a more experienced instructor and what he/she can do with expert support is termed the “zone of proximal development” (ZPD) (Vygotsky, 1978, p.86). Scaffolding, a term coined by Jerome Bruner, is an approach where a more capable person provides support to less skilled children until they develop the target skill more proficiently (Slavin, 2003). Scaffolding provided during assessment can support students in attaining targets. During the assessment process, feedback in the form of meaningful and appropriate guidance can be used to develop learners’ skills. This form of feedback reflects the view of learning as a construction of knowledge where the outcome is an extension or gaining of knowledge, and not an absorptionist view of learning.

**Theoretical Framework**

APOS (action, process, object, and schema) theory is a constructivist perspective focusing on individual’s mental constructions of mathematical knowledge and describes possible cognitive paths taken by students when developing an understanding of mathematics concepts. The mental constructions of action, process, object and schema is hierarchical in the sense that an action conception develops before a process conception and a process understanding can be transformed to an object understanding. These mental constructions allow students to engage at different levels with the particular concepts. An action may be defined as any physical or mental transformation of objects to obtain other objects. According to Piaget and adopted by APOS Theory, a concept is first conceived as an action, that is, as an externally directed transformations of a previously conceived object(s) (Dubinsky, 1997). An action is external because each step of the transformation needs to be performed clearly and guided by external instructions; additionally each step prompts the next, that is, the steps of the action (Arnon et al, 2014).

APOS theory also makes use of a genetic decomposition which can be described as description of an arrangement of concepts that characterises the linkages and prerequisite conceptions required by a student when developing an understanding of a concept. For this study, a possible genetic decomposition is provided comprising schema for understanding the concepts of determinant and solutions of systems of equations.

A schema for determinants

An action understanding of the concept of determinant is evident when the individual is able to find the determinant of a $2 \times 2$ or $3 \times 3$ matrix consisting of numerical entries. At a process, the student is able to extend the process to imagining what the result for the determinant of an $n \times n$ matrix could be without having to work out each step laboriously. An object level of engagement may have recognised when an individual is able carry out further operations, or transformation on determinant like finding unknown element in a matrix when given certain conditions, or prove given identities involving determinant of a matrix using properties of matrices.

A schema for solving systems of equations

An individual who engages at an action level is able to write a given system of equations in matrix form, that is, $Ax = B$. The individual is also able to write the augmented matrix and carry out row operations as a sequence of steps, without necessarily skipping any steps. A process level of engagement is evident when an individual is not bound to the sequence of steps but can find shorter ways of row reduction and can also identify systems which will yield unique, infinite or no solutions.
without necessarily carrying out all the steps. An individual who is able to engage at an object level with the concept of solutions to systems of equations, is able to recognise equivalent systems and is able to compare different methods to identify the most suitable method or transformation on determinant and inverse of matrices. S/he can identify what a solution of a system of equation(s) is and is not.

**Methodology**

The purpose of this qualitative study was to reflect on the effectiveness of a revision session held as part of an in-service course for practising teachers. The participants were a group of 107 Zimbabwean mature mathematics teachers enrolled in a linear algebra upgrading course at a university. The teachers’ written responses were the primary source of data. The delivery of the course was planned around the teachers’ timetables and the university systems. Hence the content of the course was taught in December for two weeks, during which time the teachers attended classes from 8 AM to 6 PM while also studying other courses. The delivery of the course was hence under a very tight timetable, and the teachers hardly found time for doing other normal activities such as carrying out family duties, sleeping, exercising, or even relaxing. They then returned in April for two weeks with the same conditions as in December, during this time they learnt more content and attended the revision session. It is in this context that the first author presented a revision of some test items that the teachers had written six months earlier. The instruction and content of the revision session was planned by the instructor of the course. The teachers returned to the campus in June to write examinations.

The study looks at 7 items that were covered in the revision session, which appeared in the examination that they wrote later with a few superficial differences. Hence data for the study were generated by each teacher’s written response to each of the items, before the intervention and after the intervention. A document analysis was carried out on the 1498 written responses. The item responses were coded and thereafter arranged in quantitative summaries. The research questions that guide this small scale study are: 1) To what extent did the intervention result in an improvement in performance in the items in the examination? 2) How can the results be explained by APOS theory?

**Results**

The results are presented for each of the items which appeared in the test and again in the examination.

**Results for Item 1**

Find the adjoint of A and hence find $A^{-1}$, where $A = \begin{pmatrix} 3 & 2 & -1 \\ 1 & 6 & 3 \\ 2 & -4 & 0 \end{pmatrix}$

Table 1. Item 1

<table>
<thead>
<tr>
<th>Blank (bl)</th>
<th>No correct idea (0)</th>
<th>Got some idea (1)</th>
<th>Correct except for a Slip (1)</th>
<th>Completely correct response (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No in test</td>
<td>6</td>
<td>Nil</td>
<td>15</td>
<td>36</td>
</tr>
<tr>
<td>No in exam</td>
<td>1</td>
<td>2</td>
<td>16</td>
<td>38</td>
</tr>
</tbody>
</table>

Table 2. Results for Item 1

For this item, twenty four students presented a correct response for both the test and exam. Twenty six students get correct response for the test only. Twenty six students get correct response for the exam only. So, thirty
one student failed to get the correct response for the test and exam. One student who did not respond to the question on the test managed to get a correct response for the determinant only. The student was unable to find the correct adjoint matrix. The student wrote \( A^{-1} = \frac{1}{64} \begin{pmatrix} 3 & 1 & 2 \\ 2 & 6 & -4 \\ 1 & 3 & 0 \end{pmatrix} \).

We represent the students’ results for this item using the Figure 1, where \( T \) is the set of students who got the item correct in the test, \( E \) is the set that got the examination version correct, and \( E \cap T \) represents those students who presented correct solutions in both the test and examination.

\[ \begin{array}{|c|c|c|c|c|}
\hline
& E & T & E \cap T & T \cap E \\
\hline
No in test & 26 & 18 & 16 & Nil \\
No in exam & 15 & 6 & 7 & 2 \\
\hline
\end{array} \]

Table 4. Results for Item 2 in the test and examination

Table 4 reveals that thirty three students get correct response for the exam and test. Five students get correct response for the test only. Forty four students get correct response for the exam only. So, twenty five students failed to get the correct response on the test and exam. Some student take \( \det(C) = C \) and \( \det(C^{-1}) = C^{-1} \) on the test and on the exam. This concurs with Aygor and Ozdag (2012) who carried out a study to investigate misconceptions by undergraduate students while solving problems on matrices and determinants. Their results revealed many misconceptions were related to confusion between matrices and the determinant of matrices. Two students just write the correct adjoint matrix with carrying out any calculations.

We represent the students’ results for this item using the Figure 2, where \( T \) is the set of students who got the item correct in the test, \( E \) is the set that got the examination version correct, and \( E \cap T \) represents those students who presented correct solutions in both the test and examination.
Let $A$ be a diagonal matrix with non zero diagonal entries $a_{11}, a_{22}, \ldots, a_{nn}$. Show that $A^{-1}$ is non singular and $A^{-1}$ is a diagonal matrix.

Table 5. Item 3

The results for this item are represented in Table 5 below.

<table>
<thead>
<tr>
<th></th>
<th>Blank (bl)</th>
<th>No correct idea (0)</th>
<th>Got idea but not all (1)</th>
<th>Slip (2)</th>
<th>Completely correct response (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No in test</td>
<td>69</td>
<td>37</td>
<td>0</td>
<td>Nil</td>
<td>1</td>
</tr>
<tr>
<td>No in exam</td>
<td>57</td>
<td>30</td>
<td>15</td>
<td>Nil</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 6. Results for Item 3 in the test and examination

Table 6 revealed that no students get a correct respond on the test and on the exam. Two students were able to show that $A^{-1}$ is non singular and $A^{-1}$ is a diagonal matrix on the exam only. Fourteen students were able to show that $A^{-1}$ is a diagonal matrix not showing that $A^{-1}$ is non singular on the exam. One student was able to showing that $A^{-1}$ is non singular on the exam. Only one student gets a correct respond on the test. The student did not show that $A^{-1}$ is non singular. He/ she only show that $A^{-1}$ is a diagonal matrix. Unfortunately the student failed to get a correct respond on the test. There was no respond on the examination script. Eight nine students failed to get the correct response on the test and on the examination.

We can represent the students’ results for this item using Figure 3, where $T$ is the set of students who got the item correct in the test, $E$ is the set that got the examination version correct, and $E \cap T$ represents those students who presented correct solutions in both the test and examination.

Figure 3. Representation of results for Item 3 in terms of a Venn diagram
**Results for item 4**

4. Find the solution of the following system of the linear equations using Gaussian elimination method:

\[
\begin{align*}
    x_1 - 2x_2 + x_3 &= 1 \\
    2x_1 - x_2 - 3x_3 &= -2 \\
    x_1 - x_2 - 2x_3 &= 0
\end{align*}
\]

Table 7. Item 4

The results for this item which appeared in the test and appeared in the examination with the matrix renamed are presented in Table 8 below.

<table>
<thead>
<tr>
<th></th>
<th>Blank (bl)</th>
<th>No correct idea (0)</th>
<th>Got some idea (1)</th>
<th>Correct except for a Slip (2)</th>
<th>Completely correct response (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No in test</td>
<td>8</td>
<td>1</td>
<td>4</td>
<td>65</td>
<td>29</td>
</tr>
<tr>
<td>No in exam</td>
<td>7</td>
<td>4</td>
<td>15</td>
<td>35</td>
<td>46</td>
</tr>
</tbody>
</table>

Table 8. Results for Item 4 in the test and examination

Table 8 revealed that nineteen students get correct response for the test and exam question. Ten students get correct response for the test only. Twenty seven students get correct response for the exam only. Fifty one students failed to get correct response on the test and examination. S107 has exactly same solution for the test and for the examination.

We can represent the students’ results for this item using Figure 4, where T is the set of students who got the item correct in the test, E is the set that got the examination version correct, and E∩T represents those students who presented correct solutions in both the test and examination.

![Venn diagram](image)

Figure 4. Representation of results for Item 4 in terms of a Venn diagram

**Results for item 5**

5. Use Cramer’s rule to solve the following system of linear equations:

\[
\begin{align*}
    5x_1 + x_2 - x_3 &= 4 \\
    9x_1 + x_2 - x_3 &= 1 \\
    x_1 - x_2 + 5x_3 &= 2
\end{align*}
\]

Table 9. Item 5

The results for this item which appeared in the test and appeared in the examination with the matrix renamed are presented in Table 10 below.

<table>
<thead>
<tr>
<th></th>
<th>Blank (bl)</th>
<th>No correct idea (0)</th>
<th>Got some idea (1)</th>
<th>Correct except for a Slip (2)</th>
<th>Completely correct response (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No in test</td>
<td>13</td>
<td>1</td>
<td>3</td>
<td>54</td>
<td>36</td>
</tr>
</tbody>
</table>
Table 10. Results for Item 5 in the test and examination

Table 10 revealed that twenty four students get correct response for the test and examination question. Twelve students get correct response for the test only. Twenty six students get correct response for the exam only. Forty five failed to get correct response on the test and examination. Some students use Gaussian elimination method when solving the system of linear equations. Most students have problem with integer operation, concur with Bansilal (2013), this might imply that lack of adequate schema for integers can work against the development of fluency in carrying out the appropriate operations on matrices.

We represent the students’ results for this item using Figure 5, where T is the set of students who got the item correct in the test, E is the set that got the examination version correct, and E∩T represents those students who presented correct solutions in both the test and examination.

Figure 5. Representation of results for Item 5 in terms of a Venn diagram

Results for item 6

6. Find a condition on the numbers a, b and c such that the following system of equations is consistent. When the condition is satisfied, find all solutions (in terms of a, b and c)

\[ \begin{align*}
    x - 2y + z &= a \\
    -x - 2y + z &= b \\
    3x + 7y - z &= c
\end{align*} \]

Table 11. Item 6

The results for this item are presented in Table 12 below.

<table>
<thead>
<tr>
<th></th>
<th>Blank (bl)</th>
<th>No correct idea (0)</th>
<th>Got some idea (1)</th>
<th>Correct except for a Slip (2)</th>
<th>Completely correct response (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No in test</td>
<td>32</td>
<td>5</td>
<td>39</td>
<td>2</td>
<td>29</td>
</tr>
<tr>
<td>No in exam</td>
<td>30</td>
<td>2</td>
<td>46</td>
<td>3</td>
<td>24</td>
</tr>
</tbody>
</table>

Table 12. Results for Item 6 in the test and examination

Table 12 revealed that sixteen students manage to find a condition on the numbers a, b and c such that the system of equations is consistent and find all solutions (in terms of a, b and c) on the exam and on the test. Fourteen students manage to find a condition on the numbers a, b and c such that the system of equations is consistent on the test and exam. Two students manage to find all solutions (in terms of a, b and c) on the test only. Thirteen students manage to find a condition on the numbers a, b and c such that the system of equations is consistent and find all solutions (in terms of a, b and c) on the exam only. One student manages to find a condition on the numbers a, b and c such that the system of equations is consistent on the test only. Two students manage to find all solutions (in terms of a, b and c) on the test only.
such that the system of equations is consistent on the exam only. Seven students find all solutions (in terms of \( a, b \) and \( c \)) on the exam only. Thirty nine students failed to get correct response on the examination only. One student S105 use Cramer’s rule on the test and on the examination.

We represent students’ results for this item using Figure 6, where \( T \) is the set of students who got the item correct in the test, \( E \) is the set that got the examination version correct, and \( E \cap T \) represents those students who presented correct solutions in both the test and examination.

![Figure 6. Representation of results for Item 6 in terms of a Venn diagram](image)

**Results for item 7**

<table>
<thead>
<tr>
<th>Test version Item 7</th>
<th>Solve the following system of linear equations using Gauss – Jordan (Reduced Row Echelon) Elimination method.</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x_1 - x_2 + x_3 - x_4 = 2 )</td>
<td>(-x_1 + 4x_2 - 2x_3 + 3x_4 = -4 )</td>
</tr>
<tr>
<td>( 2x_1 + x_3 + 3x_4 = 9 )</td>
<td>(-2x_1 + 6x_2 + 5x_4 = 2 )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Examination version Item 7</th>
<th>Solve the following system of linear equations using Gauss – Jordan (Reduced Row Echelon) Elimination method.</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x - 2y + z - w = 2 )</td>
<td>(-x + 4y - 2z + 3w = -4 )</td>
</tr>
<tr>
<td>( 2x + z + 3w = 9 )</td>
<td>(-2x + 6y + 5z = 2 )</td>
</tr>
</tbody>
</table>

Table 13. Item 7

The results for this item are presented in Table 14 below.

<table>
<thead>
<tr>
<th></th>
<th>Blank (bl)</th>
<th>No correct idea (0)</th>
<th>Got some idea (1)</th>
<th>Correct except for a Slip (2)</th>
<th>Completely correct response (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No in test</td>
<td>28</td>
<td>0</td>
<td>58</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>No in exam</td>
<td>50</td>
<td>2</td>
<td>39</td>
<td>14</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 14. Results for Item 7 in the test and examination

The Table 14 revealed that no students get correct response on the exam and test question. Six students get correct response for the test only. Two students get correct response for the exam only. Ninety nine students failed to get correct response on the test and examination. Some students end up not completing their work and some giving no response. Some students use Gaussian elimination method instead of using Gauss–Jordan elimination method.
We represent students’ results for this item using Figure 7, where $T$ is the set of students who got the item correct in the test, $E$ is the set that got the examination version correct, and $E \cap T$ represents those students who presented correct solutions in both the test and examination.

**Figure 7.** Representation of results for Item 7 in terms of a Venn diagram

**Discussion**

The results varied across the items. There were three items (1, 4 and 5) that were applications of algorithms, and could be considered as action level items. The items asked for 1) the calculation of the inverse of a $3 \times 3$ matrix $A$ by first finding the adjoint of $A$; 4) the solution of a linear system of three equations in three unknowns using Gaussian elimination; and, 5) the solution of a system of three equations in three unknowns using Cramer’s rule. For these items it was found that about 50% of the accurate responses in the examination were from students who had not produced correct answers in the test. However for the three items, it was also found that many students produced correct solutions in the test, but after the revision session were unable to produce correct solutions in the examination. For item 1, the number of students who regressed was 26 while the corresponding numbers of similar students for items 4 and 5 were 10 and 13 respectively. The reasons for this were mainly for calculation errors although some of them also had blank responses. For these students who regressed, the revision session did not have a positive effect on their performance for these test items.

Two items (2, 3) could be seen as process level items requiring simple algebraic proofs based on properties of determinants of matrices. Item 2 required students to show that if $\det A = p$, then $\det A^{-1} = 1/p$. The second process-level item was item 3, which required students to show that a diagonal matrix $A$ is non-singular and to then show that $A^{-1}$ was also diagonal. For the Item 2, 57% of the correct responses were from students who got the original question wrong in the test. There were a much smaller number (5) who produced a correct response in the test but were unable to do the same in the examination. With respect to the Item 3 which required at least two parts, the two students who presented correct solutions in the examination had previously got the item incorrect in the test. There was one student who had presented a correct solution in the test but was unable to do the same for the examination. There were 14 students who produced a partial proof to the second part without showing that the first condition held. It is of interest that the first author in the revision session presented a partial proof to this item, because she assumed that showing the condition held was uncomplicated. Perhaps these 14 students assumed that it was only necessary to show the second part.

One item (7) could be seen as an object-level item because it required an object–level engagement with the concept of solutions of equations. The question asked students to find conditions on three variables in the coefficient matrix that would result in a consistent system. The second part required students to find the solutions when the conditions were satisfied. In this item, $1/3$ of (8) of the correct responses in the examination came from students who had got the question wrong in the test. A further five students got as far as identifying the conditions on the variables that would give a solution, but did not proceed to actually finding the solution. However there were 13 students who had produced a correct response in the test but were unable to do so in the examination. This suggests that these students’ understanding was not very robust. Although the item is considered as requiring an object-level engagement, many students learn the steps by rote and produce solutions even though they do not have the necessary conceptual depth. The fact that these students were not able to sustain their approach in another setting suggests that they needed more opportunities to engage with the topic so that their understanding could develop further.
One issue is the quality of feedback that they received and the timing of the feedback. In order to help students progress, they need effective feedback, which research suggests must be tailored to the specific students’ needs and must be timely (Bansilal et al., 2010). These teachers received feedback six months after they wrote the test and the discussion was general directed to all 107 participants, because of the constraints of the programme. Research about feedback indicates that for it to be effective, it needs to provide specific information about what a student did not do correctly, why it was deemed to be incorrect, and how the student could improve in future (Slavin, 2003). Hence effective feedback needs to be tailored to the student and should be more specifically aligned to the students’ needs. However in this setting, the teachers were not privileged with this kind of detailed attention because of the large numbers and the constraints of the programme. These teachers did not have opportunities to actually engage with the mathematics beyond listening and taking down information, and hence the interventions did not make a substantial difference.

**Conclusion**

In this small scale study, we have tried to reflect on how a revision session impacted on teachers’ responses to test items that they had previously encountered. Most educators assume that a revision session where solutions to tasks which are likely to appear in an examination are taught will result in students’ performance improving. However, this study has shown that this assumption is not necessarily warranted. Across all items, there were some students who were initially able to solve the item, but in a subsequent attempt failed to solve an almost identical item. However there were teachers who improved on their first attempts.

For the action-level items (which just required teachers to carry out step by step procedures without having to consider any other issues beyond the immediate calculation), approximately 50% of correct answers in the examination came from teachers who produced incorrect responses in the test. However a large number had a reverse result- they solved the items correctly in the test but produced incorrect responses in the examination. This results may be due to the fact that these items did not require teachers to interiorise the concepts and errors they made were mainly due to slips in calculations instead of conceptual errors.

Responses to the object level item showed that eight teachers produced correct responses in the examination even though their test responses were incorrect. However many more who had initially produced a correct response in the test regressed and did not solve the problem on second attempt. This indicates that these teachers had not developed a robust understanding of the concept of solution of systems of equations, with one teacher even carrying out an irrelevant procedure to solve the given system.

In general it can be seen that many teachers regressed in their attempts even though they attended the revision session which consisted of presentations of solutions to the items. Hence the revision session did not achieve the benefits it was intended to have on the teachers’ understanding. However the reality was that the class was very large and there was insufficient time to schedule proper discussion classes so the feedback opportunities were constrained. So an overriding constraint to the teachers’ improvement in understanding was the tough conditions under which the teachers worked and studied. In fact it is understandable that so few teachers achieved success in the items requiring conceptual understanding. With the learning conditions being so harsh, it is irrational for instructors to expect the teachers to develop the necessary conceptual understanding.

We recommend that university authorities and government departments should carefully consider the demands placed on the teachers when timetables with tough timelines are designed and that the timetabling should consider instead how opportunities for engagement with the concepts could be optimised. It is unfair for teachers to be provided with upgrading opportunities only to be presented with unrealistic programme delivery timelines which only set them up for failure.

**References**


Documentary analysis of learning dispositions promoted within the transition between Grade R and Grade 1 in the South African Curriculum and Assessment Policy

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This paper emerges from a broader research study investigating the promotion of key productive learning dispositions within policy and teacher assessment practices across a selection of Grade R and Grade 1 teachers in schools in the Grahamstown district. The paper reports on the findings of a documentary analysis of curriculum policy in terms of learning dispositions promoted. It points to the need for more explicit dispositional discourse and progressive unpacking of the transition between dispositions promoted in the formative Grade R year and the first year of formal schooling in curriculum documents.

Introduction and contextual background

This paper emerges from a broader masters research study conducted as part of the South African Numeracy Chair Project (SANCP) at Rhodes University that aims to research sustainable ways forward to the challenges of numeracy education in South Africa and beyond. Research within this project points towards student mathematical learning dispositions being an underexplored area and one which requires increasing attention (e.g. Graven, Hewana & Stott, 2013; Graven & Heyd-Metzuyanim, 2014; Graven, 2014) as well as the need for early intervention in numeracy learning. The broader study investigated the following questions:

What productive learning dispositions are promoted in current curriculum policy documents and assessment criteria in Grade R and Grade 1? What are the similarities and differences in dispositions promoted across the curriculum and those promoted in assessment guidelines and support documents across these grades?

This paper reports partially on findings from a qualitative research study underpinned by a socio-cultural theoretical perspective that foregrounds learning as changing ways of being (Lave & Wenger, 1991; Wenger, 1998). Within this broad theoretical perspective two key analytic frameworks were used (for both the documentary and teacher practice analysis) that cohere with the view that learning dispositions (ways of being, habits of mind) must be prioritised. In particular the work of Kilpatrick et al. (2001) and Carr & Claxton (2010), in defining essential elements of key productive learning dispositions, were combined to enable the development of an indicator matrix used for the above mentioned analysis.

The analysis of the following policy documents, related to the Grade R to Grade 1 transitions, and in terms of the promotion of learning dispositions, area focus of this paper:

1. Curriculum and Policy Assessment Statements (CAPS) for Foundation Phase Numeracy (DBE, 2011)

The presences of certain promoted dispositions are compared with international literature and frameworks and certain absences or under represented dispositions are noted. The paper points to implications for creating a more coherent language of description and transition between the Grade
R and the Grade 1 classrooms - strengthening and supporting the newly introduced Curriculum and Assessment Policy Statements followed by these schools. The impetus for this study came from the increasing acknowledgement of learning dispositions as a central aspect of learning in general and of mathematics learning in particular, both nationally (e.g. Graven, 2012; Graven, Hewana & Stott, 2013) and internationally (Gresalfi, 2009; Gresalfi, Boaler & Cobb, 2004; Gresalfi & Cobb, 2006). Yet this is largely underexplored in local studies relating to crisis in numeracy learning.

In response to the South African Government’s 2009 ‘Green Paper’ concerned with “improving strategic planning in the country” (DBE, 2012, p. 2), of which the first of twelve national priorities, or outcomes, is “Improved quality of basic education” (DBE, 2012, p. 2) Priority Goal 11, regarding improving access to ECD, was implemented, and was envisioned to be completed by 2014 – this entailed a national campaign to establish, in the year before Grade 1 (i.e. for learners aged 5 turning 6), a year of compulsory schooling called ‘Grade R’. This recent local ‘roll out’ of Grade R pointed to the need for research into the crucial transitional phase between Grade R (the year before formal schooling) and Grade 1 both in terms of the content and assessment standards specified and the learning dispositions promoted.

**Analytical framework used for the documentary analysis**

In order to obtain Mathematical Proficiency throughout a child’s schooling, ‘how’ children engage with mathematics is important. Of specific relevance to this article is the notion of “productive disposition” - the fifth strand of Mathematical Proficiency, following ‘Procedural Fluency’, ‘Conceptual Understanding’, ‘Strategic Competence’, and ‘Adaptive Reasoning’ - as developed by Kilpatrick, Swafford and Findell in their 2001 work: *Adding it up: Helping Children Learn Mathematics*.

This fifth strand, or productive ‘disposition’, is seen as equally important to the development of mathematics proficiency because if students “believe that mathematics is understandable, not arbitrary; that, with diligent effort it can be learned and used; and that they are capable of figuring it out,” (p. 131) then the other four strands will develop, and vice versa. This strand is highlighted as being equally important in the early years, where this study is situated, especially in regards to good mathematics teaching because children:

“enter school eager to learn and with positive attitudes towards mathematics. It is critical that they encounter good mathematical teaching in the early grades. Otherwise, those positive attitudes may turn sour as they come to see themselves as poor learners and mathematics as nonsensical, arbitrary, and impossible to learn except by rote memorisation. Such views, once adopted, can be extremely difficult to change.” (Kilpatrick, Swafford, & Findell, 2001, p. 132)

Productive disposition refers to the tendency to see sense in mathematics, to perceive it as both useful and worthwhile, to believe that steady effort in learning mathematics pays off, and to see oneself as an effective learner and doer of mathematics (2001, p. 131).

Carr and Claxton (2010) identify the following three key dispositions relevant to what they term ‘learning power’:

Resilience: “the inclination to take on learning challenges where the outcome is uncertain, to persist with learning despite temporary confusion or frustration, and to recover from setbacks or failures and rededicate oneself to the learning task” (p. 14). Playfulness: Being playful, as described by Carr & Claxton (2010) does not necessarily point to ‘silliness’ or a lack of serious and meaningful intent. Rather it refers to a child who is “ready, willing and able” (p. 14) to understand, interpret or create
various strategies with which to approach learning situations. The result is a child who is able to use creativity of thought when tackling new problems and concepts.

Reciprocity: Carr & Claxton (2010) in their discussion of reciprocity identify that one of the most valuable learning and teaching resources available to young children in particular is that of ‘other people’. The exchange of ideas and understanding, and the ability to articulate thinking processes are vital in developing a capable learner. For the authors, reciprocity is “both expressive and receptive and verbal and non-verbal” (2010, p. 15). Three key contributors to the development of reciprocity include “a willingness and ability for joint attention, participation, and taking account of the opinions and needs of others” (2010, p. 15).

Drawing on the above mentioned literature, and in particular the definitions of a productive learning disposition by Kilpatrick et al. (2001) and the key learning dispositions noted by Carr & Claxton (2010) the following indicators emerged as critical and comprehensive for use in analysing the presence or absence of the promotion of learning dispositions in current government policies: Reciprocity; Playfulness / resourcefulness; Resilience; Confidence / self-efficacy; and Connections to learner’s world / see mathematics as worthwhile.

Government documents provide useful research data as they are authoritative, objective and factual (Denscombe, 2007). They are easy to access, as they are freely available online, are cost effective, offer permanence of data and also offer “authenticity, credibility and representativeness” (Denscombe, 2007, p. 232). Developing an analytical tool derived from relevant literature and using this to conduct content analysis of the documents is important as it “has the potential to disclose many ‘hidden’ aspects of what is being communicated through the written text” and “reveals 1. What the text establishes as relevant; 2. The priorities portrayed through the text; 3. The values conveyed in the text; 4. How ideas are related” (Denscombe, 2007, pp. 237-238).

Findings of the documentary analysis

Curriculum and Assessment Policy Statements (CAPS) for Foundation Phase: Numeracy


For the documentary analysis all statements that referred to or related to learning dispositions were extracted, and connected to the categories of indicators of the analytic framework described above. The table below provides an overview of the frequency of dispositional statements found in Section 1 of the CAPS document, and is laid out according to dispositional category; examples of statements related to the category; and frequency of statement. Emphasis has been added to specific words or terms within statements related to the categories.

Table 1. Frequency of dispositional statements by category – CAPS Section 1.

<table>
<thead>
<tr>
<th>Dispositional Category</th>
<th>Examples of statements related to the category</th>
<th>Frequency of statements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reciprocity</td>
<td>The National Curriculum Statement Grades R-12 aims to produce learners that are able to:</td>
<td>2</td>
</tr>
</tbody>
</table>
“work effectively with others and as individuals” and “communicate effectively” (p. 5).

<table>
<thead>
<tr>
<th>Playfulness / Resourcefulness</th>
<th>The National Curriculum Statement Grades R-12 is based on “active and critical learning” (p. 5).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resilience</td>
<td>-</td>
</tr>
<tr>
<td>Confidence / Self-Efficacy</td>
<td>-</td>
</tr>
<tr>
<td>Connections to learner’s world / see mathematics as worthwhile</td>
<td>This curriculum aims to ensure that “children acquire and apply knowledge and skills in ways that are meaningful to their own lives” (p. 4).</td>
</tr>
</tbody>
</table>

It is evident from this brief section / preamble to the CAPS that ‘reciprocity’, which includes being willing and able to communicate, is included. This means that throughout schooling, throughout the different grades, and amongst the different subjects and learning areas, the ability to communicate ideas fluently and effectively is paramount. ‘Playfulness/resourcefulness’, or the ability to think and apply concepts creatively, is also included across the wide spectrum of school learning in this section. ‘Connections to learner’s world/see mathematics as worthwhile’ is also mentioned here, in relation to making all learning “meaningful” to the children and their lives.

Noticeably absent are statements relating to developing ‘resilience’ and ‘confidence/self-efficacy’. However, a conclusion about the importance or relevance of these particular dispositions cannot be made from such a small sample of policy, and these indicators do appear in later aspects.

**Section 2: Mathematics: Aims, Skills and Content** (DBE, 2012, pp. 9-18)

The same method of analysis is used in this section. For this section, however, Grade R is discussed as a separate sub-section (DBE, 2012, p. 15) in terms of the classroom environment and appropriate programme for this grade, to be developed by teachers. An important distinction is made here in the emphasis that Grade R: “should promote the holistic development of the child” (p.15). It can therefore be expected that attributes associated with productive learning dispositions are encouraged and enhanced – through opportunities to communicate, socialise, and modelling of positive habits of mind (inquiry). Although specific dispositions are not explicitly discussed or listed herein, the environment and practices described would fit the criteria of a classroom ready to incorporate and accommodate the promotion of aspects of productive learning dispositions. The table below is similar to the one above and contains the dispositional category; examples of statements related to the category; and frequency of statements. It also distinguishes between statements intended for consideration across the Foundation Phase (Grades R-3), as well as those which are Grade R specific (i.e. statements were specific to the Grade R subsection).

**Table 2.** Frequency of dispositional statements by category – CAPS Section 2
In this section, ‘playfulness/resourcefulness’ has the highest frequency of statements, with three statements. ‘Reciprocity and ‘connections to learner’s world/see mathematics as worthwhile’ are also included with two statements each in this section.

Again, there is a noticeable absence in statements referring to ‘resilience’, and only one statement related to ‘confidence/self-efficacy’. This one statement is somewhat vague, in that it simply states that teachers should develop “confidence and competence” in the learner (p. 9).

Section 3: Content Areas Overview – Grades R-3 (DBE, 2012, pp. 15-285)

This section of the CAPS document outlines the specific content areas within Mathematics (i.e. Space and Shape), which are further broken down into different topics (i.e. two-dimensional shapes). Concepts and skills to be taught and learnt are specified within each topic, and clarifies what needs to be covered throughout the year. This section also aims to show progression across content areas throughout the Foundation Phase (Grade R-3) (DBE, 2012). The following table was developed using the same approach as above.

Table 3. Frequency of dispositional statements by category – CAPS Section 3.

<table>
<thead>
<tr>
<th>Dispositional Category</th>
<th>Example of statement</th>
<th>Frequency of statements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reciprocity</td>
<td>Grade R &amp; 1:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“Describe the position of one object in relation to another…” (p. 29)</td>
<td>Grade R: 14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grade 1: 27</td>
</tr>
<tr>
<td>Playfulness /Resourcefulness</td>
<td>Grade R &amp; 1:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“Compare and order the length, height or width of two or more objects by placing them next to each other” (p. 27)</td>
<td>Grade R: 9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grade 1: 16</td>
</tr>
<tr>
<td>Resilience</td>
<td>Grade R: “Teachers should...not simply assume that their learners cannot cope with bigger numbers” (p. 49)</td>
<td>Grade R: 1</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Confidence / Self-Efficacy</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Connections to learner’s world / see mathematics as worthwhile</td>
<td>Grade R &amp; 1: “Order regular events from their own lives” (p. 32)</td>
<td>Grade R: 8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grade 1: 14</td>
</tr>
</tbody>
</table>

**Reciprocity:**

‘Reciprocity’ can also be thought of as the ability to communicate effectively and efficiently, as well as the ability to understand another person’s articulation of their ideas. This communication can be verbal or non-verbal, expressive or receptive. In light of this, the following key words were identified as relating to ‘reciprocity’: discuss; describe; explain; report; use language; write. The frequency of these words was then counted across the content areas for the Grade R and Grade 1 respectively.

In the Grade R phase overview, these words (or variations thereof) occurred fourteen times across the numerous content areas and topics. In Grade 1, these words appeared twenty-seven times. This high frequency in both grades points to a prioritisation of communication (‘reciprocity’), which coheres with the emphasis in the general as well as specific aims of the CAPS document. The phase overview is in line with the underlying principles of the document, and teachers are expected, through the implementation of this curriculum, to invest time and energy into achieving effective and efficient communication amongst learners.

Progression by the children in this particular disposition is also present in the jump from 14 instances to 27 instances from Grade R to Grade 1 respectively. This relates to children being increasingly able to communicate more frequently and with more alacrity. The progression can thus be noted through the increased demands on the children to use their communication skills; from reading, to reading and writing number symbols; from drawing patterns, to discussing the qualities of a pattern.

**Playfulness/resourcefulness:**

As discussed earlier, ‘playfulness/resourcefulness’ in terms of a productive disposition relates not only to the physical ‘playing with’ or manipulation of concrete objects (although important in the Early Years’ setting), but also to the ability to use known concepts in a variety of contexts. A certain ‘flexibility’ of thought is implied here, as well as what is often referred to as ‘critical and creative thinking’. In light of this, the following terms can be used to describe ‘playfulness/resourcefulness’: estimate; compare; extend; create own; interpret.

In Grade R, these terms are mentioned nine times, and in Grade 1, we again see a significant jump in occurrences to sixteen frequencies. As with ‘reciprocity’, it can be determined from the analysis that this particular disposition is both prioritised, in line with the general and specific aims, as well as
designed to encourage progression form one grade to the next. This progression is once again about the sophistication with which the children can utilise and express this particular ‘habit’.

As well as the above terms relating to ‘playfulness/resourcefulness’, this document also makes reference to other elements which can be considered characteristics of this disposition. Under the content area ‘Space and Shape’, relating to the topic ‘3D Shapes’, Grade R learners are expected to “use 3D objects to construct composite objects” (p. 30). The ability to use objects in the construction of an individual composite or whole object is an expression of a child’s creativity of thought – this often manifests in the Art section of a pre-school as children use cardboard boxes glued together in a systematic way to represent a ‘machine’ of some sort of their own interpretation (i.e. explicit reference to ‘playfulness/resourcefulness’). The progression for this particular instance in Grade 1 is described as “observe and build given 3D objects using concrete materials” (p. 30). It is not clear in this particular instance just how much the ability to ‘play’ with a concept is allowed or indeed encouraged. Often, depending on the specific activity and materials selected by the teacher for the children to use in order to reach this milestone will determine the establishment or encouragement of ‘playfulness/resourcefulness’, or dismissal and restriction thereof. To elaborate: A teacher who allows children to select a box/prism/example of a 3D objects from a wide selection, and provides a host of collected objects which can be used in non-specified, varied ways to construct a chosen final shape, may find that the children all come up with different ideas and ways of achieving the same desired outcome (‘playfulness/resourcefulness’ of thinking, and creativity encouraged). Conversely, if all the children are given the same object to recreate, using a specified type of material, and guided in a step-by-step way to achieve the same final result, creativity is secondary to a procedural ‘right or wrong’ approach. Since this particular objective is ambiguous in its intended execution, it could not definitively be included as the promotion of ‘playfulness/resourcefulness’.

Resilience:

From page 39 onwards in Section 3, the document contains a section on “Content Clarification”. This section deals with the Grade R-3 overview once more, but this time it provides suggested sequencing of topics, suggested pacing, and clarification notes and teaching guidelines (p.39). Although a systematic analysis of this whole section is not in fact pertinent to this discussion, certain areas are selected where dispositions in Grade R in particular are mentioned. Corresponding mention in the Grade 1-3 areas is highlighted if at all present.

On page 49, “Problem types for Grade R” are discussed. Within this section reference is made to ‘resilience’, ‘playfulness/resourcefulness’ and ‘connections to learner’s world/see mathematics as worthwhile’, but not ‘reciprocity’. The exclusion of this disposition in this particular section, though, has been addressed in the general or specific aims, or in the content overview itself. ‘Resilience’ makes a rare appearance in this section. On page 49, in relation to Grade R, teachers are encouraged to “not simply assume that their learners cannot cope with bigger numbers”. Teachers here are not directly encouraged to motivate children to ‘keep trying’ but there is some implication to push them beyond their comfort zone (i.e. extend them). So far, little reference has been made to what should be considered an important attribute within the mathematics learning environment. With the development of ‘resilience’ amongst children comes the empowerment necessary to change the education system in South Africa from the inside-out: children feeling empowered and confident.
within themselves and with their abilities, not only in mathematics, but in life in general, will be better prepared to take on the challenges of poverty, injustice and social tension (Atweh et al., 2014). This said, however, the instruction to challenge children to explore mathematical thinking beyond what is the minimum curriculum requirement, or beyond what the learners have demonstrated they can do, is important as it indirectly encourages the development of ‘resilience’ and in turn, ‘confidence / self-efficacy’ in themselves – a positive regardless of the scope or extent to which it is done.

Confidence/self-efficacy

The development of ‘confidence/self-efficacy’ as a specific indicator is not observable in section 3 of the CAPS document as a direct intended outcome of learning and teaching. However, because of its close reciprocal relationship with the development of ‘resilience’ amongst children, it cannot be claimed that this indicator, in its absence, is overlooked in this particular policy document. Rather, it could be argued that it is present as a secondary intended outcome which arises through the development of other dispositional focused outcomes and activities.

Connections to learner’s world/see mathematics as worthwhile:

For this indicator, statements within this section of the document that foreground explicitly the connections to the world of the learner and/or those that relate to the emphasis of the usefulness of Mathematics beyond the classroom were considered. ‘Connections to learner’s world/see mathematics as worthwhile’ refers to children being encouraged to approach mathematical concepts, which get more and more abstract as they reach higher grades, in everyday contexts to emphasise practical, experienced and real-world representations of concepts as well as the usefulness and validity of the concept. An assumption here is that a child will be less inclined to utilise and fully assimilate an abstract concept if they are not explicitly shown the relevance of that concept to their lives.

This disposition is referred to a total of eight times in Grade R and fourteen times in Grade 1. Specific mention is made in the topic ‘addition and subtraction’ (p.22) of “solving problems in context”, both in Grade R and Grade 1. This refers to word problems, and represents the need to embed these ‘story sums’ in the everyday knowledge and experiences of the children, so that children may not only relate to the story itself, but also so that the mathematical concepts are less threatening. Dispositional statements related to this particular indicator also appear under the topics ‘Pattern’ and ‘Measurement’.

Although progression is not immediately evident, it can be assumed that the sophistication of thought in the children will develop as they grow older and develop their mathematical as well as literacy skills. Encouraging children to continuously rely on and make reference to their own personal lives contributes to establishing connections to their world, and provides a way of approaching mathematics that enables children to establish ‘ownership’ of this activity, making it personal, and so enabling easier retention of the concept.

The second document relates to practical teaching elements. This document is important in that it supports the implementation of the foundational CAPS document, and, although it is not possible to
achieve the same desired outcome in every classroom, in every school throughout our diverse nation, this handbook serves to supplement the guidelines and practical implications laid out in the CAPS document. It also speaks to the practical manifestations of how and when productive learning dispositions can or should be promoted.

**Documentary analysis of the Numeracy Handbook for Foundation Phase Teachers: Grade R-3**

The overall aim of this document is to “enhance the pedagogic and didactic capacity of Foundation Phase teachers, to teach Mathematics more effectively” (DBE, 2012, p. i). The document is divided into two parts; the first part consists of different units which describe “what it means to be numerate and do mathematics in the modern world” (DBE, 2012, p. 1). This section deals with the foundational principles of all mathematical learning, across the five content areas, and across the grades. It also deals with “the discussion of critical factors that contribute to the development of numeracy” (DBE, 2012, p. 1). It is this section that will be analysed here. The following table gives examples of the statements relating to the promotion of productive dispositions which can be observed within Part 1:

<table>
<thead>
<tr>
<th>Dispositional Category</th>
<th>Example of statements</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reciprocity</td>
<td>“giving children the opportunity to explain their thinking to their peers and teacher”</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>“need to encourage reflection through discussion” (p. 12).</td>
<td></td>
</tr>
<tr>
<td>Playfulness/Resourcefulness</td>
<td>“apply what you know to solve unfamiliar or non-routine problems” (p. 2).</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>“need to understand the mathematics they learn in flexible and meaningful ways…”(p. 4).</td>
<td></td>
</tr>
<tr>
<td>Resilience</td>
<td>use understanding to solve problems knowing that “they may have to struggle” and try a few different approaches” (p. 14).</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>“believe that with some effort they can solve the problem”(p. 14).</td>
<td></td>
</tr>
<tr>
<td>Confidence / Self-Efficacy</td>
<td>“need to understand the mathematics they learn in flexible and meaningful ways so that they can apply it with confidence to make sense of the world” (p. 4).</td>
<td>2</td>
</tr>
</tbody>
</table>
Reciprocity

As in the CAPS document, ‘reciprocity’ is a priority in context of teacher practices, extending the implications beyond a singular curriculum outline, and into the realm of the physical classroom environment. The implication of this prioritisation is that teachers are expected to encourage this particular disposition – the enacted curriculum is intended to align to the intended curriculum. Significant examples of the promotion of ‘reciprocity’ appear on page 5 and 19, as the document discusses ‘crucial factors’ of teaching numeracy in the Foundation Phase, and ‘guidelines for practice’, both of which contain ‘discussion’. This discussion mentioned can be observed in the children’s ability to:

(From Part 1): “demonstrate mental images”, “explain their thinking”, “present their mathematical understanding” and “reflect on their mathematical thinking” (p.i); to “reason about” what they have done (p.2); active encouragement by the teacher to “reflect on what they are doing and thinking” and “help children verbalize observations” which they can “explain to others and learn to interpret explanations of others” (p. 8); be given the opportunity to “make sense of and reflect on procedures and practices” (p. 11); they should “reflect on and think about” (p. 12) how they have solved a problem; develop understanding “through reasoning” (p 12); and finally, reflection should be encouraged through discussion (p. 12).

These many manifestations of ‘discussion’ as advocated in the ‘crucial factors’ and ‘guidelines for practice’ can be articulated by the children in a number of ways: “with concrete objects or use of drawings and sketches”, “to their peers and to their teacher”, “verbally and graphically” and through “a variety of dialogues” (p.i).

Playfulness/resourcefulness:

As with ‘reciprocity’, ‘playfulness/resourcefulness’ is again prioritised in this document, appearing in multiple instances throughout Part 1. Similar to the descriptions present in the CAPS document, ‘playfulness/resourcefulness’ here is described as the ability of the children to:

Apply what they know to “solve unfamiliar or non-routine problems” (p. 2); “understand the mathematics they learn in flexible...ways” (p. 4); make sense of, use and relate basic mathematical ideas in a range of situations, and when solving problems (p. 11); and finally “use understanding of learnt mathematics to solve meaningful problems” (p. 14).

Teachers are encouraged to do the following in order to support and encourage these abilities, and so promote the production of ‘playfulness/resourcefulness’: “create activities that reveal underlying
structures of numbers, operations and mathematical relationships” (p. 8), and expose the children to “non-routine problems in which they have to apply the knowledge and skills that they have developed” (p. 12).

Resilience:

Although only four instances were observed where this particular disposition is mentioned throughout the nineteen pages of this section, it is significant that it is mentioned. Again, as with CAPS document, ‘resilience’ as a term is not directly referred to, but rather variations thereof or attributes which support the development of ‘resilience’ are instead referred to as using their understanding while acknowledging that “they may have to struggle and try a few different approaches” and “believe with some effort they can solve the problem” (p. 14) (emphasis added). Finally, the document describes the ability of being able to ‘engage’ as seeing mathematics as “sensible, useful and doable – if you work at it – and are willing to do the work” (p.14) (emphasis added). This notion of ‘doing the work’, or putting in the effort is at the heart of ‘resilience’ – the end result, the success or failure of the child, is irrelevant here, but rather the ability to ‘engage’ and sustain that engagement regardless of the complexity of the activity. No mention is made here of practical ways in which teachers can encourage the development of this habit amongst learners.

Confidence/self-efficacy:

Notably fewer frequencies of this particular dispositional category are observable within this document. ‘Confidence/self-efficacy’ is directly related to or referred to only twice, on page 4 as: children “need to understand the mathematics they learn in meaningful ways so that they can apply it with confidence”; and on page 14 as: “believe that with some effort they can solve the problem” (emphasis added).

Connections to learner’s world/see mathematics as worthwhile:

The promotion of connections to the learner’s world, or the importance of seeing mathematics as worthwhile, is also prioritised in this document. This is shown on the first page, where the practice of ‘embedding’ mathematical processes in meaningful contexts is mentioned, as well as in the section regarding ‘crucial factors’ – where the use of “meaningful problems” is advocated (p. 5). Finally, in the ‘guidelines for practice’ section, this indicator is again brought to the fore as the document calls on teachers to make mathematics “meaningful and relevant” (p.19). This is reiterated throughout the nineteen pages of Part 1, and is highlighted through stating children should:

“experience Numeracy as a purposeful, meaningful and sensible activity” (p. 2); and
experience it as “meaningful, interesting and worthwhile” (p. 3); the desire to encourage children to use mathematics to “make sense of their world” (p. 4); and to use their understanding of learnt mathematics to “solve meaningful problems” (p.14) (emphasis added).

It can be argued from the above analysis of Part 1 of this teacher’s guide that the five productive learning dispositions are not only encouraged, but seen as fundamental in the effective teaching and doing of mathematics across the content areas and topics. This is in line with the intended CAPS curriculum, and many instances of teacher practice guidelines are mentioned herein – although not
detailed, a general idea is conveyed to the teachers around how to create an environment, and what sort of activities to conduct, in order to foster the development of these learning dispositions.

**Concluding Remarks**

Across the documents analysed, as well as across the various sections within these documents, the key indicators of dispositional categories most prevalent are: ‘reciprocity’; ‘playfulness/resourcefulness’ and ‘connections to learner’s world/see mathematics as worthwhile’. ‘Reciprocity’ was consistently high in frequency, and the lowest instances of frequency were for the key indicators ‘resilience’ and ‘confidence/self-efficacy’. This speaks to the inclusion of all key characteristics of disposition in international Mathematics Education (Kilpatrick et al., 2001) and general key learning dispositions in Early Childhood Development and Education (Carr & Claxton, 2010).

Across Grade R and Grade 1, there was no observable dissonance in respect of the prioritisation and promotion of key productive learning dispositions as outlined by the indicator categories. In instances where one particular indicator had a high frequency of statements in Grade R specific documentation, the same occurred in Grade 1, and the same for those indicators with lower frequencies. Notable as well, in terms of the two different grades, is the presence (especially in Section 3 of the CAPS document) of progression from Grade R to Grade 1 in terms of the expected level of sophistication of key productive learning disposition development.

**References**


**Acknowledgement:** This research was supported by funding from the DHET/EU, the FirstRand Foundation (with the RMB), Anglo American Chairman’s fund, the DST and the NRF.
This qualitative study investigated a preservice secondary school teacher’s mathematical knowledge for teaching equations (MKT). The study was carried out with Mr. Mwati (Pseudonym). Data was generated using an open ended paper and pencil test and interviews. I analysed the data using thematic analysis. Analysis of the results indicates that Mr. Mwati demonstrated some evidence of knowledge of solving equations. The findings also reveal that Mr. Mwati’s knowledge of students was intertwined with his knowledge of subject matter and knowledge of pedagogy. Limited specialised content knowledge, limited knowledge of content and students as well as limited knowledge of content and teaching were also evident. This study is believed to inform preservice teacher educators about the content of mathematics teacher preparation.

Key Words: Mathematical Knowledge for Teaching, Preservice Teacher, Secondary School, Equations

Introduction

The vision of the education sector in Malawi is to be a catalyst for socio-economic development and industrial growth. Malawi’s mission is to provide quality and relevant education to the Malawi nation. The purpose of secondary education in Malawi is to prepare students for further education in keeping with their abilities and aptitudes. In implementing the vision and mission, Malawi is focusing on quality in both primary and secondary education. The quality of education in Malawi has been compromised by access since the introduction of Free Primary Education in 1994 (Ministry of Education, 2008).

In Malawi, examination results are regarded as one of the standard measurements of quality of education. Malawi Ministry of Education (2008) reports that, the overall performance of students in secondary schools is poor. The National Education Sector Plan for 2007-2018 (Malawi Ministry of Education: 2008) adds that secondary school students experience poor learning achievement with only around 50 percent of students passing end-of-cycle examinations. In following up this problem in mathematics, I analysed Malawi National Examinations Board Chief Examiners’ Reports for years 2008 to 2013. The major finding for this analysis was students’ poor performance in Algebra and Geometry. Considering that algebra is the foundation of higher mathematics, I followed up students’ performance in algebra. The results indicate overwhelming failure due to misconceptions and errors. For instance, students were unable to formulate and solve equations. When solving quadratic equations, students were unable to change the quadratic equations to standard form. For those who managed to change the equations to standard form, they could not solve for the unknown. When given simultaneous equations, students could not make one unknown subject in the equation when they attempted to use substitution. Those who attempted to use elimination method, say in an equation like \( x + 3y = 11 \), could completely eliminate \( 3y \) and remained with \( x = 11 \). Despite the yearly recommendations, the problem of poor performance in is still existing (Malawi National Examinations Board Chief Examiners’ Reports, 2008-2013).

The problems outlined above were a motivation for the current study. The problems indicate a need for a focus on mathematics teacher education and the algebraic concept of equations. Even (1993)
suggests that an important step in improving teaching and learning should be better subject matter preparation for teachers. In order to improve students’ performance in mathematics in general, the teacher should enhance profound understanding and acquisition of algebraic concepts and thinking skills. In addition, it is important that preservice mathematics teachers understand the concept of equations, to be better equipped for effective teaching of secondary school mathematics. Thus, this study is believed to inform preservice teacher educators about the content of mathematics teacher preparation. The overall purpose for this study was to investigate a preservice secondary school teacher’s mathematical knowledge for teaching equations. In this paper, I show how task-based interviews were used to identify Mr. Mwati’s mathematical knowledge for teaching equations. Hence this investigation examined the following question: What mathematical knowledge for teaching equations is displayed by a Malawian preservice secondary school mathematics teacher?

Theoretical Framework

Two constructs guide the theoretical framework for this study; mathematical knowledge for teaching and equations. The theoretical perspective for this study is based on the mathematical knowledge for teaching model which was developed by Ball, Thames, & Phelps (2008). This framework is used to categorise and assess the knowledge needed for teaching mathematics. The mathematical knowledge for teaching framework is a practice based theory (Ball et al., 2008). It focuses on the kind of professional knowledge of mathematics which is different from that demanded by other mathematically intensive occupations. It moves beyond the limiting boundaries of knowledge to include skills, reasoning, habits of mind and sensitivities needed to teach mathematics effectively (Ball et al., 2008).

The mathematical knowledge for teaching (MKT) model elaborates the use of the Shulman’s (1986) subject matter knowledge (SMK), pedagogical content knowledge (PCK) and curriculum knowledge categories, organising and defining them in a different way. According to Shulman (1986), the SMK of teachers is “the amount and organisation of knowledge (of a subject) per se in the mind of the teacher”. PCK is the most powerful analogies, illustrations, examples, explanations and demonstrations – in a word, the ways of representing and formulating the subject that makes it comprehensible to others (Shulman, 1987, p.8). There are six elements of MKT: Common Content Knowledge (CCK), Specialised Content Knowledge (SCK), Horizon Content Knowledge (HCK), Knowledge of Content and Teaching (KCT), Knowledge of Content and Students (KCS), and Knowledge of Content and the Curriculum (KCC). The organisation of the domains of knowledge is indicated in Figure 1 below. Definitions for each of the domains follow.

![Figure 1: Domains of Mathematical Knowledge for Teaching (Ball et al. 2008)](image-url)
Common content knowledge (CCK) is the mathematical knowledge held by an adult who can use a method to solve a mathematical problem (Ball et al., 2008). It involves correctly solving mathematical problems. Specialised content knowledge (SCK) is the mathematical knowledge and skill unique to teaching. It involves unique mathematical understanding and reasoning and requires knowledge beyond that being taught to learners. Knowledge of content and students (KCS) is knowledge that combines knowing about learners and knowing about mathematics. It involves anticipating what learners are likely to think and what they will find confusing as well as possible difficulties they may experience. It also involves recognising errors and identifying most likely errors learners make, interpreting learners’ responses and developing learners’ justifications. Knowledge of content and teaching (KCT) combines knowing about teaching and knowing about mathematics. Teachers have to have mathematical knowledge of the design of instruction. They must be able to sequence particular content for instruction and select and use effective instructional models. They have to identify what different methods and procedures to use to make the mathematics salient and usable by learners. It involves making decisions about what learner contributions to pursue and which to ignore or save for a later time.

While it may be clear that knowledge for teaching is multi-dimensional, the model categories appear static. It is somewhat difficult to decide where one category starts and another finishes. However, this model tries to elaborate what knowledge is required for teaching and to design suitable items to measure the different categories of knowledge. It recognises that definition and precision within each category is problematic. Despite the static nature, the Ball et. al. (2008) model is a useful framework for understanding what mathematics teachers need to know for the task of teaching. The mathematical knowledge for teaching framework is useful when discussing different types of knowledge. As such, this framework informed this study. For this research, I studied preservice teachers’ common content knowledge of equations, specialised content knowledge, knowledge of content and students and knowledge of content and teaching equations. I focused on the four MKT domains because I recognised that studying both SMK and PCK provides a much broader and deeper picture about students MKT than either can do alone. Furthermore, by trying to differentiate, distinguish and study the individual categories of MKT, we lose important information on how these categories interact with each other.

Equations

The second construct of the theoretical framework for this research largely draws from the work of Kriegler (2007). Kriegler developed a framework for algebraic thinking which is based on many years of work. Kriegler asserts that algebraic thinking is organised into two major components: the development of mathematical thinking tools and the study of fundamental algebraic ideas. Mathematical thinking tools are analytical habits of mind. They are organised around three topics: problem solving skills, representation skills, and quantitative reasoning skills. Fundamental algebraic ideas represent the content domain in which mathematical thinking tools develop. They are explored through three lenses: algebra as generalised arithmetic, algebra as a language, and algebra as a tool for functions and mathematical modelling (Table 1).

Table 1: Components of Algebraic Thinking

<table>
<thead>
<tr>
<th>Mathematical Thinking Tools</th>
<th>Fundamental Algebraic Ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem solving skills</td>
<td>Algebra as generalised arithmetic</td>
</tr>
<tr>
<td>• Using problem solving strategies</td>
<td>• Conceptually based computational strategies</td>
</tr>
<tr>
<td>• Exploring multiple approaches</td>
<td>• Ratio and proportion</td>
</tr>
<tr>
<td>• multiple solutions</td>
<td>• Estimation</td>
</tr>
</tbody>
</table>
The focus on algebraic thinking in this study involves problem solving, representation skills, quantitative reasoning skills, algebra as the language of mathematics and algebra as a tool for functions and mathematical modelling. This involves formulating and solving equations, describing relationships among different representations of equations, translating among different representations, interpreting information within representations, analysing problems to extract and quantify essential features, inductive and deductive reasoning. The algebraic thinking framework was used to analyse Mr. Mwati’s common content knowledge.

**Literature Review**

Li’s (2006) study characterises the mathematical knowledge upon which secondary school algebra teachers draw when pondering problem situations that could arise in the teaching and learning of solving algebraic equations. It also examines the potential connections between teachers’ knowledge and their academic backgrounds and teaching experiences. Seventy-two middle school and high school algebra teachers in Texas participated in the study. Results revealed three topic areas in equation solving in which teachers’ mathematical subject matter understanding should be strengthened: (a) the balancing method, (b) the concept of equivalent equations, and (c) the properties of linear equations in their general forms. The participants provided a wide range of instances of student misconceptions and difficulties in learning how to solve linear and quadratic equations, as well as a variety of strategies for helping students to improve their understanding. Teachers’ subject matter knowledge played a central or prerequisite role in their reasoning and decision-making in specific contexts.

Li (2011) also describes the sequence of mathematical practices that a teacher designed and enacted during three consecutive lessons about four algebraic routines for solving quadratic equations, and focuses on the mathematical knowledge that is entailed in the teacher’s actions and decisions. Among the three domains of mathematical knowledge for teaching (MKT), the teacher’s knowledge of the equation solving routines played the most crucial role in shaping the lessons and potentially promoting mathematical proficiency in a balanced approach. The findings suggest that mathematics
teacher preparation and professional development programs should provide more opportunities for teachers to revisit the features and applicability of various mathematical routines, and develop skills in making instructional decisions that would balance all domains of teachers’ MKT, teacher beliefs, and other factors related to proficiency in algebraic routines.

In a different study of equations, Ellarton & Clements (2011) used a pencil-and-paper instrument to investigate prospective middle-school mathematics teachers’ knowledge of equations and inequalities. Data analysis revealed that hardly any of the 328 students knew as much about elementary equations or inequalities as might reasonably have been expected.

Huang and Kulm (2012) also examined prospective middle grade mathematics teachers’ knowledge of algebra for teaching with a focus on knowledge for teaching the concept of function. One hundred and fifteen prospective teachers from an interdisciplinary program for mathematics and science middle teacher preparation at a large public university in the USA participated in a survey. It was found that the participants had relatively limited knowledge of algebra for teaching. They also revealed weaknesses in selecting appropriate perspectives of the concept of function and flexibly using representations of quadratic functions. They made numerous mistakes in solving quadratic or irrational equations and in algebraic manipulation and reasoning. The participants’ weaknesses in connecting algebraic and graphic representations resulted in their failure to solve quadratic inequalities and to judge the number of roots of quadratic functions. Follow-up interview further revealed the participants’ lack of knowledge in solving problems by integrating algebraic and graphic representations.

My analysis of previous studies has found out that a lot of research has been carried out on teachers’ mathematical knowledge for teaching (e.g. Ma, 1999; Hill et al., 2008; Bartell et al., 2012). However, these studies report more on elementary preservice and in-service teachers’ mathematical knowledge for teaching rather than the knowledge of middle grades and high school preservice teachers. Not much research on preservice teachers’ MKT of equations has been done in the Southern Africa Development Community (SADC) region and Malawi in particular. This study, therefore, is intended to fill this gap.

In addition, all these qualitative studies used tests, interviews and lesson recordings to investigate preservice teachers’ mathematical knowledge for teaching. All the studies found out weaknesses in preservice teachers’ MKT. The findings of these studies provide several implications for improving mathematics teacher preparation. For instance, Huang and Kulm (2012) recommend that at the teacher preparation curriculum level, it is important to provide an appropriate foundation for prospective teachers to obtain a sound and well-structured knowledge base needed for teaching. Mostly, they emphasise on deepening understanding of mathematics for preservice teachers as contrasted with connections of the mathematical topics to teaching. Ellarton & Clements (2011) propose a 5 – R Intervention Model to help preservice teachers pass from darkness into light. They used this model in their study and found out that it placed many preservice teachers of middle school mathematics on a new track which they suggest would lead them into knowledgeable and competent teachers.

Research Methodology

According to Marshall and Rossman (1999), this research essentially falls into the qualitative design with multiple case study approach. Merriam (1998) asserts that qualitative research focuses on process, meaning and understanding. In order to arrive at judgments regarding preservice teachers’
MKT, “richly descriptive data” were needed (Cohen and Manion 1980: 29). Words, therefore, were used instead of numbers to convey the outcomes of the research findings. In this study, I conducted semi-structured one-on-one interview (Patton, 2002). The interview was in two parts. The first part was a follow up of the paper and pencil tests that the participants wrote while the second part consisted of a task based-interview.

The tasks for the interview were selected basing on the fact that they fit in the theoretical framework. This means, the tasks assessed specific Ball’s et. al. (2008) MKT domains. In addition, I also considered the dynamic nature of the MKT categories. For instance, an item would assess one category of MKT more strongly than the other. For example, it would assess CCK more than SCK, KCS and KCT or; in attempting to reveal his CCK, for example, Mr. Mwati would also reveal his KCS. Now, the selection of items to assess a particular MKT category was based on which category a particular item assessed more strongly than another. The tasks were then piloted prior to commencement of the formal data collection. The purpose of this pilot study was to assess the clarity of the problems on the students’ paper and pencil tests and interview schedule as well as space and time issues relating to written students’ tests and interviews and to check whether instructions were comprehensible and checking the validity and reliability of the results (Mayoux, 2013). Three preservice mathematics teachers participated in the pilot study.

Mr. Mwati was a final year Diploma in Education preservice teacher aged between 30 and 40. He was originally trained as a soldier. Later, he joined teaching and was trained as a primary school teacher for two years under the Integrated Primary Teacher Education program (IPTE). The IPTE program in Malawi is run in such a way that students learn theory for one year and they go for teaching practice in the other year before they graduate. After Mr. Mwati graduated as a primary school teacher, he taught at one of the primary schools in the Malawi defence force for two years before joining the secondary school teacher education program. He was the best student in his class.

I analysed data using thematic analysis (Ritchie & Lewis, 2003; Creswell, 2008). Themes were developed from the theoretical framework as well as the data. For common content knowledge, I developed themes from the algebraic thinking model and the themes for the other MKT categories were developed from Ball’s et. al. (2008) framework.

Results and Discussion

The analysis of Mr. Mwati’s MKT shows that he demonstrated some evidence of conceptual understanding of equations. For instance, he was able to solve the equation \( x^2 + 2x + 8 \) by factor method, quadratic formula, completing squares and by graph in that order (see table 2). Being able to explore multiple approaches to a problem is an example of problem solving skills. Mr. Mwati also displayed deductive reasoning. When solving the equation \( x^2 = 2x + 8 \), Mr. Mwati used rules of algebra to solve for the unknown. Using rules of algebra to solve an equation is an indicator of deductive reasoning.

When I asked him which comes first between the quadratic formula and completing squares, Mr. Mwati stated that completing squares comes first because the quadratic formula is derived from the general quadratic equation by completing squares. Despite that he solved the equation using the quadratic formula first before using completing the square method, Mr. Mwati knew that completing the square is the prerequisite for the quadratic formula.

Coming up with a table and graph from an equation may imply that Mr. Mwati was also able to display relationships visually and to translate among different representations. It might also be inferred that Mr. Mwati was able to represent mathematical ideas using equations, tables and graphs.
Additionally, he interpreted the graph that I gave him before he answered the questions related to the graph. Ability to interpret a graph indicates that Mr. Mwati was able to interpret information within a representation. The problem solving skills that he displayed enabled him to interpret the graph that he was given during the interview.

Table 2: Common Content Knowledge

<table>
<thead>
<tr>
<th>Preservice Teacher’s Knowledge (CCK)</th>
<th>Examples from Mr. Mwati</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recognising why a particular method failed and what to do</td>
<td>Mwati: Aah! It is because we are looking at factors of -10 which could give us the coefficient of x. Now, the factors of -10 that could give us the coefficient of x, we don't have such. That is why I chose to use the other method for solving the particular equation. Mwati: … Because factor method involves factors. There are some problems in which you can have factors but when you add or subtract them, you cannot get the coefficient of x. Now, if that situation comes in, it is when we are saying we need to have other methods of solving such equations because factorisation now failed…</td>
</tr>
<tr>
<td>Exploring multiple approaches to a problem</td>
<td>Mwati: Yes, because this is factorisation, I will also use quadratic formula to solve the equation Mwati: I think the problem can also be solved by graphical method. … We can also use completing the square.</td>
</tr>
<tr>
<td>Displaying relationships visually / Translating among different representations</td>
<td>Mwati: A method I can call the final one is graphical method. FM: ok. Can you now solve the equation graphically? Mwati: We need to equate this equation to y. Now, it will be ( x^2 - 2x - 8 = y ). Now from there we need to find the range of values of x. Maybe, we can start from (-3) to (5). This range has just been chosen arbitrarily. Now we need to have a table whereby we are saying the values of x should range from (-3) to (5).</td>
</tr>
</tbody>
</table>

Although Mr. Mwati displayed some evidence of conceptual understanding; we cannot assume that he has a comprehensive and well-articulated mathematical knowledge for teaching. There are some things that he needs to improve. For example, when changing a quadratic equation to standard form, he referred to this process as equating the equation to zero. The more precise way of putting this is to refer to the process as to equate all terms to zero or just to change the quadratic equation to standard form. Secondly, Mr. Mwati did not pronounce the “coefficient of \(x^2\)”. Instead, he pronounced it as the coefficient of the highest power. Furthermore, the change from \( x^2 = 2x + 8 \) to \( x^2 - 2x - 8 = 0 \) was unnecessary when solving the quadratic equation by completing the square. A solution process which begins as this one indicates the participant’s reliance on procedural knowledge and some overgeneralisation of rules. An example of such an overgeneralisation of a rule when solving quadratic equations is “when we solve quadratic equations we are required to change them to standard form”. As much as this works when solving by factor method or the quadratic formula, the rule does not apply to equations such as \( x^2 = 2x + 8 \) when we want to solve by completing the square. Mr. Mwati also had difficulties with posing a word problem that was meaningful and correct for the given symbolic problem \( 2x + 4 = 3x - 9 \). He pronounced 2x as multiplying x twice and 3x as multiplying x three times. The language that he used is not conventional. According to Adler and Patahuddin (2012), mispronouncing terms is an indication of limited common content knowledge.

For specialised content knowledge, the interview tasks involved explanations, representations, working with learners’ ideas and questioning (see Kazima, Pillay, & Adler: 2008). The specialised content knowledge that Mr. Mwati demonstrated during the interview includes giving mathematical
explanations, linking representations to underlying ideas and connecting a topic being taught to topics from prior or future years. When I asked him why he added the square of half of the coefficient of x to both sides of the equation when solving the equation by completing the square, Mr. Mwati explained that he did that in order to make the left hand side of the equation a perfect square so that in the end he could factorise. Of the many descriptors of SCK described by Kazima et al (2008), only four descriptors were identified during the interview with Mr. Mwati (see table 3). One possible cause might be that the questions posed were more suitable for getting access to the participants’ CCK. It could also be because in Ball’s et. al. (2008) framework, there is no clear distinction between CCK and SCK. The results may also reflect the fact that specialised content knowledge is the knowledge enacted in practice hence not much of the specialised content knowledge was displayed during the interviews. Similar results were found from a study conducted by Huang (2012) in the USA and China. It was found out that the participants had relatively limited knowledge of algebra for teaching. They also revealed weaknesses in selecting appropriate perspectives of the concept of function and using representations of quadratic functions flexibly.

Table 3: Specialised Content Knowledge

<table>
<thead>
<tr>
<th>Preservice Teacher’s Knowledge (SCK)</th>
<th>Examples from Mr. Mwati</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linking representations to underlying ideas</td>
<td>FM: ... Now, what is the relationship between the number of roots and the graph of a quadratic equation? Mwati: Ok. The relationship is that the graph is cutting at the values of x two times like in the graph I drew.</td>
</tr>
<tr>
<td>Connecting a topic being taught to topics from prior or future years</td>
<td>Mwati: (To solve this problem), I think they need to have the knowledge of the Cartesian plane where we have the x axis and the y axis and its values. Now, if they know the values of x they are going to tackle this problem correctly.</td>
</tr>
<tr>
<td>Being able to show what steps of a procedure mean and why they make sense</td>
<td>FM: Why should you add to both sides the square of half of the coefficient of x? Mwati: We want to make this a perfect square because we are completing the square. We are adding half of the coefficient of x to make it a perfect square. FM: … (Relationship between roots and graph of quadratic equation). Why do you think this relationship exists? Mwati: Because the highest power of the equation is 2. That is why we are having the graph cutting the x axis in 2 places.</td>
</tr>
</tbody>
</table>

For knowledge of content and students, Mr Mwati was able to anticipate students’ thinking and confusions, identify students’ misconceptions, understand reasons for the misconceptions and ask questions to understand or reveal students’ reasoning and misconceptions. However, Mr. Mwati displayed limited ability to ask questions to understand or reveal students’ reasoning and misconceptions. This was indicated by the fact that he came up with one question only when I asked him to give examples of questions he could ask in order to identify students’ misconceptions. The findings also reveal that Mr. Mwati was able to identify the source of students’ misconceptions, and errors but had difficulty in generating effective ways different from telling the rules or procedures to confront such misconceptions. Although there are a number of more conceptual approaches to address students’ difficulties, errors and misconceptions, Mr. Mwati did not mention them during the interviews (table 4). Kılıç (2011) also found similar results when the researcher studied preservice secondary mathematics teachers’ knowledge of students.

Table 4: Knowledge of Content and students

143
Preservice Teacher’s Knowledge (KCS) | Examples from Mr. Mwati
---|---
Anticipating student thinking and confusions | **FM:** Now what errors may students exhibit as they try to answer this question?
- **Mwati:** Maybe to find the correct F if the graph is cutting were there are no numbers.

- **FM:** What do you mean when you say “where there are no numbers”? **Mwati:** The numbers between 0 and 10 or between 10 and 20. Now because the numbers are not written here, the students will confuse.

Identifying students’ misconceptions | **FM:** Now, what misconceptions might lead to the error you have mentioned?
- **Mwati:** Maybe they may be thinking that these are the only degrees; we do not have other degrees apart from the ones we are being given here.

Understanding reasons for the misconceptions | **FM:** How would that thinking develop?
- **Mwati:** It will develop due to the way they are taught by their teacher maybe the teacher did not explain that in between we have numbers. Now if the teacher did not explain this, it can be a source of the errors or the misconceptions

Asking questions to understand or reveal students’ reasoning and misconceptions | **FM:** Now suppose you want to teach this to your students, what questions may you ask your students to identify the misconceptions?
- **Mwati:** Maybe we can ask for the numbers that are not written on the graph. For example, how many degrees Fahrenheit are equivalent to 93°C? The answer that the students will give will show whether they have misconceptions or not.

Just as with specialised content knowledge and knowledge of content and students, Mr. Mwati displayed limited knowledge of content and teaching. For instance, in the case of interpreting a linear graph, Mr. Mwati stated that he would explain and demonstrate to the students that there are numbers in between say 10 and 20, 20 and 30, although they were not written on the x axis of the graph. When it came to how he would present the equation \( x^2 = 2x + 8 \), Mr. Mwati explained that he would give them steps to follow for them to come up with the roots of the equation. Mostly, Mr. Mwati relied on explanation and demonstration as methods of enhancing students’ conceptual understanding. Analysis has shown that he mentioned only one case where he could ask questions to students or ask volunteers to explain their solution processes (see table 5). These findings illuminate results of a study conducted by Li (2011) who found out that one preservice teacher’s mathematical knowledge for teaching algebraic routines was weak.

Table 5: Knowledge of Content and Teaching

<table>
<thead>
<tr>
<th>Preservice Teacher’s Knowledge (KCT)</th>
<th>Examples from Mr. Mwati</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge of representations for teaching particular topics</td>
<td><strong>Mwati:</strong> … We can represent that in an equation. For example, to say maybe, you are taking age between father and son. Maybe the father’s age can be twice the age of the son. This can be represented as an equation</td>
</tr>
<tr>
<td>Explanation and demonstration as a means of enhancing conceptual understanding</td>
<td><strong>Mwati:</strong> I would explain to them that there are numbers in between say 10 and 20, 20 and 30 etc although they were not written on the graph. <strong>Mwati:</strong> I would use demonstration and explanation.</td>
</tr>
</tbody>
</table>
Knowledge of instructional strategies

Mwati: I will give them steps to follow for them to come up with the roots of the equation.

Mwati: Giving them questions and asking volunteers to come in front to give the solution in any way they want so that I can say ok this is the way the students understood the problem.

Despite the high success rate of solving the equation given during the interview session, Mr. Mwati displayed some misconceptions which were evident during the analysis. For instance, Mr. Mwati regarded variable as object (see table 6).

Table 6: Misconceptions

<table>
<thead>
<tr>
<th>Preservice Teacher’s Misconception</th>
<th>Example from Mr. Mwati</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable as object</td>
<td>FM: How could you let learners understand that x and y could represent anything?</td>
</tr>
<tr>
<td></td>
<td>Mwati: Ok. We can take for example things around them. For example; mangoes, textbooks, people or even learners themselves. We can call and let them be like letters like x and y representing an object or any material.</td>
</tr>
</tbody>
</table>

When I asked him how he could deal with a misconception about variable as object, Mr. Mwati stated that he could deal with a student’s misconception by letting x and y represent anything. Mr. Mwati displayed this misconception during a follow up interview of the test results. This is how the conversation went:

*FM: Let us look at question 2b. In this question, you are saying you could let learners understand that x and y can represent anything. How could you let learners understand that x and y could represent anything?*

*Mwati: We can take for example things around them, for example; mangoes, textbooks, people or even learners themselves. We can call and let them be like letters like x and y representing an object or any material.*

Mr. Mwati’s interpretation of variable as object violates the mathematical meaning of variable which represents a number. In addition to interpreting variable as object, Mr. Mwati did not link representations to underlying ideas and to other representations. He also had difficulties with posing a word problem that was meaningful and correct for the given symbolic problem $2x + 4 = 3x - 9$.

Conclusion

In this study, Mr. Mwati’s mathematical knowledge for teaching equations was investigated through a one-on-one interview. On one hand, Mr. Mwati displayed success when solving the equation $x^2 = 2x + 8$ using four methods namely, factoring, completing the square, quadratic formula and by graph. When solving the equation $x^2 = 2x + 8$, he was able to explore multiple approaches to a problem, to use rules of algebra to solve an equation and hence displayed deductive reasoning, to display relationships visually and to translate among different representations and to interpret information within a representation. All these are algebraic thinking skills conceptualised by Kriegler (2012) in the theoretical framework. On the other hand, Mr. Mwati displayed some misconceptions and other difficulties. The results have also shown that Mr. Mwati had difficulties with pronouncing terms. He also unnecessarily changed the equation $x^2 = 2x + 8$ to standard form when solving by
completing the square. Mr. Mwati also had difficulties in asking effective questions to identify students’ errors and misconceptions. Similarly, Mr. Mwati’s specialised content knowledge and knowledge of content and teaching were limited.

The fact that Mr. Mwati displayed limited MKT during the interview could also result from the fact that the measurement of his knowledge within the categories of SCK, KCS and KCT was somewhat constrained due to the limitation of not having access to classroom students. In his responses, Mr. Mwati had to ‘work’ within a hypothetical situation. While his CCK was more evident during the task-based interview, it is possible that given a wider range of problems, additional evidence of knowledge within CCK, SCK, KCS and KCT categories could be obtained. It is also possible that additional evidence of MKT would be obtained using tests and video lesson recordings.

Finally, the findings in this study suggest that Mr. Mwati lacks the knowledge necessary for teaching equations effectively to his students. Since this apparent lack of knowledge could be observed with one of the best students, it appears that Malawian teacher education needs to emphasise on developing preservice teachers’ MKT. This aspect is lacking in contemporary education of secondary school mathematics teachers in Malawi. With sufficient mathematical knowledge for teaching, they will be able to interpret student thinking, identify misconceptions provide tasks and pose questions that will guide students’ interpretations of mathematics. The teachers will also be able to find appropriate strategies for inducing cognitive conflict that will help students to deconstruct their naïve theories and reconstruct correct mathematical conceptions. The results also suggest that the implications for translating CCK into effective SCK, KCS and KCT are paramount in raising the profile of mathematics teaching and learning.

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Content knowledge and pedagogical content knowledge conversations

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There is currently some debate in South Africa about the relative importance of content knowledge and pedagogical content knowledge in mathematics teacher development programmes and how these should relate to each other. In this paper we present results from a project in which mathematics teachers work together in professional learning communities to understand and engage with their learners’ errors. The paper argues that the engagement with learner errors, a pedagogical content knowledge focus, provides opportunities for teachers to engage in both pedagogical content knowledge and content knowledge conversations. Through analysing the conversations of teachers during professional learning community meetings over one year, the paper shows that teacher conversations provide opportunities for the development of content knowledge and pedagogical content knowledge and that content knowledge conversations are sometimes triggered by pedagogical content knowledge conversations and vice versa.

Introduction

This paper is part of a larger mathematics teacher development project, which works with teachers to support them in understanding and engaging with learner errors. In this paper, we present an analysis of the conversations of teachers during professional learning community (PLC) meetings in order to show the extent to which the community talks about content knowledge (CK) and pedagogical content knowledge (PCK), as well as to show the relationships between CK conversations and PCK conversations. We present two primary arguments. First, we argue that engaging with learner errors through a particular set of developmental activities provides opportunities for the development of both PCK and CK. Second, we argue that CK conversations do not have to precede PCK conversations but that both CK and PCK conversations trigger each other.

Theoretical framework

This paper draws on theories of teacher knowledge, particularly CK and PCK, on theories of learner errors, and the relationships between these.

Teacher knowledge

It was Shulman’s interest in conceptions of teacher knowledge and knowledge growth in teaching (1986a; 1986b) that brought the construct of teacher knowledge to the fore in the educational research community about 25 years ago. Shulman (1987) presented a knowledge base for teachers which consisted of the following seven categories: content knowledge (or knowledge of the subject matter), pedagogical knowledge, pedagogical content knowledge, curriculum knowledge, knowledge of learners and their characteristics, knowledge of educational contexts and knowledge of educational ends, purpose and values. In this paper we focus on content and pedagogical content knowledge and so we discuss these in more detail.

Knowledge of subject matter has been variously referred to as content knowledge, subject knowledge or subject matter knowledge. Although researchers use slightly different terminology, all include some form of content knowledge as an important component of teacher knowledge. Ball et al., (2008, p. 399) describe common content knowledge as “the mathematical knowledge and skill used in settings other than teaching” going further to say that it is the knowledge “required by everyone
Ball et al. (2008, p.400) differentiate common content knowledge from specialised content knowledge which they describe as “mathematical knowledge and skill unique to teaching” and which is “not typically needed for purposes other than teaching”.

Since Shulman (1987, p.15), described PCK as a “distinct body of knowledge that differentiates teachers from content specialists”, there has been on-going debate as to the exact meaning of the construct of PCK. The notion that “the transformation of subject matter knowledge for the purposes of teaching is the heart of PCK” (Park et al., 2010, p.248) is common to the work of most scholars. Shulman (1987) describes PCK as “the capacity of a teacher to transform the CK he or she possesses into forms that are pedagogically powerful.” Other scholars, for example Abell (2007), argue that the construct of PCK is still being explored, and Park, Jang, Chen & Jung (2010) hold that there is “no agreed-upon definition of PCK”. Ball et al., (2008, p. 390) speak of the meaning of PCK being “underspecified”, adding that this lack of definition and empirical foundation has limited its usefulness. However, it should be noted that the current debates revolve more around the relationship between CK and PCK than trying to pinpoint exactly what constitutes what PCK is, and that there is general agreement that PCK is an important aspect of an effective teacher’s repertoire of knowledge.

Much of our work was framed by the work of Soonhye Park. Although Park focuses on PCK in science teaching, we found her work on PCK sufficiently broad to extrapolate it to frame our study of mathematics teacher knowledge. Park (2007, p. 745) presents a pentagonal model of PCK. Park’s selection of the five components of PCK in her model is based on an in-depth literature study in which the components of PCK from different conceptualisations were identified. While the identification of the components that were deemed most important was nothing new, Park’s presentation in a pentagonal shape, the emphasis on the interaction between the components of PCK and her conclusion that the total PCK is greater than the sum of the parts (Park, 2014, personal communication) brought new ideas into the PCK arena. The five integrated components of PCK presented by Park (2007) are (1) orientation to teaching science, (2) knowledge of student understanding; (3) knowledge of the science curriculum (both horizontal and vertical); (4) knowledge of instructional strategies and representations; and (5) knowledge of assessment of science learning. Although Park’s pentagonal model is silent with regard to CK, the placement of PCK at the centre, with the implication that the “development of one component may simultaneously encourage the development of others [components], and ultimately enhance PCK” (Park, 2007, p. 745) suggests that development of PCK can lead to the development of other components of teacher knowledge, of which CK is one.

**Relationships between CK and PCK**

There is on-going debate as to whether subject matter knowledge (CK in our study) and PCK are separate knowledge components or are merged (Kind 2009, p 180). In integrative models, PCK is not recognised as a separate knowledge component, whereas in transformative models PCK is described
as “new knowledge arising from the act of transforming subject matter, pedagogical and contextual knowledge for the purposes of instructing students” (Kind 2009, p. 180).

Our research focuses on the relationship between these two forms of teacher knowledge. Some researchers, for example Rollnick, Bennett, Rhemtula, Dharsey and Ndlovu (2008), hold that subject matter knowledge (or CK) is a pre-requisite for the development of PCK. Other researchers, for example Brodie and Sanni (2014), contest the stance that developing CK is necessarily primary and that the development of all other forms of teacher knowledge has to be founded on CK. While not disagreeing that the development of teachers’ CK is important, Brodie and Sanni argue that “the relationships between teachers’ CK and PCK are more nuanced” (2014, pg. 1). Brodie and Sanni speak of a two-way relationship between CK and PCK, which they regard as being “mutually constitutive” (2014, p. 3). The view that CK is not always primary supports Park’s assertion that the development of one component of teacher knowledge may “simultaneously encourage the development of others, and ultimately enhance PCK” (2007, p.745). Our study provides evidence to challenge the standard view that the development of CK precedes the development of PCK.

**Learner errors**

Nesher (1987) defines errors as “systematic, persistent and pervasive mistakes performed by learners across a range of contexts”. Errors are distinguished from slips, which are mistakes that are easily corrected when pointed out (Olivier, 1996). According to Brodie (2014), “in constructivist theories of learning, errors are said to arise from misconceptions, which are conceptual structures constructed by the learner that make sense in relation to her/his current knowledge, but which are not aligned with conventional mathematical knowledge (Nesher, 1987; Smith, DiSessa, & Roschelle, 1993)”. So errors can be an indication of (partially) valid mathematical reasoning. During professional learning community meetings teachers are encouraged to understand the reasoning behind learners’ errors, to understand what is valid and what is not valid in the learners’ reasoning, and to think about how to engage learners’ reasoning in a meaningful and productive manner in order to help them transform the errors (Brodie, 2014). Understanding and embracing learner errors is a difficult task and teachers need substantial practice and a variety of experiences in order to be able to do this. We argue that engaging with learner errors provides opportunities for the development of teacher knowledge in the form of CK and PCK and we show that this happens differently across a range of carefully designed activities.

**Empirical site: The DIPIP Project**

The Data Informed Practice Improvement Project (DIPIP) is a professional development programme that works with high school mathematics teachers to design and reflect on lessons, tasks and instructional practices, and builds professional learning communities. The project focuses on building teachers’ understanding of learner errors generally and in particular topics. Teachers engage with data from a range of sources and they work together to better understand the nature of learners’ errors and how they might respond to them (Brodie, 2013, 2014). The project takes the position that by working with teachers’ PCK through learner errors, opportunities will be provided for them to work on CK and that working towards CK through PCK is useful because it situates CK more closely in relation to teachers’ work. When working with PCK, teachers sometimes become aware of areas in which they require additional support regarding their own CK (Brodie, 2014).
DIPIP creates a platform for professional conversations in which mathematics teachers, together with university academics or teachers as facilitators, discuss what information test data provide, how the data can be used to think about reasons for learner errors and how learner errors might be addressed through collaborative lesson planning, teaching and reflection. These conversations take place during professional learning community meetings. A professional learning community is a group of professionals (in the case of DIPIP the professionals are teachers), who interact collectively (as suggested by the term community) in order to bring about professional learning. Professional learning is learning informed by the knowledge base of the profession (Jackson & Temperley, 2008). Researchers, including Borko (2004), Jaworski (2008) and Brodie (2013) view professional learning communities as an effective, lasting and sustainable method of professional development in mathematics education. Brodie (2013, p. 15) holds that “professional learning communities can be sites where deep and powerful learning among teachers takes place”. In this paper we elaborate empirically on the possibilities for powerful learning.

Research design and methodology

The research approach was qualitative in that we attempted to look for patterns in the data collected from recordings of the conversations of teachers in one professional learning community. Five teachers from three schools in one DIPIP professional learning community participated in the study. All teachers held teaching qualifications (three had a bachelor’s degree as well as a professional teaching diploma, and two had teaching diplomas or certificates), had between seven and thirty years teaching experience and were all teaching mathematics during 2013, the year under study. Three of the five teachers were teaching in secondary schools, while the other two were teaching in a junior secondary school (Grade 7-9). The three schools in which the teachers taught were in close proximity to each other. Two of the teachers alternated in taking the role of facilitator for the meetings.

We analysed teacher conversations during 17 professional learning community meetings. The meetings were classified according to the primary activity that took place during the meeting. The breakdown of the meeting types was as follows: two error analysis meetings, two learner interview meetings, five lesson planning meetings and eight lesson reflection meetings. During error analysis meetings, the teachers discussed learners’ answers to selected items from the 2012 Grade 9 Annual National Assessment5, focusing on common errors and learner thinking and reasoning behind the errors. During learner interview meetings the teachers selected and discussed errors that they planned to probe in one-on-one interviews with learners. Lesson planning meetings consisted of the teachers working collaboratively to plan and prepare a set of lessons on a selected topic. During lesson reflection meetings teachers reflected on lessons they had taught and which had been video recorded. In total, 14 hours and 46 minutes of conversation time was analysed.

Informed by the literature, and based on the DIPIP project programme structure, we developed the analytic framework for use in our study. The two main categories in our analytic framework, which is represented visually in Figure 1 below, were Activity Type and Knowledge. The four Activity Types that we chose to analyse for this community were error analysis, learner interviews, lesson preparation and lesson reflection. The development of the Knowledge category was theoretically grounded in Park’s pentagon model in which PCK was defined as an “integral knowledge of five

5 The Annual National Assessment is a standardised national assessment that is administered annually to all Grade 3, 6 and 9 learners in mathematics and English.
components” (Park and Oliver 2008b). We only focused on two of the five components, namely knowledge of student understanding (KSU) and knowledge of instructional strategies and representations (KISR) because these two components fitted closely with the aims of the DIPIP project in terms of teacher knowledge development. The Knowledge category was divided into two sub-categories, namely CK and PCK, with the PCK category being further divided into two sub-categories - KSU and KISR. KSU was further dissected into two sub-categories: the identification of errors and learning behind errors; and the identification of what makes a topic or concept difficult. KISR was divided into five sub-categories: teaching strategies to accommodate errors and misconceptions; the rationale for strategies and representations in connection with learner understanding; the use of questions to probe learner thinking and understanding; teachers’ spontaneity to challenge misconceptions or resolve learning difficulties; and teachers’ use of new understandings of learner understanding to modify instructional strategies and representations. The CK category was not divided into sub-categories.

The relationship between Knowledge and Activity Type speaks to our first argument, and the relationship between different types of knowledge conversations speaks to our second argument.

![Diagram of Analytic framework](Image)

**Figure 1.** Analytic framework.

We developed a PCK rubric and a CK rubric to use as research instruments for coding the teacher knowledge components of the conversations. The PCK rubric was based on Park et al.’s (2010) rubric. As Park is silent on content knowledge, we developed a separate CK rubric. The data were divided into conversation units, which were demarcated on the basis of shifts in the conversation – that is,
when there was a change in topic and/or conversation type (CK or PCK). Using the CK and PCK rubrics, each conversation unit was coded according to Activity type, Knowledge and Depth. The coding was done using a software programme called Studiocode™, which allows conversation units in video footage or audio recordings of the professional learning community meetings to be plotted along a timeline. Each conversation unit was coded according to a code window, a Studiocode™ feature, which, in the case of our study, was based on the analytic framework and the PCK and CK rubrics. Once all meetings had been coded using Studiocode™, the Studiocode™ programme was used to generate the matrices and code reports, which formed the basis of the data analysis in our study.

Coding of the conversation units was done according to a coding manual, which was developed for use in conjunction with the rubrics. CK conversations and PCK conversations were differentiated as follows: conversations which focussed on mathematical knowledge (subject knowledge) were coded as CK conversations, while conversations which focussed on ways of teaching mathematical content were coded as PCK conversations. PCK conversations, which dealt with knowledge of learner understanding, were coded as KSU conversations; and PCK conversations, which dealt with knowledge of instructional strategies and representations of the subject matter were coded as KISR conversations. Most KSU conversations in which errors and reasoning behind errors were identified took place in error analysis activities, while most KSU conversations which focussed on what makes topic or concept difficult took place in lesson planning activities. The descriptors of the five subcategories of KSIR were: teaching strategies to accommodate errors and misconceptions; rationale for teaching strategies and representations in connection with learner understanding; questioning to probe learner understanding; spontaneity to challenge misconceptions or resolve learning difficulties discovered; and the use of new understanding of learner understanding to modify instructional strategies and representations.

The first author did all the coding. Strategies used to strengthen the reliability and the rigour of our study included doing both intra- and inter-rater reliability checks on the coding of the data. In the intra-reliability checks, the first author checked the consistency of the coding over time by re-coding the same three conversations two weeks after the initial coding and then comparing the results. In the inter-rater reliability check, the supervisor and one doctoral student each coded one PLC meeting and their coding was checked against the coding done by the first author. Both the intra- and inter-rater reliability was found to be above the acceptable standard of 95%. The major cause of differences in inter-rater reliability emanated from ambiguities in the rubric used to do the coding. The rubrics were further strengthened on the basis of the results of the coding reliability checks.

**Results: CK and PCK Conversations**

Table 1 shows that teachers spent 34% of the total teacher knowledge conversation time in CK conversations and 66% of the total teacher knowledge conversation time in PCK conversations.

<table>
<thead>
<tr>
<th>Type of conversation</th>
<th>Time*</th>
<th>Percentage of total teacher knowledge conversation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>CK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCK</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

6 The CK and PCK rubrics developed for use in our study included a four point depth scale which allowed for conversations to be classified and coded as limited, basic, developing or exemplary. The depth of conversations is not discussed further in this paper.
This finding is important because it suggests that, even in an approach that focuses explicitly on PCK conversations, teachers spent substantial time in CK conversations. While this finding differs from Ceresto (in preparation), who found that CK conversations occupied very little of the total conversation time, additional research from the DIPIP project (Chimhande & Brodie, 2016) supports this finding in another DIPIP community.

Table 2 shows that lesson reflection and lesson planning were the two activities that accounted for the majority of the conversation time, accounting for 43% and 41% of the total conversation time respectively.

Table 2. Percentage of conversation time by activity type.

<table>
<thead>
<tr>
<th>Activity type</th>
<th>Conversation time</th>
<th>Percentage of total conversation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error analysis</td>
<td>01:51</td>
<td>13</td>
</tr>
<tr>
<td>Learner interviews</td>
<td>00:40</td>
<td>3</td>
</tr>
<tr>
<td>Lesson planning</td>
<td>05:45</td>
<td>41</td>
</tr>
<tr>
<td>Lesson reflection</td>
<td>06:26</td>
<td>43</td>
</tr>
<tr>
<td>Total</td>
<td>14:46</td>
<td>101</td>
</tr>
</tbody>
</table>

The high percentage of conversation time devoted to lesson reflection and lesson planning activities reflects the planned focus of the DIPIP project - there were more sessions devoted to these activities. Looking at the breakdown of CK and PCK time by activity type (Table 3), we show that the amount of time the PLC spent talking about CK and PCK is closely related to the activity type. Table 3 shows that all activities, and lesson planning activities in particular, provides teachers with opportunities for the development of CK; and that most activities, and lesson reflection activities in particular, provides teachers with opportunities for the development of PCK.

Table 3. CK and PCK conversation time by activity type.

<table>
<thead>
<tr>
<th>Activity type</th>
<th>Percentage of CK conversation time</th>
<th>Percentage of PCK conversation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error analysis</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>Learner interviews</td>
<td>9</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Lesson planning</td>
<td>58</td>
<td>32</td>
</tr>
<tr>
<td>Lesson reflection</td>
<td>22</td>
<td>53</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

A study of Tables 2 and 3 in conjunction with each other reveals that lesson planning activities accounted for 32% of the PCK conversation time (Table 3) and 41% of the total conversation time (Table 2). It should be noted from Table 3 that a high percentage of the total CK conversation time (58%) time took place during lesson planning activities. Lesson reflection activities accounted for [7 This number is lower than the total coded time of 14:46 because there was some off topic conversation time embedded in the total conversation time.]

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7 This number is lower than the total coded time of 14:46 because there was some off topic conversation time embedded in the total conversation time.
22% of the CK conversation time, 53% of the PCK conversation time (Table 3) and 43% of the total conversation time (Table 2). During error analysis activities, the percentages of CK conversation time (11%) and PCK conversation time (14%) were similar to the percentage of total conversation time (13%). During learner interviews, the percentage of CK conversation time (9%) was higher than the percentage of total conversation time (3%), while the percentage of PCK conversation was negligible (<1%).

Lesson planning activities elicited the most CK conversation, with 58% of the total CK conversation time occurring during these sessions, in spite of the fact that lesson planning activities accounted for 41% of the professional learning community meeting time under study. The main reason for such a high amount of CK conversation time occurring during lesson planning meetings is that during these meetings teachers attempted the examples themselves and, when they encountered difficulties, they spoke about the content with their colleagues and the facilitator. The second highest amount of CK conversation time - 22% of total CK conversation time - occurred during lesson reflection activities. A possible reason for this is that during lesson reflection meetings teachers’ analyses of learner errors in class provided the stimulus for CK conversations.

There was more PCK conversation during lesson reflection activities than in any other activity type, with 53% of the total PCK conversation time occurring during lesson reflection activities (Table 3), even though lesson reflection activities accounted for 43% of the conversation time (Table 2). A possible explanation for the high level of PCK conversation during lesson reflection activities is that during lesson reflection meetings teachers identified “good” and “not so good” episodes in terms of the way in which they dealt with learner errors during the lesson. As a professional learning community, the teachers viewed video clips of these episodes and discussed what makes them good or not so good. The bulk of the teacher discussions during lesson reflection meetings were PCK conversations because the teachers talked about teaching and its relationship to learning and mathematical thinking.

An in-depth analysis of the amount of time spent on the different types of PCK conversation revealed that less PCK conversation time was spent on KSU than KSIR (see Table 4). 42% of the PCK time and 27% of the total conversation time was spent on KSU conversation; and 58% of the PCK conversation time and 38% of the total conversation time was spent on KISR conversation.

| Table 4. KSU and KISR in professional learning community conversations. |
|-----------------|-----------------|
| Percentage of PCK time | Percentage of total conversation time |
| KSU             | 42              | 27               |
| KISR            | 58              | 38               |
| Total PCK time  | 100             | 66               |

This was an unexpected finding, given the fact that DIPIP prioritises understanding learner thinking (KSU) ahead of practice (KISR). The fact that there was more KISR conversation time than KSU conversation time can be explained, at least in part, by the fact that most conversations around errors (the kernel of KSU conversations) quickly led to KISR conversations which centred on instructional strategies for dealing with the errors. In other words, KSU conversations usually triggered KISR conversations. This finding can inform future iterations of the DIPIP project where facilitators’ attention can be drawn to guard against the tendency to move too quickly into discussing practice.

Within the category of KSU conversation, more time was spent identifying errors and learners’ reasoning behind the errors than on discussing what makes a topic or concept difficult. Table 5 below...
shows that the majority of KSU conversation time (88%) was spent identifying errors and reasoning behind errors.

<table>
<thead>
<tr>
<th>Activity type</th>
<th>Percentage of KSU time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identifies errors and reasoning behind errors</td>
<td>88</td>
</tr>
<tr>
<td>What makes topic/concept difficult?</td>
<td>12</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

A lot of time was spent identifying errors and working through what the error was. This can be attributed to the DIPIP focus on learner errors. Table 6 below shows that the majority of KISR conversation time (71%) was spent discussing teaching strategies to accommodate errors and misconceptions.

<table>
<thead>
<tr>
<th>Activity type</th>
<th>Percentage of KISR time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaching strategies to accommodate errors and misconceptions</td>
<td>71</td>
</tr>
<tr>
<td>Rationale for teaching strategies and representations in connection with learner understanding</td>
<td>17</td>
</tr>
<tr>
<td>Questioning to probe learner understanding</td>
<td>3</td>
</tr>
<tr>
<td>Spontaneity to challenge misconceptions or resolve learning difficulties discovered</td>
<td>1</td>
</tr>
<tr>
<td>Use of new understanding of learner understanding to modify instructional strategies and representations</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>101</strong></td>
</tr>
</tbody>
</table>

The results in Tables 5 and 6 are best explained by viewing the results from the two tables together. As is shown in Table 5, the bulk of the KSU time (88%) was spent identifying errors and reasoning behind errors. It is thus reasonable to find that most of the KISR time was spent discussing teaching strategies to accommodate the identified errors and misconceptions as teachers discussed ways of implementing their learning and findings. The professional learning community spent a relatively low percentage (17%) of KISR conversation time discussing rationales for teaching strategies and representations in connection with learner understanding, and a high percentage (71%) of KISR time discussing teaching strategies to accommodate errors and misconceptions (Table 6). Once again, this can be attributed to the DIPIP focus on these aspects of practice and the fact that facilitators are trained to support teachers to think about how they might deal with learner errors. An implication of this finding is whether the DIPIP project might want to shift its focus slightly to include the rationales and representation for strategies in both Lesson Planning and Lesson Reflection sessions.
We have shown that the analysis of learner errors in professional learning communities does provide opportunities for the development of teacher knowledge in the form of both CK and PCK conversations. In addition, we have shown that, by influencing the amount of CK or PCK conversation, the activity type influences the opportunity to develop CK and PCK.

Our second argument speaks to the relationship between the development of teacher knowledge in the form of CK and PCK. Based on the work of Brodie (2013) and Brodie and Sanni (2014), the DIPIP project approach to the development of teacher knowledge was to develop CK via PCK. We show here that PCK conversations did in fact lead to CK conversations.

Table 7 below shows counts of teacher conversation units, activity type, conversation unit switches, CK conversations triggering PCK conversations, and PCK conversations triggering CK conversations. The count of conversation unit switches was restricted to switches between CK and PCK in both directions. It should be noted that the count of conversation units does not necessarily equate to the sum of the CK triggering PCK conversations and PCK conversations triggering CK conversations because not all teacher knowledge conversations were triggered by CK or PCK. In addition, CK and PCK conversations often switch back and forth during the course of one meeting. Of the 58 CK conversations across the 17 meetings, 30 (52%) were triggered by PCK conversations. Of the 161 PCK conversations, 23 (14%) were triggered by CK conversations.

The relatively low CK-PCK trigger rate could be ascribed, at least in part, to the fact that there were many more PCK conversations (by count) than CK conversations and that the focus of the DIPIP activities was to start with PCK. The larger number of PCK-CK switches shows that opportunities to develop CK were created via PCK.

Table 7. Conversation unit switches in all 17 PLC meetings.

<table>
<thead>
<tr>
<th>Activity type</th>
<th>Teacher knowledge conversation units</th>
<th>CK conversation units</th>
<th>PCK conversation units</th>
<th>Conversation unit switches</th>
<th>CK triggering PCK</th>
<th>PCK triggering CK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error analysis</td>
<td>35</td>
<td>8</td>
<td>27</td>
<td>12</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Learner interviews</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Lesson reflection</td>
<td>94</td>
<td>14</td>
<td>80</td>
<td>13</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Lesson planning</td>
<td>84</td>
<td>32</td>
<td>52</td>
<td>39</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>219</strong></td>
<td><strong>58</strong></td>
<td><strong>161</strong></td>
<td><strong>65</strong></td>
<td><strong>23</strong></td>
<td><strong>30</strong></td>
</tr>
</tbody>
</table>

These results support the argument that teacher conversations provide opportunities for the development of content knowledge and pedagogical content knowledge and that content knowledge conversations are sometimes triggered by pedagogical content knowledge conversations and vice versa. Thus, starting the conversations with PCK conversations gives teachers an opportunity to gain confidence and this, in conjunction with limitations in teachers’ own CK that may be revealed in the PCK conversations, provides a platform for the initiation of CK conversations.

We contend that, while we cannot draw strong conclusions, our results suggest that designing activities in such a way as to stimulate PCK conversations is an effective way of leading teachers to CK conversations, and the strengthening of both their PCK and CK. We add that the development of
CK and PCK is often iterative, as conversations, and thus the potential for the development of CK and PCK, switch between PCK and CK.

**Conclusion**

We found that PLCs focusing on error analysis provide fertile grounds for the development of teacher knowledge in the form of both CK and PCK. We also found that, since PCK conversations trigger CK conversations, and vice versa, the development of PCK and CK is iterative as conversation types switch back and forth during the course of the teacher conversations. Furthermore, we found that activity type has some influence on the type of teacher knowledge conversation, with lesson planning and lesson reflection activities creating the most opportunities for the development of teachers’ CK. In addition, we found that more PCK conversation time was spent on KISR than on KSU. Our findings in terms of the sub-categories of KISR and KSU are that the majority of KISR conversation time was spent discussing teaching strategies to accommodate errors and misconceptions and that significantly more KSU conversation time was spent identifying errors and discussing the reasoning behind the errors than on discussing what makes a concept difficult.

The designers of teacher professional development programmes can do a lot of planning and monitoring work in order to create situations which are conducive to the development of teacher knowledge, but in order to do this, programme developers need to know more about how CK and PCK are developed among teachers as they engage in particular learning activities. As both CK and PCK are regarded as important components of a teacher’s knowledge repertoire, any programme to develop teacher knowledge should take the relationships in the development of these two types of teacher knowledge into account.

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Teachers’ use of productive questions in promoting mathematics classroom discourse

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The focus of this study is to investigate how teachers use productive questions to promote discourse in the mathematics classroom. Teachers are faced with a myriad of challenges and make use of productive questions that are geared towards stimulating and promoting mathematics classroom discourses and seeking solutions to problems. Teachers also require a deep understanding of both knowledge of mathematics and how students learn mathematics. The video-recorded footage of one lesson of a high school mathematics teacher was the basis for this study. This video-recorded lesson demonstrating classroom discourse involving student-teacher interactions through questions and answers was transcribed verbatim and analysed interpretively. An analysis of the classroom discourse in the recorded video serves not only as an analytic tool to study classroom interactions, but also as a resource for discussions and reflections on the teacher’s continuous professional development (CPD) activities. The findings of the study show that the teacher made use of a range of productive questions to direct students towards solutions; he also involved students in completing procedural processes, provided opportunities for students to demonstrate solutions to their peers, made visible their thinking processes, and encouraged them to assist one another, through peer-to-peer interaction, to find solutions.

Introduction

Asking productive mathematics questions is one of the cornerstones of classroom discourse. Productive mathematics questions in a classroom setting have an interrogative function. Such classroom questioning provides instruction cues on the content to be learned, and directs how learning should occur (Cotton, 2001). Research over the past two decades has focused on teacher questioning in terms of three aspects, viz. Initiation, Response, Evaluation (IRE); research has also highlighted the importance of waiting time during questioning, as a way of enabling students to make meaning of the events in an instructional activity, to reflect systematically on the learning activities and to recognise choices and alternatives in such learning activities (Chin, 2006; 2007; Mason, 2002; Sherin, Jacobs, & Philip, 2011). However, more recent research on teachers asking productive mathematics questions has focussed on posing questions that encourage students’ construction of mathematics knowledge. This is a departure from the traditional type of questioning used in lessons, which followed the IRE model, to a more constructivist-based model of questioning. In the constructivist-based model of questioning, teachers orchestrate mathematics classroom discourse by asking questions that are open-ended, and that encourage students to “elaborate on their previous answers and ideas, and to help students construct conceptual knowledge” (Chin, 2006, p. 1319), in addition to making the students’ misconceptions and thinking processes visible to the teachers. We posit that, through the use of open-ended questions, teachers can enhance classroom mathematics discourse. Open-ended questions allow teachers to engage students in activities that require higher-order
thinking, and to reflect on the students’ developments of conceptual knowledge; it also employs other learning strategies such as, for example, problem solving (Baird & Northfield, 1995; Martino & Maher, 1999).

Educational reformists view the process of knowing about mathematics as a social endeavour that takes place within a ‘classroom community’ through iterative interactions between teachers and students, and among students themselves (Ball, 1993; Cobb, Wood & Yackel, 1993). These classroom interactions are complex to manage on the part of teachers because they involve the development of students’ mathematics knowledge through “conjecturing, scrutinising, and defending one’s ideas, as well as learning about them” (Nathan & Knuth, 2003, p. 176). The discourse-based mathematics classroom that is envisaged here poses certain challenges to teachers, since it does not resemble, in many ways, their current practices or the way in which they were taught as students (Nathan & Knuth, 2003; Sowder & Schappelle, 1995).

**Productive questioning – a sociolinguistic perspective**

In this study, we use the sociolinguistic perspective as a lens to study the productive questioning that took place during a video-recorded mathematics lesson that was the focus of this study. One of the central tenets of the sociolinguistic approach is that classroom discourse (or dialogical questioning and answering) is embedded within a specific context, and that the same context can be re-constructed and modified by teachers and students through classroom dialogical discourse (Cazden, 1986; Green, 1983). From a sociolinguistic perspective, and through a dialogical discourse, “teacher questions can be viewed as mutually generated by teachers and students (rather than exclusively teacher generated) and may reinforce authority relationships in the classroom” (Carlsen, 1991, p. 159). In effective mathematics classroom discourse, teachers initiate and orchestrate conceptual open-ended questions with the aim to elicit, engage and facilitate productive thinking from students, while at the same time inviting and encouraging students’ responses and questions that seek to clarify and justify, and stimulate their mathematical thinking (Chin, 2007; National Council of Teachers of Mathematics [NCTM], 1991; White, 2003). The use of dialogical discourse (or interaction) by mathematics teachers through the use of open-ended questioning can induce conceptual change among students during teaching, as it targets and probes students’ alternative conceptions (Mortimer & Scott, 2003; Roth, 1996; Yip, 2004). This narrows students’ “zones of proximal development”, to use the expression coined by Vygotsky (1978). In addition to ‘eliciting student thinking during interactions’, ‘anticipating students’ responses and ‘eliciting further thinking’, as summed up by Grossman et al. (2009, p. 280), teachers also have the responsibility of creating a teaching and learning environment that encourages students to share their answers, in whatever form they are in, irrespective of whether they are correct or not, in accordance with the answers of the rest of the class, including the teacher (Ghousseini, 2008; Leinhardt & Steele, 2005). Ideally, such teaching and learning environments should develop the following: a deep understanding of the instructional objectives, critical mathematical thinking, decision-making among peers, and learning through higher-order conceptual reasoning (Gutstein, Lipman, Hernandez & de los Reyes, 1997; White, 2000).

Notwithstanding the dominant and widely accepted forms of learning, as discussed herein, under the guise of constructivism, ongoing research into actual teacher practices indicates, in contrast to the
teachers’ beliefs, that the traditional, transmission mode of teaching is still very much present in the mathematics classroom today, notably at secondary level. In fact, the distinction between theoretical beliefs and practices may be a significant pointer to understanding how and why teachers teach the way they do in modern classrooms (Ravitz, Becker & Wong, 2000). In the localised context of the study, as we will show, the use of so-called transmission forms of teaching remains dominant; the nuance lies in the extent to which teachers reinterpret that space, given the enormous constraints that they face to, as it were, “draw out” constructivist outcomes in their interactions in the classroom. The use of productive questioning techniques is often a useful vehicle to give effect to this. Carlsen (1991) proposes three categories as a way of analysing classroom questioning: “[the] context of [the] questions, the content of [the] questions, and [the] responses and reactions that students and teachers have to the questions” (p. 159). From a sociolinguistic point of view, it is helpful to look at these three categories in turn.

Firstly, the context of the questions refers to the situation in which the teachers find themselves at the beginning of the lesson, viz., the environment sets the tone for all the communications that follow in the classroom. Context also refers to the environment during the mathematics lesson, which is being guided and directed by both the teacher and the students. In other words, when teachers start to ask questions, it frames the context of the lesson. When the students are attempting to answer the questions, whether posed by the teacher or by other students as follow-up contributions, they are further defining the context. That is, once interaction starts in the classroom, the context continues to change in response to the questions and the shifting dynamics in the classroom (Cazden, 1986; Chin, 2007). Secondly, the content of the questions refers to the questions, which shape the scope of the discourse topic or subject matter, the essence and sequencing of these questions, and how the students and the teacher influence or change the mathematics activities during the lesson in response to such questioning.

Thirdly, the responses and reactions refer to how students react to the questions posed by the teachers and by their peers. Such responses and reactions need to be mediated properly during lessons, as they could reflect and entrench the social status and the power dynamics between teachers and students, and a failure to mediate them effectively can have counterintuitive effects on classroom discourse.

This study

In this study, we argue that classroom discourse is important to the teaching and learning of mathematics. Skilful questioning lies at the core of developing classroom discourses, it facilitates growth in the students’ mathematical cognition, and it facilitates the development of mathematics ideas and knowledge that the mathematics teacher would not have been able to access during lessons. It takes time for teachers to develop the use of productive questioning but, once it has been mastered, it becomes a very powerful tool that can be used by both teachers and students during discursive mathematics activities (Maher, Martino & Alice, 1993). Research has also shown that asking productive questions by teachers during learning mathematics advances students’ mathematical thinking; the use of open-ended questions, in particular, contributes to the acquisition of more sophisticated mathematical conceptions and knowledge (Perry, Vanderstoep & Yu, 1993; Sullivan & Clarke, 1992). Other researchers have cited the lack of discussing connections among mathematical
ideas by teachers. This could be addressed by means of continuous professional development (CPD) programmes for teachers, aimed at improving mathematics classroom discourses through timely dialogic conversation between teachers and students during instructions (Boaler & Brodie, 2004; Franke, Webb, Chan, Ing, Freud & Battey, 2009; Hiebert, 2003).

More research is required to understand how teachers’ questioning during classroom discourse can be used to make explicit and visible students’ mathematical thinking, and to inform CPD programmes for teachers. Therefore, this study seeks to provide answers to the following research question: What types of productive questions do teachers ask and/or use to promote mathematics classroom discourse during teaching? Of interest to the researchers, and to the mathematics education fraternity, is how the findings of this study can be used to inform the CPD activities of mathematics teachers, particularly those CPDs that aim to improve mathematics classroom discourses by means of productive questioning during lessons.

Methodology

This study is part of a bigger project called Local Evidence Driven Improvement of Mathematics Teaching and Learning Initiative (LEDIMTALI), whose aim is to improve the teaching and learning of mathematics in under-resourced schools in the Cape Metropole through particular CPD activities of mathematics teachers. Some of the CPD activities involve teachers watching video-recorded mathematics lessons of their peers, with the aim of giving constructive feedback on how the teaching and classroom discourse could be improved. In this study, a video-recorded lesson from one of the teachers participating in the LEDIMTALI project was analysed to find out how the teacher was ‘asking productive questions’ during his interactions with students in a mathematics lesson. For the purposes of this study, we have given this teacher a pseudonym, Abdul. Abdul’s lesson was a revision lesson on the content area of measurements, with the content being: Calculation of perimeters of squares, rectangles, triangles, and compound shapes (Curriculum and Assessment Policy Statement (CAPS), 2011). The choice of the lesson taught and its scheduling during the course of the day were left to the teacher’s discretion. Discursive teacher-student and student-student talk from the video-recorded lessons was transcribed verbatim, and the transcriptions were analysed interpretively. In order to extract meaning from the transcription data, they were read several times. We analysed how the teacher’s questioning directed the discursive activities during the mathematics lesson, and particularly how the teacher’s questions were used to “engage students in the vicinity of instructional objectives, [and to] help move instructional objectives to the forefront of students’ attention” (Erdogan & Campbell, 2008, p. 1893).

Table 1: Framework for analysing productive questioning during a mathematics lesson

<table>
<thead>
<tr>
<th>Question type</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed questions</td>
<td>Requiring either ‘yes’ or ‘no’ answers</td>
</tr>
<tr>
<td>Verification</td>
<td>Requiring students to choose between two alternatives, e.g. true/false</td>
</tr>
<tr>
<td>Disjunctive</td>
<td>Requiring students to complete statements started by the teacher</td>
</tr>
<tr>
<td>Contributive</td>
<td>Requiring students to identify a number of attributes of an object or process</td>
</tr>
<tr>
<td>completion</td>
<td></td>
</tr>
<tr>
<td>Quantification</td>
<td></td>
</tr>
</tbody>
</table>
We were able to observe three categories of patterns that the teachers consistently used when questioning their students: closed questions, open questions, and task-oriented questions. Firstly, closed questions could be further grouped into themes that included: verification, disjunctive, contributive completion, and quantification. Secondly, open-ended questions could be attributed to the following themes: definitions, explorative, prior knowledge, pumping, and constructive challenge. Thirdly, task-oriented questions had only one theme, viz., directive.

Table 1 summarises and describes these question types. They are based on the data obtained from the analysis of the video-recorded lesson, on the findings of other research studies that have looked at the questions used by teachers in the classroom (Carlsen, 1991; Chin, 2007; Erdogan & Campbell, 2008; Franke et al., 2009; White, 2003), and on own experiences as researchers in teacher and mathematics education.

Findings

Using the framework introduced in the previous section, the data from the transcriptions were analysed. This data analysis was furthermore guided by Carlsen’s (1991) three categories of analysing classroom questioning, which are: the context of the questions, the content of the questions, and the responses and reactions to the questions. In other words, we regarded all aspects of questioning as a true reflection of the situation within the existing learning environment, the development of the mathematical content knowledge of the students, and the dynamics of managing the mathematics classroom discourse on the part of the teacher. Table 2 shows the distribution of the proportions of question by types; this table only shows examples of question types and the frequencies of the questions that were asked within these respective categories. For example, under the verification category, questions that could be answered with either ‘yes’ or ‘no’ were asked, such as “Do you find the square root of both sides”? In Abdul’s lesson, there were eight such questions, which constituted 12% of all the questions asked during the entire lesson. From Table 2, one can conclude that the teacher used contributive completion question types more than any other types.

Table 2: Distributions of proportion of question types
<table>
<thead>
<tr>
<th>Question type</th>
<th>Description</th>
<th>Example of question</th>
<th>Number (%) of each questions type</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Closed questions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Verification</td>
<td>Requiring either ‘yes’ or ‘no’ answers</td>
<td>Do you find the square root of both sides?</td>
<td>8 (12%)</td>
</tr>
<tr>
<td>Disjunctive</td>
<td>Requiring students to choose between two alternatives, e.g. true/false</td>
<td>What did I say, metres or centimetres?</td>
<td>3 (4%)</td>
</tr>
<tr>
<td>Contributive completion</td>
<td>Requiring students to complete statements started by the teacher</td>
<td>The answer will then be…?</td>
<td>14 (21%)</td>
</tr>
<tr>
<td>Quantification</td>
<td>Requiring students to identify a number of attributes of an object or process</td>
<td>Why would it give you 4 multiplied by the side?</td>
<td>4 (6%)</td>
</tr>
<tr>
<td><strong>Open-ended questions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Definitions</td>
<td>Stating the meaning of conceptions through writing or verbally</td>
<td>What is the formula for the perimeter of a square?</td>
<td>3 (4%)</td>
</tr>
<tr>
<td>Explorative</td>
<td>Making students’ thinking and analytical processes visible to the teacher and their peers</td>
<td>Is that the perimeter?</td>
<td>5 (7%)</td>
</tr>
<tr>
<td>Prior knowledge</td>
<td>Requiring students to reflect on or use concepts that have already been covered in previous topics or grades</td>
<td>What is the perimeter of a square?</td>
<td>10 (15%)</td>
</tr>
<tr>
<td>Pumping</td>
<td>Prompting students to elaborate further on their thoughts, procedures and/or ideas</td>
<td>So what would be our goal?</td>
<td>12 (18%)</td>
</tr>
<tr>
<td>Constructive challenge</td>
<td>Redirecting a student, after he/she has failed to answer the teacher’s first question</td>
<td>Divide? Wait-wait, so, why are we dividing, Bradley?</td>
<td>4 (6%)</td>
</tr>
<tr>
<td><strong>Task oriented questions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Request/directive</td>
<td>Asking questions for students to share and/or demonstrate their solutions on the white board</td>
<td>Do you want to come and do it on the board for us?</td>
<td>5 (7%)</td>
</tr>
</tbody>
</table>

In the analysis of the following excerpts, […] means that there was a wait time after asking a question, “…” means that an irrelevant part of the question or answer was omitted, words in bracket indicate that the accuracy of the transcription is uncertain, T – refers to the teacher, S – refers to a student, SF – is a female student, SM – is a male student. For the purposes of an in-depth analysis of productive questioning, we focussed on four main question types, namely: directive, constructive challenge, pumping, and contributive completion. The reason for not focussing on all the questioning types is that we discovered during the analysis of the latter four, the other question types were also implied.

*Excerpt 1: Question type – Directive*
The excerpt that follows relates to how Abdul and his class interacted in determining the perimeter of the shape whose diagram is shown. Students had to figure out the lengths of the missing sides, before calculating the total perimeter of the shape. Abdul’s questions are guided by what he has noticed from the ways in which students are solving this question, as he was interacting with them. The phrase “mathematics teacher noticing” refers to how teachers understand the details of what is going on in classroom situations (Choy, 2014; Mason, 2002). Noticing on the part of the teacher is about “attending to particular events and making sense of events in an instructional setting” (Sherin et al., 2011, p. 5). In this case, after Abdul noticed that some students found the question challenging, he decided to respond by asking Crystal to solve the questions on the board (line 1).

1. T: Crystal, are you done with this one? Do you want to come and do it on the board for us?
2. Crystal: Yes, sir.
3. T: Please check if what she is doing is correct? […] Is she correct so far?
4. SF: Yes, sir.
5. T: Please explain, what was your first step that you did there and why?
6. Crystal: Firstly I had to figure out what the length of KL is by saying: KL = PO – MN.
7. T: Please carry on.
8. Crystal: And then I got KL=15 kilometres. … And then to get the distance LM I had to say, LM=KP-NO, which is 30 minus 12, which is equal to 18. So I have KL=15, and LM=18. Now that I have all the lengths of the sides, I can find the perimeter, which is the distance round the shape, and then we add the sides and we get 132.
9. T: Agreed?
10. SM: Yes.
11. T: What I have seen going round is that, when calculating the perimeter, some of you are not including the sides whose lengths are not given; just remember they are part of the perimeter.

While observing Crystal writing on the board, he also instructed the other students to check her work (line 3). Whilst Crystal was busy solving the problem, the teacher used the opportunity to ask her explorative questions (line 5). This allowed her to make clear her own thinking processes, both to the teacher and to the other students (line 6). In addition, in this excerpt the teacher was also using verification questions, such as “Agreed?” (line 9), and “Is that correct so far?” (line 3).

Thus we notice that, within one scenario (Crystal writing on the board and explaining to the teacher and the class), the teacher continued to ask productive questions, which were geared at keeping the class focussed on the main activity (Crystal writing a solution on the blackboard), while involving them in the process of following the procedure on the blackboard, and indicating their agreement and participation. To aid him with his task, he made use of a variety of question types to help him coordinate and manage the process, all the time keeping as many of the students involved as possible.
His actions served multiple purposes. For the student, it was an opportunity to showcase her solution, and it demonstrated her confidence in her work. For the teacher, the procedural solution written on the board by the student functioned as another example of that kind of procedure: the rest of the class could thus compare their own solutions to what was being written down, or they simply had another opportunity to view the construction of that particular procedure. For the teacher, moreover, there was an opportunity to demonstrate to the class how the procedure was meant to work. Thus there are many gains in using the directive form. The teacher involved the class by asking them to join him in checking the solution (line 3). Moreover, by asking the student to explain the steps in her procedure (line 5), the teacher created the space for a concept to be clarified, either by the student or by anyone else in the class, should she not give the right response. Again, here is a demonstration that the transmission approach is not that simple.

Excerpt 2: Question type - constructive challenge

The following excerpt relates to the problem: Find the length of a square field whose perimeter is 64 metres. In this excerpt, we can observe that the teacher is confronted by a situation, where some students are unable to solve the equation: \(64 = 4 \times \text{side}\) (line 4). One of the students said, in order to get “side”, she would subtract 4 from the right side – which was incorrect. The teacher then asked, “Are we dividing or subtracting?” (line 9). This prompted the students to reflect on and reconsider their answers, until they eventually realised that they were actually supposed to divide by 4, instead of subtracting (lines 10-12).

1. T: So the perimeter of a square field is 64 metres. … What is the length of one side of the field? Who has got something to show me?
2. SF: Me, sir.
3. T: So first thing I would like us to do is to write down the formula for the perimeter of a square. … So \(P\) equals to what?
4. SM: \(64 = 4 \times \text{side}\).
5. T: What do we call that? [Teacher pointing at the expression \(64=4x\text{side}\)].
6. SM: Equation.
7. T: That is correct. … How do we find the length of the side from the equation? So I carry over the 4 and it becomes … [teacher pauses and waits for the students to complete the statement].
8. SF: A negative 4, sir.
9. T: Wait-wait, are we dividing or subtracting?
10. SM: We are dividing both sides by 4.
11. T: Why can’t we minus 4 from both sides of the equation. Because on the right hand side we are [teacher pauses].
12. SF: Multiplying.
13. T: So it is going to be 64 divided by 4. Which gives us [teacher pauses] … Do not forget units.

This is an example of constructive challenge, where the teacher did not give direct feedback in a situation where students were providing the wrong answers (line 9). Instead, the teacher posed further questions to re-direct the students’ thinking processes towards the correct answers (line 9, 11). In addition, in this excerpt we observe that the teacher also used questions in the form of contributive
completion, such as: “Which gives us…?” (Line 13). Disjunctive question types were also asked by the teacher, resulting in the students responding: “A negative 4, sir” (line 8).

**Excerpt 3: Question type - pumping**

In the following excerpt, we can see how the teacher made use of peer interaction to revise the properties of a square, while leading them towards a solution to the procedural problem that he posed. In line 1, he posed the problem of finding the perimeter of a square whose one side is known. While he was dealing with the whole class, one student was already offering up a solution (line 2). The teacher, having slowed down the student (SF) (to allow the rest of the class to catch up), then allowed SF to continue (line 3). When the crucial property of the square was left out of the student’s answer, however, the teacher, instead of correcting SF, drew on the class’s knowledge of the properties of rectangles to point to the omission (line 8). The class, being within the same social context as the teacher, recognised the need to respond, and filled in the gap left by the teacher. This is part of the subtle nature of teaching: the social contract that exists between this teacher and this class is unique to them. The questioning technique used here allows the class to seek common ground and to find the correct answer – a form of constructive challenge.

1. T: So, offhand, if I tell you I’ve got a square that has a side of 20 meters, what is the perimeter of that square? How would you calculate?
2. SF: ... 4 x 10.
3. T: Let’s start ... 4 x 10?
4. SF: 4 x ...
5. T: And why would it give you 4 x (…)?
6. SF: Because there is four sides.
7. SM: Because there is four sides.
8. T: Okay, there are four sides to a square and four sides to a rectangle as well. Okay, (Dylan)?
9. SM: All four sides are equal.
10. T: All four sides are?
11. SM: Equal.
12. T: Equal.

**Conclusion**

This study on the use of productive questions to promote mathematics classroom discourse, as analysed through video footage, provides some evidence on how mathematics teachers can use questions to support students’ learning. It shows how the process of using productive questions enhances classroom discourse and aids in finding solutions to mathematics problems posed in class. Teacher questioning can potentially invite students to reflect on their mathematical thinking processes in addition to making both students and teachers aware of each other’s ideas (Martino & Maher, 1999).

We have shown that, in one episode, teachers may use a range of question types to steer the class in a certain direction and to open up the space in the classroom for participation through discourse and conceptual engagement of the students. The teacher may, for instance, make use of constructive
challenge type questions, explorative questions, and directive questions to keep building procedural and conceptual links.

The analyses of Abdul’s questioning techniques in this study can potentially be used as exemplars to provide some practical insights into how discursive mathematical activities can be implemented in the mathematics classroom. We are not at all suggesting that Abdul’s classroom context can be replicated in other classroom contexts. However, we are confident that the practice, as illustrated in the examples from Abdul’s lesson, can be a useful guide to teachers whose interests lie in promoting and improving mathematics classroom interactions, and that it can support students’ learning in mathematics. The framework developed and shown in Tables 1 & 2, moreover, provides specific guidelines for mathematics teachers to enable them to improve their repertoire in productive questioning skills.

Given that this study is located within a broader CPD project focusing on mathematics teachers (LEDIMTALI), one of the practical significances of this study is that it will contribute towards the body of knowledge that can be used to inform the activities of pre-service training and in-service training in the art of classroom questioning skills. In addition, developers of CPD programmes for mathematics teachers can use the analyses from Abdul’s classroom interactions to give feedback and to highlight to teachers the importance of questioning skills in fostering classroom discourses.

Research by Graesser and Person (1994) shows that good teacher questioning skills increase students’ active inquiry and classroom participation. That said, we posit that our knowledge and understanding of the mathematics classroom discourse and the effects of productive questioning is still very rudimentary. More research that extends beyond the exemplars illustrated in this study is required. In particular, research that interrogates the successful practices of ordinary teachers operating in classrooms with diverse students is required. Through this kind of research, a great deal can be learned about the relationship, if any, between the teacher’s questioning skills in mathematics classroom and the students’ achievements in mathematics. Since this study has been carried out within a larger project and within an education system that uses high-stakes examinations, further research can also focus on how the teachers’ questioning skills in mathematics classroom discourses can influence the students’ mathematics scores in such high-stakes examinations.

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How can high school teachers modify classroom instruction to meet the needs of mathematically gifted students in the regular classroom?

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Currently there appears to be a general consensus amongst scholars that the educational needs of gifted students are not being met in the regular classrooms. This is mainly because teachers were not trained in gifted education. The study followed a qualitative approach where four Grade 11 mathematics teachers (2 male, 2 female) were video recorded teaching in regular classrooms. In each of the four classrooms it was possible through the teacher’s nomination and book inspection to identify three top achievers who in Gagné’s definition would constitute the ‘garden variety’ of intellectually gifted students. The aim was to exploring the various ways in which gifted students distinguish themselves from their peers and the types and quality of connections that teachers created in support of such creativity. Results show that only one teacher out of the four was strong in terms of creating mathematical connections. This study has both theoretical and practical implications. Theoretically gifts and talents are not synonymous and gifts will not translate into talents if there are no formal programmes designed for such to happen. Practically regular classrooms seem not to present ideal environments for gifted students to develop to their full potential. This paper recommends that further studies be carried out to understand more about how gifted students are catered for in the regular classroom if inclusive education were to be truly inclusive and catering for the needs of all learners.

Background of the study

Driven by a desire to reverse the imbalances which were inherent in the educational systems of the past, post-democracy educational policies in developing countries placed more emphasis on inclusive educational provision for ‘all’ students. It was hoped that such an education system would respond to the needs of all including the disabled, those below average, the average, the above average as well as the most able students. This is evident in the United Nations Educational Scientific & Cultural Organization (UNESCO), 1994, Framework for Action on Special Needs Education (FASNE), which is the foundation of the whole idea on inclusive education. The framework states that a school should, …accommodate all children regardless of their physical, intellectual, social, linguistic or other conditions. This should include disabled and gifted children, street and working children, children from remote or nomadic populations, children from linguistic, ethnic, or cultural minorities and children from other disadvantaged or marginalized areas and groups (1994:6).

Despite the framework being clear on the inclusion of the gifted children, the form of inclusion that has pervaded the schooling system in many developing countries has been skewed towards those students who are disabled or those who have performed poorly in academic areas such as literacy and numeracy rather than those who show promise in these domains. Hence we see some kind of a paradox where on one hand in many developing countries claims have been made in clichéd form that ‘our’ mathematically gifted students are an invaluable resource; yet on the other hand the translation of that claim into practice has been sporadic and at times barely visible. This is incomprehensible given that mathematically gifted students are considered to be the hope for the future in the 21st century economy (Persson, 2010). In this modern economy the development and transformation of human resources in science, engineering and technology depend in a fundamental way on the gifted children’s mathematical understanding and their significant presence in each field (Department of Science & technology, 2008). A number of challenges both economic and social have
been attributed to the general neglect of gifted education post-democracy. Despite these challenges, it is timely to question this treatment of our gifted students and to give greater consideration to the ordeal faced by such students in the regular classrooms where they were placed following inclusive reforms to education. It is against this background that this study was embarked on.

Statement of the problem

In South Africa like many other developing countries, most of the gifted students are in the regular classrooms following post democratic reforms which were guided by the UNESCO framework for inclusive education. Much has been written about inclusionary practices for children with disabilities but a concern that has been totally ignored is whether or not teachers in the regular classroom would be able to expand or limit the mathematically gifted child’s creativity. This is mainly because gifted education was neither mentioned nor foregrounded within the guidelines for mainstream classroom activities despite many of these developing countries’ propagation of democratic and inclusive education (Kokot, 2011). This paper does not intend in any way to suggest the resurgence of separate schools for the gifted because that would not only be inconsistent with the noble intentions of the UNESCO framework for inclusiveness but it would also be counterproductive given that there is clear research evidence of the academic and social gains in carefully designed homogenous groupings of gifted students (Kearney, 1996; White, 1990; Robinson, 1990). Instead the paper suggests that in order for our education systems to be truly aligned with the original vision of the UNESCO framework for inclusiveness there is need to find solutions to the challenge of meeting the needs of all students (including gifted students) within heterogeneously grouped mathematics classrooms.

In South Africa findings from inclusive education studies by Lumadi (2013) and Oswald & de Villiers (2013) show that regular classroom teachers were not trained to deal with the needs of the gifted. According to Persson (2010) gifted children do not fare well in regular schools if they are unrecognised, ignored, and/or if teachers are unprepared for them. A significant advice from the Mathematics Enrichment Project (MEP) is that there should be adequate provision of professional development to enhance teachers’ methodological expertise in teaching promising children (Koshy, Ernest & Casey, 2009). Yet this issue has not been addressed sufficiently especially in South Africa where there is limited knowledge of who the gifted are and what their particular needs are. Teachers interviewed by Oswald & de Villiers, (2013) confirmed this pressing need for professional development as they declared themselves inadequately trained to address the needs of gifted learners, lamenting that nowhere was any information given on what they should do with the gifted child. Their major concern was that they had been trained to address the needs of the learner who struggled rather than the learner who was gifted.

Teachers play a central role in promoting ‘inclusive education’. Paradoxically, as Mittler (2000) notes, they represent the single greatest obstacle to inclusive education because of a number of factors including their levels of knowledge, perceptions and attitudes. Research shows overwhelmingly that good teaching is vital for better results hence according to Henning (2012) a country cannot claim social justice in education if teachers do not know how the children and youth that they teach learn these subjects. It is against this background that I explore possible effective pedagogies for gifted students that take into account how these students learn in regular classrooms. The specific research questions driving this paper are as follows:

1. What distinguishes gifted students from their non-gifted peers?
2. How can teachers align their instructional strategies with the needs of the mathematically gifted students?

Significance of the study

As an entry point into why it is important to cater for the needs of the gifted students, I start by clarifying how the terms ‘gifted’ and ‘talented’ are being conceptualised in this paper. For more than
three decades, Gagné (1985 -2015) researched on giftedness and argued that the neglect for gifted learners was often attributed to a failure to distinguish between ‘gifts’ and ‘talents’ – terms which are often used synonymously yet there was a clear and appropriate distinction to be gainfully made. His argument was that an interchangeable use of terms gifts and talents may suggest that talent or ability has appeared without systematic learning or teaching and that those who possess such gifts have somehow been endowed with a particular ability in a way that is beyond the control or scope of education (Gagné, 2013). This is contrary to clear indications that the gifted individuals usually spent years honing their skills. Gagné (2015) then proposed to make a distinction between “outstanding natural abilities” to which he assigns the term “gifts” and “specific expert skills” he terms “talents”. Gagné’s (2015:15) definition of giftedness and talents states that:

Giftedness designates the possession and use of untrained and spontaneously expressed outstanding natural abilities or aptitudes (called gifts), in at least one ability domain, to a degree that places an individual at least among the top 10% of age peers.

Talent designates the outstanding mastery of systematically developed competencies (knowledge and skills) in at least one field of human activity to a degree that places an individual at least among the top 10% of ‘learning peers’ (those having accumulated a similar amount of learning time from either current or past training).

In this way Gagné then differentiated between giftedness as raw capacity and talent as systematically developed ability. This distinction points to the first and most important justification for my study. Gifts are different from talents and will not develop into talent if there is no systematically developed programmes. Hence I see my study as contributing to this systematic development of talents. Gagné (2015) argues that it is a ‘myth’ that gifted students will develop to their full potential without intervention. In fact in an effort to formulate a coherent set of basic statements, or rationale, concerning the nature of human abilities, gifts and talents Gagné (2007) developed a list of what he referred to as the ‘ten commandments for academic talent development’. He further argues that if the Ten Commandments were followed the local gifted/talented policies and practices would be guided by a desire to respond to the students’ immediate educational needs; their well-being and personal development would be prioritised rather than a preoccupation for a long-term high return on that educational investment.

Another justification for my study can be seen in that it aims at supporting teachers of the gifted students. Gagné (2009) showed how teachers play a critical role in the academic talent development process. Over the 3 decades of his research he proposed and developed his Differentiated Model of Giftedness and Talent (DMGT) as a developmental theory, which represents the process of transforming natural abilities (aptitudes or gifts) into skills (talents). Through this developmental model, Gagné (2009) attempts to explain the factors (catalysts) that influence the transformation of a natural gift into a talent. Gagné (2007) then examined the relative strength of these causal links in order to pinpoint the weakest among them. His argument was that an awareness of the weakest link would put professionals in the field of gifted education in a better position to design effective interventions. Acknowledging the complex choreography between the causal components, Gagné (2015) came to the conclusion that the educational milieu subcomponent would easily receive the title of ‘weakest link’. Within this subcomponent teachers are the key players as they represent the single greatest obstacle to the talent developmental process. Interpreted differently it means that if teachers for the gifted students are not properly supported through education and training then our gift students will never develop to their full potential.

Given that this study was carried out in disadvantaged schools, it was also hoped it would not only benefit gifted learners in general but disadvantaged gifted learners in particular. Recommendations from research are that in addition to catering for the needs of the gifted generally, the needs of the disadvantaged gifted require special attention, as these could differ from the needs of the other gifted learners (van der Westhuizen, 2007). Improved achievement would not only open up doors to economic access for such learners but specifically for the gifted from disadvantaged communities,
such opportunities have been shown to change the poverty cycles in such families. According to van de Westhuizen (2007) empirical evidence shows that children born to parents in the lowest fifth of the income scale are very likely to end up in the same lowest scale as adults. This current study would be one way of responding to our society’s diversity by adequately serving economically disadvantaged gifted students so that they move out of these low income scales.

Providing for the gifted students in our schools is also a question of equity – as with all other students, they have a right to an education that is suited to their particular needs and abilities. In terms of educational equity, it is also essential to remember that in the process of implementing inclusive reform, the charge to provide all students with challenging mathematics requires consideration of these high ability students. Yet in practice it is only the struggling students that are focused on. One teacher interviewed by Oswald & de Villiers (2013) recounted on this sad state of affairs:

We all try to throw out rescue buoys for the child who does not want to work, but the child who can really make a difference for the country, this child is ignored. It is a crying shame.

The concern for the mathematically gifted as learners who can make a difference for the country is supported in literature. There is a global discourse that positions mathematical competence as the key to the welfare of a nation in a global economy. Mathematics education is therefore viewed as the school subject that can save excluded children from their lack of a future hence it has been argued that who gets to learn mathematics and the nature of the mathematics that is learned are therefore matters of consequence (Persson, 2010). Within these debates, international studies warn that the student most neglected/excluded in terms of realizing full potential was the talented student of mathematics. Particularly at risk of this exclusion are the gifted children from economically disadvantaged backgrounds as they cannot afford to receive appropriate education elsewhere yet they do not have protection under national statute for a free and appropriate public education.

Theoretical Framework

This paper investigates effective instructional strategies for gifted students within regular classrooms hence there was need to identify models suitable in heterogeneous groupings. The paper acknowledges that the list of effective models for teaching gifted students is inexhaustible. However, studies which have explored the specific types of mathematical knowledge a teacher should possess suggest three types (1) teachers’ knowledge of facts (2) teachers’ knowledge of concepts and connections (3) teachers’ knowledge of models and generalisations (Tchoshanov, 2011). This paper argued that the second type of teacher knowledge ‘teacher’s knowledge of concepts and connections’ incorporates the other two hence connections became central to my investigations. This is further supported by Leikin, (2011) who argues that while there are many effective ways of teaching mathematically gifted students; building mathematical connections is a common principle among mathematics education programs for all students. Even in the internationally renowned Trends in Mathematics & Science Studies (TIMSS) it was observed that high performing countries placed greater cognitive demands on students by encouraging them to focus on concepts and connections among those concepts in their problem solving (Mullis, Martin, Foy & Arora, 2012). Similarly a recommendation made by Sheffield (2009) regarding effective ways of teaching mathematically gifted students was that learners must develop mathematical connections of different types; between representations of the mathematical concepts, between various mathematical tools and concepts from the same field, and between various mathematical topics. Taken from this perspective, this paper argues that one possible indicator of effective teaching of mathematically gifted students in the regular classroom would be the manner in which a teacher creates opportunities for learners to make such connections.

Given the centrality of mathematical connections in this study it was then necessary to consider conceptualisations of such connections from different perspectives then take a position. While there were many conceptualisations from literature, Businskas (2008) suggested a model with five forms
of mathematical connections which encompassed most of these different orientations. These forms of connections were (1) different representation (2) part-whole relationships (3) logical relationship of the form A implies B (4) procedural connection and (5) instruction oriented connection. Businskas provided both a description and an example for each form of connection that appeared identifiable in a typical mathematics classroom situation (see Table 1). It is important to note that Businskas did not provide a table with codes like the one in Table 1. Both the table and codes thereof were added by the author following the phrases that were used to describe these connections e.g. code DR from Different Representations. In my study Businskas model was preferred as a reference point because the connections she identified were not constrained by a topic as they span across number theory, geometry, trigonometry, algebra, calculus and probability (Businskas, 2008). Admittedly it might not have been possible to account for every conceivable teacher action in relation to these connections (Andrews, 2009) but judged by their prevalence in teachers’ descriptions, these mathematical connections were considered a sufficient reference point for my study.
While this framework formed the starting point for the development of a lesson observation tool, the interest in this study was not only in the identification of connections that teachers enabled or constrained. I was also interested in analysing the quality of such connections in practice i.e. linking connections to their cognitive demand. This follows Barmby, Harries, Higgins & Suggate’s (2009) proposition that to determine someone’s understanding of mathematics it is not just a case of “looking at the number of connections that a person makes but the quality or strength of the connections as well” (p. 221). Consistent with this view there was need to superimpose a quality element onto Businskas’ initial conceptualisation of connections. When it comes to quality of mathematical understanding literature tends to dichotomise procedural and conceptual understanding. However the view taken in this paper is that procedural and conceptual understanding should complement each other (Rittle-Johnson & Schneider, 2013). They further argue that elevated mathematical thinking process comes into play when students focus on mathematical concepts and connections among those concepts while high level cognitive processes require emphasis on the reasons about those connections. From this perspective justification and articulation is used to provide sufficient reason
that distinguishes between superficial and deep knowledge in mathematical thinking. So in developing an analytical tool for my study a connection was coded at level 0 if it was mathematically erroneous, level 1 if it was mathematically acceptable but without justification or further articulation, and at level 2 when it was mathematically acceptable and with further justification. For example a teacher’s utterance was coded DR0 if it was a different representation that was mathematically faulty, DR1 when the different representation was recognised at a rote/superficial mathematical level and DR2 when the different representation was recognised with further justification and/or articulation. Occurrence of the other four forms of connections were coded in a similar way leading to the final version of my analytical tool as in Table, 2.

Table 5 Analytical Tool

<table>
<thead>
<tr>
<th>FORM OF CONNECTION</th>
<th>LEVELS OF KNOWLEDGE QUALITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>0</td>
</tr>
<tr>
<td>DR</td>
<td>1</td>
</tr>
<tr>
<td>PWR</td>
<td>2</td>
</tr>
<tr>
<td>IM</td>
<td></td>
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<tr>
<td>P</td>
<td></td>
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<tr>
<td>IOC</td>
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Method

Research Design
A qualitative design was considered the best for an in depth investigation regarding the teachers’ choices of instruction strategies when teaching in an inclusive classroom.

Context
The study took place in four high schools located in previously disadvantaged communities of South Africa.

Participants
Purposive sampling was used to recruit four high school mathematics teachers (2 female and 2 male) that took part in this study. Within each of the teachers’ classes, three top achievers were identified as ‘mildly gifted’ following Gagné’s (2015:15) definition of giftedness which states that;

Giftedness designates the possession and use of untrained and spontaneously expressed outstanding natural abilities or aptitudes (called gifts), in at least one ability domain, to a degree that places an individual at least among the top 10% of age peers.

According to Gagné (2007) practically speaking, in a regular classroom of 30 students or so, the three highest achievers deserve to be called “academically gifted” according to both the definition and the Metric Based System for levels of giftedness and talents. This prevalence of gifted students according to Gagné suggests that every regular classroom teacher is a teacher for the gifted. The identification of the 3 gifted learners in each class followed teacher nominations together with a review of their academic records.

Ethical considerations
The provincial Department of Education granted approval to proceed with this study under permit number T-728 P01/02 U-848. At institutional level the university ethics committee granted approval under protocol 2007EC007. At school level the researcher received informed consent from the school
principals, teachers and parents of learners who would take part in this study. At both school and individual levels, the researcher maintained participants’ anonymity and confidentiality through the use of pseudonyms (school 1, 2, 3, & 4; teacher R, M, T and B).

**Data collection procedure**

A total of 20 lessons from the four teachers were video recorded while the teachers were teaching different topics in mathematics. Within each lesson the focus was on both the teacher and the gifted learners. The intention was to understand what these learners do differently from their peers and how the teachers support/inhibit their potential.

**Data analysis**

The researcher used the analytical tool Table 2 to analyse teachers’ utterances and activities during their interactions with the learners.

**Results to question 1 and discussion**

Let us recall that the first research question driving this study was “What distinguishes gifted students from their non-gifted peers?” Below I provide some few examples of excerpts from teachers’ interactions with the gifted learners which capture some of these learners’ characteristics. Teacher R’s lessons for the week were on multiplying binomials and trinomials using the distributive law. She goes through one of the examples as follows:

**Teacher:**

*The task was*(b - 4) (b² - 4b + 16) after which she explained how to move to the next step

*b (b² - 4b + 16) - 4(b² - 4b + 16)*

explained how to remove the brackets

*b³ - 4b² + 16b - 4b² + 16b - 64*

*After that we try to collect the like terms which are*

*b³ - 4b² + 16b - 4b² + 16b - 64*

*and this is our final answer*

*b³ - 8b² + 32b - 64*

The class was then assigned similar tasks to work on the board and one of the gifted learners by the pseudonym Senzo had done her working and got to the solution in just 3 steps as follows:

**Teacher:** Senzo can you explain your working to the class?

**Senzo:** *(Using coloured chalk the leaner shows her steps as follows :)*

3x², x = 3x²

3x².2y = 6x²y

xy.x = x²y

xy.2y = 2xy²

-2y², x = -2xy²

179
-2y^2, 2y = -4y^3

(All the above terms are arranged horizontally as:)
3x^3 + 6x^2y + x^2y - 2xy^2 - 2xy^2 - 4y^3. So I'm looking at this and I want to cancel and find what goes with each other (and she demonstrates how she identifies the like terms as highlighted). That's how I got my answer.

Teacher: (to the class) What are you saying about her approach? She was finding the product of a binomial and a trinomial using the distributive law. Did she apply the distributive law? (After a lengthy debate it is agreed she did not apply the distributive law and another learner is summoned to come to the board and correct her)

Learner 1: Writes on the board (x + 2y) (3x^2 + xy - 2y^2) then writes the two brackets as follows 
x (3x^2 + xy - 2y^2) 2y (3x^2 + xy - 2y^2) and then multiplies to get 
3x^3 + x^2y - 2xy^2 + 6x^2y + 2xy^2 - 4y^3. He then takes some time trying to identify the like terms which he connects with coloured chalk as follows: 3x^3 + x^2y + 2xy^2 - 2xy^2 - 2xy^2 - 4y^3 I add the x^2y and the 6x^2y and I get 7x^2y. This and that (pointing to the other two like terms in red) cancel each other. (He then cancels them out living the final answer as what Senzo had found previously) i.e. 3x^3 + 7x^2y - 4y^3

Senzo: (Points to the answer and says) There is the answer Mam.

A number of characteristics of gifted students can be discerned from this excerpt. Gifted students grasp new material quickly. This is evident in the way Senzo was able to move quickly to the solution in just three steps. Her solution was correct and she was articulate in explaining how she got to the solution. All these are signs that she had grasped the new material quickly.

Gifted students think flexibly and are not constrained by routines and stereotype procedures. We can also see this in the way Senzo was able to deal with a problem where the arrangement of the trinomial and binomial had been altered. The example that the teacher worked on the board was arranged with the binomial on the left hand side and the trinomial on the right hand side. The task that Senzo was given had the trinomial coming first before the binomial. However this altered arrangement did not constrain her at all.

Gifted students often leave out intermediate steps when solving familiar problems. We can also see this in the way Senzo worked her way to the solution in just 3 steps. The examples that the teacher worked on the board and the one that was worked by Learner 1 'to correct’ Senzo, all involved many more steps which Senzo was able to skip. For example Senzo skipped the re-arrangement of binomial on the left and trinomial on the right, perhaps because she was cognisant of the commutative law and its application in multiplication and addition (order is not important).

Lastly from this same excerpt we can see that gifted students provide logical arguments to explain mathematical results. Despite the teacher agreeing with the class that Senzo had not applied the distributive law, Senzo pointed to the class that her answer was still correct. This also confirms an observation in the literature that gifted students are prepared to approach problems from different directions and persist in finding solutions. In fact Senzo was not convinced that her working was incorrect until the teacher cautioned her that in the examination ‘such a working would not earn marks’.

Results to question 2 and discussion

Given these characteristic features of gifted students the second research question for this study was: “How could teachers modify their instructional strategies in order to effectively meet the needs of the mathematically gifted students?” The assumption was that the type and quality of connections that
teachers make during classroom interaction with the learners would make a difference in terms of supporting gifted learners. Coding of teachers’ mathematical connections was therefore done in accordance with the Analytical Tool Figure 2 as explained under theoretical framework. Coding at level 2 was the ideal as it suggested that the connection the teacher made was not only mathematically sound/correct but that the teacher further provided reasons, articulation or justification why it works that way.

![Figure 2 Summary of the four teachers' utterances and activities by knowledge levels](image)

Looking at Figure 1 one might notice that with the exception of Teacher M, the lowest frequencies in all the other three teachers utterances were recorded in the targeted level 2. This suggests that minimal opportunities were created for learners to develop higher order thinking skills. The first two bars in each of the first three teachers R, B & T again confirm that those teachers’ connections during classroom interactions were either faulty (level 0) or focused at a superficial level (level 1).

Given that Teacher M appears to be a very strong teacher let us analyse his utterances in more details. The aim is to answer the question: What can we learn from this strong teacher which could assist regular classroom teachers to be more supportive of their gifted learners.
### Figure 3 Teacher M’s utterances and activities by knowledge levels

<table>
<thead>
<tr>
<th>FORMS OF MATHEMATICAL CONNECTION</th>
<th>LEVELS OF KNOWLEDGE QUALITY</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>Code</td>
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<tr>
<td>Different Representation</td>
<td>DR</td>
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<tr>
<td>Part-whole Relationship</td>
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<tr>
<td>Implication</td>
<td>IM</td>
</tr>
<tr>
<td>Procedure</td>
<td>P</td>
</tr>
<tr>
<td>Instruction-oriented Connection</td>
<td>IOC</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
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</tbody>
</table>

### Figure 4 Summary of Teacher M’s Utterances by knowledge levels
What this relative frequency graph suggests is that Teacher M is quite a strong mathematics teacher. This can be evidence by the fact that that most of his utterances (61% in the DR category, 46% in the PWR category, 76% in the IM category, 64% in the P category and 68% in the IOC category) were coded in the highest level 2. This suggests that the teacher created opportunities for learners’ deep understanding in most of the utterances/activities. In fact in this series of teacher M’s lessons there were no utterances which were mathematically faulty in the P category, the IM category and the PWR category. Only two utterances were mathematically faulty in the DR category. Generally most of his definitions of mathematical terms were characterised by well thought out examples which clearly brought out mathematically accurate meanings. The strategies were justified and well explained and learners’ observations were probed with questions that solicited clear articulation and reasons why.

Taking a closer look at the distribution of teacher M’s utterance within different categories one might notice that the DR, P and IOC categories have the highest number of data counts. This is consistent with earlier classroom observations which have shown that teachers are constantly engaged in a process of defining and constructing a mental image of some mathematical object and using instructional representations in the process (Businskas, 2008). Capturing the importance of all these three forms of connections in conceptual development, one summary of research concluded that the five components used by successful teachers to help students develop mathematical ideas are: attending to prerequisites, developing relationships, employing representations, attending to student perceptions, and emphasising the generality of mathematical concepts (Sullivan, 2009). So what is the specific importance of each one of the three most prevalent categories?

Starting with different representations, literature suggests that instructional representations play such an important role in the development of student understanding (Ball, 2003; Sheffield, 2009). Empirical evidence suggests that this activity of representing is considered fundamental and a core activity of teaching mathematics (Ball, 2003) because the ways in which mathematical ideas are represented is fundamental to how people understand and use those ideas. Given that the instructional representations that students encounter define formal opportunities for learning about the subject content, findings from this study (61% in the DR category at level 2) suggest that opportunities for gifted learners to develop deep understanding were likely to have been created in teacher M’s class.

In discussing the importance of procedural connections Davis (2004) links them to representations and shows their complementary role. He argues that the resource that enables one to monitor correct rules or procedures was the knowledge of mathematical ideas, principles and definitions that function as grounds for those procedural rules. So according to Davis if teachers appear to be providing students with a great deal of information on what (mathematical ideas and concepts), but students still fail, then it is likely that they are not providing sufficient information on how to do so (the procedures). This suggests that conceptual knowledge (understanding the ‘what’ and ‘why’) is important for the development of procedural fluency while fluent procedural knowledge supports the development of further understanding. In that sense, production of a solution to a standard problem requires that one knows both what to do (the mathematical idea or concept) and how to do what needs to be done (the procedure). Results from this current study show that teacher M is strong in both the ‘what’ and the ‘how’ (61% and 64% respectively) hence I argue again that gifted students in this class were likely to have been supported towards their full potential.

With reference to instruction oriented connections, in this study this form of connection was defined in terms of how ‘A’ and ‘B’ are both prerequisites concepts/skills that must be known in order to understand ‘C’. This form includes linking new concepts to prior knowledge or extension of what students already know. The importance of taking account of students’ ideas is captured in Ausubel’s (1968) statement that the most important single factor influencing learning is what the learner already knows. Fostering better understanding in students requires taking time to attend to the ideas they
already have, both ideas that are incorrect and ideas that can serve as a foundation for subsequent learning. Without explicit assistance in connecting ideas or procedures people do not usually learn concepts simply by building up pieces of knowledge. So unless new information is linked to students’ prior knowledge and teachers are alerted to it, the sequence of activities might be inappropriate and further misconceptions may develop or achievement will be diminished partially due to persistent errors. Empirical evidence suggests that students learn efficiently when their teachers first structure new information for them and help learners to relate it to what they already know, then monitor their performance and provide correct feedback (Peterson & Leatham, 2009). Findings from this study again confirm that Teacher M was strong in terms of his instructional oriented connections (68% in the IOC category).

Conclusion

This study has both theoretical and practical implications. Theoretically gifts and talents are not synonymous and gifts will not translate into talents if there are no formal programmes designed for such to happen. Practically regular classrooms seem not to present ideal environments for gifted students to develop to their full potential due to a number of pressures that regular classroom teachers have. This paper recommends that further studies be carried out to understand more about how gifted students are catered for in the regular classroom if inclusive education were to be truly inclusive and catering for the needs of all learners.

References


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The work of teaching mathematics from a commognitive perspective

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It is generally agreed upon that teachers are crucial for pupils’ learning of mathematics. Whereas most research on mathematics teachers seem to focus on teacher abilities – like beliefs and knowledge – this theoretical paper argues that the work of teaching is imperative. In order for investigations of the work of teaching mathematics and its components to have more impact, clearer and more operational definitions of these components need to be developed. This paper discusses how the discursive theory of thinking as communicating might inform the practice-based theory of mathematical knowledge for teaching, and in particular conceptual analytical investigations of the work of teaching mathematics. Applying such a theory might provide support to arguments that the work of teaching is mathematical and clarify the meaning of the word teaching. A theory of thinking as communicating might also inform investigations of tasks of teaching by focusing on observable discursive acts.

Introduction

By “mathematical knowledge for teaching,” we mean the mathematical knowledge needed to carry out the work of teaching mathematics. Important to note here is that our definition begins with teaching, not teachers. It is concerned with the tasks involved in teaching and the mathematical demands of these tasks (Ball, Thames, & Phelps, 2008, p. 395).

What constitutes the work of teaching mathematics? This question is lurking in numerous research projects – including this one. Although this paper draws heavily on the work of Deborah Ball and colleagues (2008), the focus is on the work of teaching rather than on mathematical knowledge for teaching (MKT). An underlying assumption is that (mathematics) teaching is a professional practice, and the professional community of teachers, teacher educators and researchers should thus be able formulate plausible conceptions of this professional practice (Hoover, Mosvold, & Fauskanger, 2014). Conducting a conceptual analytical investigation of the work of teaching mathematics can be described as doing a “job analysis” (Ball & Forzani, 2009), and several studies have pursued such a job analysis of the professional work of teaching mathematics (e.g., Adler & Ronda, 2014). In their efforts to formulate a practice-based theory of MKT, researchers at the University of Michigan investigate the work of teaching mathematics – as expressed in the epigraph – and they refer to tasks of teaching mathematics as core components of this work (e.g., Ball & Bass, 2003; Ball & Forzani, 2009; Ball, Thames, & Phelps, 2008). Tasks of teaching can be considered the backbone of both their theory and their efforts to design measures of MKT (Hoover et al., 2014).

The theorisation of MKT by Ball and colleagues can be described as cognitively laden (Fauskanger, 2015). As a reaction to the strong cognitive focus that was prevalent in the 1970’s, 80’s and early 90’s, mathematics education researchers have turned towards more social theories in the last decades (Lerman, 2000). Discursive psychology is one such theory (e.g., Lerman, 2001), and, in recent years, numerous studies have attempted to apply discursive perspectives in studies of mathematics teachers’ knowledge and practice (e.g., Adler & Ronda, 2014; Barwell, 2013; Cooper, 2014; Mosvold, 2015; Venkat & Adler, 2012). Many of these studies draw upon Sfard’s (2008) theory of thinking as communicating, but they emphasise different perspectives of this theory in their attempts to “discursify” MKT. Some of the studies suggest that the sub-categories of MKT can be seen as different discourses, and Cooper (2014) presents a framework that he refers to as “mathematical discourse for teaching” where he distinguishes between a subject matter discourse and a pedagogical
content discourse. These two discourses parallel two of Shulman’s (1986) initial categories of teacher knowledge, that were presented as the two main categories of MKT in the model by Ball and colleagues (2008): subject matter knowledge and pedagogical content knowledge (see Figure 1). Another study suggests that developing such mathematical discourse for teaching can be seen as moving from being a peripheral to a more central participant in a mathematical discourse for teaching (Mosvold, 2015). Other studies focus on applying discourse perspectives to investigations of the work of teaching mathematics (e.g., Adler & Ronda, 2014; Venkat & Adler, 2012). These latter studies propose a framework for mathematics discourse in instruction that emphasises teachers’ communication of mathematics in the classroom context. To my knowledge, however, in their various attempts to investigate mathematical knowledge for teaching or the mathematical work of teaching from a discourse perspective, researchers have directed little or no attention to the important construct of tasks of teaching.

The present paper hinges on the idea that tasks of teaching are paramount in studies of the work of teaching mathematics; in fact the work of teaching as well as mathematical knowledge for teaching has been defined by tasks of teaching (Ball & Forzani, 2009; Ball et al., 2008). In this paper, I aim at discussing how Sfard’s (2008) theory of thinking as communicating can be applied in investigations of the work of teaching and tasks of teaching. Unlike some other studies, the purpose of this study is not to replace the practice-based theory of MKT with discursive theories, but rather to investigate how Sfard’s theory could inform the conceptual analytical investigations of the work of teaching. I will point towards some examples of such an implementation in this theoretical paper in order to possibly spur further investigations in the same direction. Before going into this discussion in full, however, I start by describing some often overlooked building blocks of the MKT framework.

The work of teaching mathematics

Studies on mathematical knowledge for teaching (MKT) often seem to emphasise “the egg” (Figure 1) – a commonly used nickname for the oval figure that represents Ball and colleagues’ (2008) further development of Shulman’s typologies of teacher knowledge. The egg model has been extensively used, and many seem to think of this model – and only this – when they discuss MKT.

![Figure 1. Categories of MKT (Ball et al., 2008, p. 403)](image_url)

Although categories of teacher knowledge are arguably important, the practice-based theory of MKT goes beyond a categorisation of teacher knowledge into subject matter knowledge and pedagogical content knowledge with sub-categories. In their discussion of core aspects of MKT, Hoover and colleagues (2014, p. 11) emphasise the following three points:

1. The role of the discipline of mathematics in and for teaching;
2. The meaning of the term “teaching” in the phrase “for teaching”;
3. The mutual importance of both conceptual work and the validation of proposed conceptualisations in advancing early-stage research.

With reference to the first point, Ball’s research group at the University of Michigan stresses that mathematics teachers’ work is mathematical (e.g., Ball & Bass, 2003). The mathematical work of teaching differs, however, from the mathematical work of other professions. Moving on to the second point in the list, which underlines the importance of the term “teaching”, Hoover and colleagues suggest that a particular view of teaching orients the research on MKT. They reiterate this view by stating that, “teaching is seen as a plausible conception of professional practice” (p. 11, original emphasis). Analysing the work of teaching mathematics is crucial in developing such plausible conceptions of professional practice, and the aim of such analysis is to identify “what is entailed mathematically in that teaching” (Hoover et al., 2014, p. 12).

Teaching can be regarded as a professional practice, and it entails carefully designed activities that aim at helping pupils learn a particular content (Ball & Forzani, 2009). From such a definition, it can be argued that this professional work can be decomposed into some core activities. This argument is repeated in several publications from the Michigan group, often with reference to research on other professions (e.g., Ball & Forzani, 2009). In earlier publications, Ball and her colleagues regarded teaching as mathematical problem solving and decomposed the mathematical work of teaching into mathematical problems that teachers had to solve (e.g., Ball & Bass, 2003). The focus gradually shifted from the work of teaching to the problems of teaching and finally to the mathematical tasks of teaching. In successive publications and presentations, lists were presented of mathematical problems that teachers had to solve in their work of teaching; these problems were later referred to as tasks of teaching (Thames, 2009). Tasks of teaching can thus be defined as activities, challenges or problems that teachers regularly encounter in their professional practice. This “focus on the mathematical tasks that teachers have to deal with in the work they do that have significant mathematical entailments” (Hoover et al., 2014, p. 13) is important in the research of Ball and colleagues. Identifying and analysing core tasks of teaching are at the core of the conceptual analytical research that the Michigan researchers engage in (e.g., Ball & Forzani, 2009). Based on their efforts to identify recurrent tasks of teaching and scrutinise these tasks, Ball and colleagues (2008, p. 400) present the following list of core tasks of teaching:

- Presenting mathematical ideas
- Responding to students’ “why” questions
- Finding an example to make a specific mathematical point
- Recognising what is involved in using a particular representation
- Linking representations to underlying ideas and to other representations
- Connecting a topic being taught to topics from prior or future years
- Explaining mathematical goals and purposes to parents
- Appraising and adapting the mathematical content of textbooks
- Modifying tasks to be either easier or harder
- Evaluating the plausibility of students’ claims (often quickly)
- Giving or evaluating mathematical explanations
- Choosing and developing useable definitions
- Using mathematical notation and language and critiquing its use
- Asking productive mathematical questions
- Selecting representations for particular purposes
- Inspecting equivalencies

Defining a set of agreed-upon core tasks of teaching can be useful in different ways. Ball and Forzani (2009) suggest utilising this for developing and organising curricula in teacher education, whereas Hoover and colleagues (2014) suggest that identification of tasks of teaching, “can serve as a common
foundation for conceptualizing and measuring mathematical knowledge for teaching internationally” (p. 7). Although this endeavour is arguably important, it is also difficult. Some researchers have criticised the tasks of teaching for not taking cultural differences into consideration (e.g., Ng, Mosvold, & Fauskanger, 2012), whereas others have extended the list (e.g., Delaney, 2008). Complete correspondence of observable tasks of teaching across countries might not be found, they argue, but investigating mathematical tasks of teaching might still be useful, to develop a common language for describing the work of teaching across countries (Delaney, 2008).

Spotlighting tasks of teaching represents a shift in attention from teachers’ mathematical knowledge to their mathematical work (Thames, 2009). This shift is significant. Conceptualising tasks of teaching as components of the work of teaching mathematics does, however, require some further clarifications. The work of teaching – which goes beyond classroom instruction – is not easy to define or delimit. Ball and Forzani (2009) propose to define the work of teaching as “the core tasks that teachers must execute to help pupils learn” (p. 497). Although this definition appears straightforward, it includes the ambiguous term “task” that is ambiguous. In mathematics, a “task” often refers to a mathematical problem that pupils work with. In the practice-based theory of MKT, however, tasks of teaching refer to activities, challenges or problems that teachers have to perform in their work of teaching. Defining tasks of teaching in this way is, however, still unclear. Not all aspects of the work of teaching or the tasks of teaching are directly observable. This, I argue, might be a main reason why existing definitions are still ambiguous. Defining tasks of teaching as challenges, for instance, depends on the views of the active teacher – what he or she regards as challenges – and such views can be described as latent traits. Some tasks of teaching, like presenting mathematical ideas, appear to be more easily observable. Other tasks, like recognising what is involved in using a particular representation, appear to be more difficult to observe directly.

In this paper, I propose to consider possible benefits of applying Sfard’s (2008) theory of thinking as communicating to investigations of the work of teaching mathematics. This corresponds with the work of Jill Adler and her colleagues, where they have shifted the attention from teachers’ mathematical work to their mathematical discourse (e.g., Adler & Ronda, 2014; Adler & Venkat, 2014; Venkat & Adler, 2012). In the following section, I describe some core aspects of their framework for mathematical discourse in instruction.

**Considering the work of teaching mathematics as discourse**

When presenting the framework of mathematical discourse in instruction (MDI), Venkat and Adler (2012) clarify that it refers to teachers’ communication of mathematics while interacting with pupils in the classroom. Compared to Ball and Forzani’s (2009) definition of the work of teaching mathematics, mathematical discourse in instruction can be described as a subset of this work. There are aspects of the work of teaching mathematics that surpass teachers’ communication in the classroom, but mathematical discourse in instruction focuses on aspects of the work of teaching that are arguably important. Focusing on teachers’ mathematical communication in the classroom entails the advantage of dealing with a more clearly delimited – and observable – aspect of teachers’ professional practice.

Venkat and Adler (2012) contend that the mathematical discourses in instruction “include a problem, a selected representation that is subsequently transformed, and explanations and justifications for the representations selected and transformations performed” (p. 1). Their aim of introducing such a framework is to initiate a conversation that would eventually lead to developing “a more robust language for thinking about what constitutes coherence and connection within mathematics teaching” (Venkat & Adler, 2012, p. 2).

In a subsequent publication, Adler and Ronda (2014) present a further developed framework for mathematics discourse in instruction that highlights the acts of exemplifying and explaining. Their approach seems related to Skott’s (2013) efforts to develop a framework that “uses a participatory
approach and searches for patterns in individual teachers’ participation in different social practices” (p. 547). Whereas Skott focuses on patterns of participation, however, Adler and colleagues aim their attention at the discourse of a particular social practice. The framework of mathematics discourse in instruction could be seen as an attempt to create a more robust way of thinking about the mathematical discourse in teachers’ interaction with students in the mathematics classroom (Venkat & Adler, 2012). This interaction is one of several social practices that constitute mathematics teachers’ professional work. An asset of this framework is that it focuses on observable communication. It thereby avoids latent constructs like beliefs and knowledge. A potential weakness is that such a framework might become detached from the related frameworks upon which it builds. When I suggest investigating the work of teaching – and in particular tasks of teaching – from a discursive perspective, my aim is not to substitute previous theories with new ones. It is rather to investigate how a theory of thinking as communicating can inform and possibly sharpen the language for describing the work of teaching mathematics. In the following, I present some basic aspects of Sfard’s (2008) theory that I intend to apply.

Thinking as communicating

A main idea in Anna Sfard’s (2008) theory is that cognition and communication are inseparable, and she melds the two in a new term: “commognition”. In her theory of commognition, she defines concepts that are commonly used in cognitive research in terms of discourse; thinking, for instance, is defined as “an individualized version of (interpersonal) communication” (Sfard, 2008, p. 81). The cognitive term knowledge is in Sfard’s theory regarded in terms of participation in discourse – not acquisition of an objectified entity. Learning is seen as a permanent change in discourse, and this change can be either on an object level (where new words are introduced) or on a meta level (where the rules of discourse change). For the commognitive researcher, then, the study of communication and participation in discourse(s) becomes pertinent. Sfard’s theory is multifaceted and complex, and in this paper, I particularly draw upon her discussions of how to categorise a “mathematical discourse”.

Communication is understood in Sfard’s (2008, p. 86) terms as “a collectively performed patterned activity”. A discourse can then be regarded as a type of communication in which some people are drawn together and other people are excluded. In other words, mathematical discourse in instruction can be seen as the type of communication that is specific to the professional work of mathematics teachers. Sfard (2008) suggests four critical properties that identify a discourse (as mathematical): 1) word use, 2) visual mediators, 3) endorsed narratives, and 4) routines. A discourse is characterised by the keywords used, and mathematical discourses include a number of specific keywords – in particular words related to shapes and quantities. Mathematical discourses also include certain visual mediators, and these are often symbolic artefacts (e.g., numerals, operators and other mathematical signs). The objects of a discourse are described in some kind of narratives, and these narratives – especially in a mathematical discourse – are subject to endorsement or rejection. Finally, there are some characteristic patterns of a mathematical discourse, and these patterns are referred to as routines (Sfard, 2008).

Sfard uses the above-described properties to analyse and discuss mathematical discourses (mainly school mathematical), and I suggest that these properties can be applied to analysis of the work of teaching mathematics when regarded in terms of discourse. Following Hoover and colleagues (2014), and combining their view with Sfard’s (2008) theory, I first suggest that it is important to clarify the role of mathematics in the mathematical discourse entailed in the work of teaching mathematics. In other words, it must be explained why and how the discourse in the work of teaching is a mathematical discourse. Second, it is important to clarify the term teaching when investigating the work of teaching in terms of discourse. Third, the importance of conceptual work related to tasks of teaching mathematics must also be discussed from a commognitive perspective. In the following section, I use
some examples to discuss these issues, and I thereby provide some pointers towards how Sfard’s
theory could further inform studies of the work of teaching mathematics.

**Investigating the work of teaching mathematics as discourse**

Where other studies have attempted to apply Sfard’s (2008) commognitive theory on the knowledge
categories included in the MKT framework (e.g., Cooper, 2014), my investigation follows the efforts
to investigate the work of teaching by Adler and colleagues (e.g., Adler & Ronda, 2014; Venkat &
Adler, 2012). I concur with Hoover and colleagues (2014) when I emphasise the focus on
mathematics, the meaning of the term “teaching” and the importance of conceptual work as well as
validation of proposed conceptualisations.

Consider the following example of the work of teaching mathematics where a teacher wants to show
her pupils that $1 \frac{1}{2}$ multiplied by $\frac{2}{3}$ equals 1 (from the public released MKT items, Ball & Hill,
2008). In preparing the lesson, the teacher inspects different possible models of this:

![Image of models A, B, C, D](image)

**Figure 2.** Example item from Ball and Hill (2008, p. 7).

A presentation of these ideas in the classroom context is clearly a matter of communication, and it
can be regarded as a type of communication that is typical for mathematics teachers – thus a discourse.
Contemplating about these issues when preparing for the lesson can also be viewed as communication
according to the theory of thinking as communicating, since thinking is defined as an individualised
version of interpersonal communication. For this to be regarded as a mathematical discourse,
however, crucial aspects such as word use, visual mediators, endorsed narratives and routines must
be discussed (Sfard, 2008). In this context, the teacher has to communicate words like multiplication,
equality, fraction and composite number. These are mathematical words, and some of them – like
equal and composite – are used in specific ways within a mathematical discourse that differ from how
they are used in everyday discourse. In order to explain abstract concepts like these, the teacher opts
to use certain visual mediators. These visual mediators – illustrated in Figure 2 – are also
mathematical. In order to establish the truthfulness of a statement that $1 \frac{1}{2}$ multiplied by $\frac{2}{3}$ equals 1
within a mathematical discourse, a purely deductive relation between the narratives must be
established. This includes a mathematical proof, which can be considered as a discursive construct.
Being faced with such examples (Figure 2), the pupils get the opportunity to discover the connection
between the statement in words and the visual mediators involved, and Sfard (2008) refers to this as
routines. Sfard’s theory can thus be applied to support the argument that the work of teaching mathematics – as illustrated in discussing this particular example of a task of teaching – is indeed mathematical work. The discourse involved, is arguably mathematical since it contains word use, visual mediators, endorsed narratives and routines that characterise a mathematical discourse. The term “teaching” is also important in the conceptual analytical work of the Michigan researchers. Ball and Forzani (2009) define teaching as helping other people learn. This might sound straightforward, but it hinges on a clear definition of learning. In Sfard’s (2008) theory, learning is defined as an observable change in discourse. Revisiting the example above, it can be argued that this is a work of teaching in that the teacher acts in certain ways with the intention of helping pupils learn about fractions. When including the visual mediators in Figure 2, the teacher presents some new objects into the discourse. When facilitating a discussion among pupils about possible connections between these figures and the initial statement about the equality of the product of two fractions and the number 1, the teacher creates a situation where learning can take place. The pupils might have to change their discourse in one of two possible ways. In her discourse, the teacher uses mathematical words that might be new to the pupils, for example words like composite number or fraction. Sfard (2008) refers to the introduction of new words in a discourse as learning on an object level. When discussing the possible connections between the statement and the figures, the pupils might discover that figure C cannot be used to illustrate that 1 \( \frac{1}{2} \) multiplied by \( \frac{2}{3} \) equals 1 since we cannot know if the areas of the rectangle and the circle are the same. Such a discovery has the potential to initiate a change in the meta-rules for this mathematical discourse, and Sfard (2008) refers to this as learning on a meta level. This illustrates how Sfard’s theory can be used to highlight the meaning of teaching – and its connection with pupils’ learning – in discursive terms.

Finally, I will focus on the conceptual work involved. It can be argued that the example above illustrates the task of presenting mathematical ideas. Presenting a mathematical idea – in this example related to fractions – is an act of communication. It involves some words that are particular to – although not necessarily exclusive to – the work of teaching as discourse. This situation also involves examples of visual mediators that are commonly used in this discourse (e.g., Figure 2). The task of presenting mathematical ideas often includes use of such models or other types of representations or examples that illustrate a more abstract mathematical idea. Another example relates to the task of choosing and developing useable definitions. Consider a context where the teacher wants her pupils to work on and further develop their definition for triangle. She comes across several possible visual aids to use in the lesson, and she has to consider which is more likely to help the pupils improve their definition (see Figure 3).
Like in the previous example, it can be argued that this illustrates how the work of teaching involves word use, visual mediators, narratives and routines that characterise a mathematical discourse. In particular, this is can be seen as an example of endorsed narratives – in the form of defining mathematical concepts. This corresponds with the task of teaching presented by Ball and colleagues (2008, p. 400) as “choosing and developing useable definitions”. When discussed in terms of discourse, this task of teaching involves presenting examples, asking for (and giving) explanations, posing questions, responding to questions and more. All of these can be described as acts of discourse, and I suggest that investigating the work of teaching as well as the tasks of teaching in terms of discourse can be useful in a process of developing more operational concepts in the framework.

Concluding discussion

Although the practice-based theory of MKT arguably appears to be cognitively laden (Fauskanger, 2015), it does not clearly build upon any of the grand theories of thinking and learning. Applying Sfard’s (2008) theory of thinking as communicating to investigations of the work of teaching mathematics – as it has been carried out by Ball and colleagues at the University of Michigan (e.g., Ball & Bass, 2003; Ball & Forzani, 2009; Ball, Thames, & Phelps, 2008) – I argue, has some potential advantages.

Hoover and colleagues (2014) contend that the following three elements are crucial to the theory of MKT: the role of mathematics, the emphasis on the term “teaching”, and the emphasis on conceptual work. First, Sfard’s (2008) theory contains some specific criteria for how a particular discourse is mathematical, and I suggest that the role of mathematics in the work of teaching can be more clearly articulated by applying these theoretical perspectives. Investigating the work of teaching in terms of word use, visual mediators, routines and narratives, can support the argument that the work of teaching mathematics is mathematical work. Similarly, such analysis of the tasks of teaching indicates how these are mathematical tasks of teaching mathematics. Second, although it is mainly a theory of
learning and not of teaching, application of Sfard’s (2008) theory might provide more solid definitions of important terms like teaching and learning – terms that the practice-based theory of MKT build upon, but that seem to lack clear definitions in the MKT literature. Third, and finally, I suggest that the theory of thinking as communicating has the potential to inform the further conceptual analytical investigations of the work of teaching mathematics – investigations that often focus on identifying and analysing core tasks of teaching. I will elaborate a little bit more on this latter point in the following.

The focus on investigating mathematical tasks of teaching mathematics is an often-overlooked core aspect of the practice-based theory of MKT (Hoover, et al., 2014). Some challenges are that the tasks are difficult to define, and the list of tasks of teaching, it appears, can be extended almost indefinitely. Whereas Ball and colleagues (2008) present a list of 16 core tasks, Delaney (2008) suggests a significant extension. A concise list of core tasks of teaching that clearly refer to different aspects of the mathematical work of teaching is useful for theorising the work of teaching, but continually extended lists of tasks might potentially muddle the picture. When focusing on the discursive aspects of the tasks of teaching mathematics, there is a potential to create a more manageable decomposition of the tasks of teaching mathematics into core acts of discourse. Adler and Ronda (2014) emphasised two such acts when they focused on exemplification and explanation. By looking at the discursive aspects of the list of tasks from Ball and colleagues, I suggest that questioning and responding can be added to this list of what might be referred to as discursive acts of teaching. To illustrate this, the discursive act of exemplification is important in several mathematical tasks of teaching (Ball, Thames, & Phelps, 2008): Presenting mathematical ideas (or content); Finding an example to make a specific mathematical point; Giving or evaluating mathematical explanations.

Questioning – which is another act of discourse – is emphasised in the task of “asking productive mathematical questions”, whereas the act of responding appears in the tasks of “responding to students’ «why» questions”. “Evaluating the plausibility of students’ claims (often quickly)” is another example of a task of teaching where the act of responding is prevalent. Several tasks of teaching – as presented by Ball and colleagues (2008) – are already closely connected with acts of discourse. The examples above illustrate this. Other tasks of teaching – like finding an example or evaluating explanations – are not directly observable acts of discourse. Restating these tasks and connecting them with core acts of discourse, could clarify what the tasks are and how they are manifested in discourse. Regarding tasks of teaching in terms of discourse, and defining them in terms of the discursive acts involved, might thus be useful, I propose, in that it enables the development of more comprehensive language for considering the work of teaching mathematics and its components. Defining tasks of teaching more clearly in terms of observable acts of discourse has the potential to make the process of identifying and analysing tasks of teaching more transparent. This increased transparency is crucial for the efforts to identify mathematical tasks of teaching that are professionally defensible across cultures, and thus important for enabling tasks of teaching to become the common foundation for further investigations of mathematical knowledge for teaching internationally that Hoover and colleagues (2014) call for.

References


The challenges of constructing mathematical meaning through symbolisation at secondary school level: Some instructional strategies

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This paper reports on a pilot study of an ongoing study which investigates how the use of mathematical symbols influences learners’ (grade 10-12) understanding of mathematical concepts in the Limpopo Province (South Africa). Multi-stage sampling (for the district), simple random sampling (for the schools), purposive sampling (for the teachers) and stratified random sampling with proportional allocation (for the learners) were used. The sample included 3 schools, 36 grade 10 learners, 38 grade 11 learners and 36 grade 12 learners and 10 mathematics teachers currently teaching those learners. Questionnaires and interviews were used to solicit data from the participants. Thematic analysis was used to analyse the data. Four themes related to learners’ difficulties with mathematical symbols were observed: textbooks and problem-solving, informal versus formal mathematics symbols, context and multiple meanings, and instructional strategies. Teachers indicate that they face the following difficulties when teaching: the challenge of introducing unfamiliar notation in a new topic; teaching reading, writing and verbalising symbols; signifier and signified connections; and teaching both symbolisation and conceptual understanding simultaneously. The study therefore recommends teachers to use strategies such as informed choice of subject matter and its pedagogy in which concepts are understood before they are symbolised.

Keywords: Symbols, symbolism, symbolisation, symbol barrier, symbol sense.

Introduction

Written mathematical symbols play an important role in the teaching and learning of mathematics, but learners sometimes experience difficulties in using them to construct mathematical meaning. Symbols form the foundation of mathematical communication. Bardini and Pierce (2015) conjecture that the increase in symbol load due to unfamiliarity and increased density may cause learners to lose confidence and subsequently choose a study path that minimises the need for mathematics. A symbol is an image or a figure with a certain feature that enables it to represent an object, situation, concept or process (Mitchelmore and White, 2008). Chandler (2007) describes a symbol as comprising a signifier and a signified. The signifier is the perceptible image of something and the signified is the concept to which the signifier refers. Rubenstein and Thomson (2001) use the term symbolisation to describe the correspondence between two worlds, the one being symbolised (signified) and the one containing the symbols (signifier). Similarly, Santos and Thomas (2001) describes correspondence and the relationships between the represented and the representing worlds as symbolisation.

An essential feature which distinguishes mathematics from other subjects is its eventual dependence upon symbols (Jacobs, 2006). Elia, et al. (2007) show that, at all levels of mathematics learning, learners encounter difficulties in coping with the meaning of mathematical objects in relation to their
semiotic representations. It is reasonable to presume that much of the difficulty experienced by learners in mathematics, and the lack of popularity of mathematics in high schools could be traced to the problem of symbolization. The confusion between meaning and symbol is the root cause of a great number of misunderstandings in mathematics (Samo, 2009). Learners experience difficulties in understanding the meaning of written symbols if the referents do not well represent the mathematical meaning or if the connection between the referent and the written symbol is not appropriate (Muijs & Reynolds, 2010). Thompson et al. (2010) observed that when learners fail to attach meaning to a symbol by drawing upon the context in which it occurs, they often give up on developing understanding of the symbols, instead they simply look for clues as to what algorithm the symbol suggests. For instance, \( ax^2 + bx + c = 0 \) can be solved using the formula:

\[
x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}
\]

while the same can cannot be applied when solving \( 3^{2x} + 2.3^x + 1 = 0 \). Mathematical symbols are used in different contexts. However, they carry different meanings in different contexts. This can be to represent concepts, operations, processes and equations Maharaj (2008). It is this multiple meanings nature of mathematical symbols that cause great confusion among learners (Reynders, 2014). For example, the use of parentheses is a frequent source of confusion. In algebra, parentheses indicate the product of two expressions. In set notation \( n(S) \) is interpreted as the product of a numbers \( n \) and \( S \) instead of number of elements in set \( S \). Learners derive meaning for the symbols from either connecting with other forms of representations (e.g. physical objects, pictures and spoken language) or establishing connections within the symbol systems (Yetkin, 2003).

Sfard (2008) argued that mathematical symbolism is more than just a language with which to record mathematics. Rather, since the objects of mathematics are not accessible to the senses except through their symbols, the symbols act as objects in mathematics, and we work with these signs as if they were the objects signified. Mathematics, Sfard (2008) says, is an autopoietic system, creating the very things that it talks about. At the core of her discussion is a description of the process by which mathematical procedures are reified to become the objects represented by the symbols, a process of that is mediated symbolically. Mathematics is a symbolic language in which problem-situations and the solutions found are expressed. The systems of mathematical symbols have a communicative function and an instrumental role. It is clear that the learning of mathematics involves the appropriation of symbols and that constructing meaning for these symbols entails complex challenges (Ernest, 2008).

O’Halloran (2005), on the other hand, describes mathematical symbolism as an information dense language, although with strategies for organizing meaning that differ from those of natural language. While the symbols remove the human dimension, they increase the operational, relational, and existential meaning, and they can be operated on to solve problems without recourse to the world. Meaney (2005) and O’Halloran (2005) concur that mathematical symbolism is not taught linguistically and assert that this adds to the difficulty learners have in mastering it. Mathematics text is essentially multimodal, and researchers are in substantial agreement that the three modes, verbal, visual, and symbolic, are all necessary for the learning of mathematics. O’Halloran (2005) asserts that the different modes provide different ways for making meaning in mathematics and that the division of work is complementary. This observation was in accordance with Schleppegrell (2007) who posits that the modes must work together to construct meaningful mathematics, language providing the context for problems, symbolic mathematics describing patterns or relationships, and
drawings providing a connection to the physical world. Symbols together with words, graphs, pictures and numerical data are often used to communicate and represent mathematical ideas. For example, the symbol π can stimulate a mathematics learner to think about circles. Ideas are represented by symbols, and symbols stimulate thinking about those ideas. Symbolic representations represent math ideas clearly and succinctly, and help learners to manipulate the mathematical objects. Teachers often forget that the words, phrases, and symbols that are meaningful to them are unfamiliar to learners. As a result, many learners have difficulty verbalizing, reading, understanding, and writing mathematics to express their mathematical thoughts, reflect on concepts, or extend ideas. The use of formal algebraic symbols can be a barrier to some learners who are first learning about algebraic concepts. Learners begin to use the mathematical symbols, such as addition (+), subtraction (−), and equals (=). The special written symbolism of mathematics is the hardest form of language for learners to learn (Hughes, 1986).

A key challenge in mathematics teaching is to help learners move from everyday, informal ways of construing knowledge into the technical, symbolic and academic ways that are necessary for disciplinary learning in all subjects. Learners need to learn the appropriate use of mathematical language and symbols. They must develop symbolic knowledge. Mathematics has its own ways of using symbolic language to construct knowledge, and learners need to acquire and use language effectively to participate in those ways of knowing. The symbolisation challenges of mathematics education were highlighted by Halliday (1978) in his discussion of the “mathematical register.” He pointed out that the kind of mathematics that learners need to develop through schooling uses symbolic language in new ways to serve new functions.

This paper emerges from a broader study that investigates the influence of mathematical symbols and their use in the way secondary school learners grasp mathematical concepts. It is also intended to sensitize secondary school teachers to problems, or challenges, that learners often have with mathematical symbols and to suggest instructional strategies that can reduce such difficulties since using symbols fluently and correctly is a necessary condition for overall mathematics achievement (Rubenstein and Thompson, 2001).

**Problem statement**

Mathematics is generally regarded as one of the most unpopular subjects in South African secondary schools (Makgato & Mji, 2006). Learners do not achieve well in the subject. The spectrum of possible causes of poor performance ranges from genetic disposition to deficits in learning behaviour (Chisholm, 2008). Other factors contributing to poor performance of learners in mathematics were identified by Makgato (2007) as: teacher's content knowledge, time management, parents’ commitment to children's education, motivation and interest and teaching strategies. However this research is informed by the researcher’s classroom based experiences. The researcher observed that most learners experience difficulties in grasping mathematical skills and concepts. The researcher speculates that the reason for this failure could be the symbols which are unfamiliar, confusing and sometimes contradictory. Learners struggle to understand the mathematical concepts due to the way in which symbols are used to develop the concepts. Some symbols act dually as processes and as concepts. It is this dual nature of mathematics symbols which makes it problematic. Earle (1977) also speculates that learners’ problem with mathematical symbols lies in the way they use and perceive
symbols. She argues that if a learner cannot recognise and pronounce a symbol correctly, then he or she will have difficulties in using it.

**Research Questions**

The following questions guide this study:

a) What are the challenges experienced by secondary school learners when constructing mathematical meaning through symbolisation?

b) What are the instructional strategies used by teachers to facilitate the connection between symbols and their meanings.

**Purpose of the study**

The purpose of this study is to gain insight into learners’ experiences with symbolism when learning mathematical concepts. The study intends to investigate learners’ difficulties in grasping mathematical concepts through mathematical symbols. When learners have a problem with symbols, it is almost always due to a problem with the learners’ meanings. Learners might be able to manipulate expressions and equations, but they often fail to attach meanings to those symbols, or attach vague, imprecise meanings. The study also intends to sensitise mathematics teachers to problems and challenges that learners often have with mathematical symbols and to suggest instructional strategies that can reduce such difficulties since using symbols fluently and correctly is a necessary requirement for achievement in mathematics (Rubenstein & Thompson, 2001).

**Theoretical Framework**

This study adopts Arcavi’s (2005) symbol sense framework. An explicit definition of symbol sense, he argues, is not viable due to the complexity and variations in what is needed to effectively use and reason with various symbolic forms in algebra. Arcavi (2005) describes a number of features that characterise what he refers to as “symbol sense” in the domain of high school mathematics. Arcavi (2005) suggests a list of attributes that are indicative of symbol sense. His list covers the thinking involved at all stages of mathematical problem solving including formulating the problem and interpreting the solution. The attributes include: (1) an aesthetic feel for the power of symbols including an appreciation of what they can and cannot do, (2) a feeling for when to abandon the use of symbols and turn to other representational forms, (3) the ability to read symbolic expressions and equations, (4) the ability to initiate symbolic forms, and (5) a sense for the different roles that symbols play in different contexts. However, these components of ‘symbol sense’ are interrelated and closely linked. If a learner has one component then she/he will probably display other components but not having one component might result in not having any of the components. Symbol sense, as described by Arcavi (2005), is an understanding and appreciation of symbols necessary at all stages of problem solving. Arcavi (2005) describes symbol sense as “a quick or accurate appreciation, understanding, or instinct regarding symbols” (p.31) that is involved at all stages of mathematical problem solving. Arcavi (2005) argues that having ‘symbol sense’ is central to algebra and teaching should be geared towards achieving ‘symbol sense’. Naidoo (2009) explains that communication in mathematics is viable if symbolic systems are understood and relations between systems could be used to enhance symbolic understanding. Bergsten (2003) described symbol sense as an appreciation for the power of symbolic thinking, an understanding of when and why to apply it, and a feel for mathematical
structure. The combination of awareness and skill seems to imply a sense of symbols and their role in a mathematical activity. Learners who are fluent, or informed, users of symbols would have notational options available and would be able to judge when such options are appropriate. Learners need to develop a strong symbol sense in order to work fluently with symbols in mathematics (Kenney, 2008; Chirume, 2012). Quinell and Carter (2012) warned that teachers should be cautious about the use of symbols and asset that if mathematical symbols are misused, pupils' understanding of concepts would be greatly retarded.

**Instructional strategies**

Tall and Vinner (1981) revealed that every learner carries his or her own personal concept image of a mathematical concept. Learners' concept images often align poorly with the concept's standard mathematical definition, and many difficulties arise when this is the case. Mathematics instructors can assist learners in using symbols meaningfully by changing the culture of their classrooms. Learners should be encouraged to develop meaning for a mathematical concept before it is symbolized. Later, when the symbol is introduced, learners will view it simply as an abbreviation of the concept rather than as an indicator of an algorithm or object.

Another way to alleviate confusion with mathematical symbolisation suggested by Barclay (2012) is to explicitly point out to learners that symbols often have different meanings in different contexts, and that alternate symbolism often exists with the same meaning. One way to help learners with potentially confusing symbolism is to offer historical insight into the development of those symbols. For example, a story about the development of Leibniz notation might help learners understand the $dx$ in integral notation. Another strategy that can be used by teachers is to unpacking complex symbolism by breaking complex expressions into simple and understandable pieces. Unpacking the meaning of a symbolic expression includes breaking down expressions into smaller reference units. By habitually unpacking complex symbolic statements' meanings, learners can more readily attach meaning to symbols and extract meaning from symbolic expressions. Dienes (1963) argues that understanding of mathematical concepts is increased or hindered by how teachers use symbols together with how they design the process of learning. He proposes three phases in the mathematics learning process: abstraction phase, symbolization phase and routinizing the rules for using symbols. Chirume (2012) claimed that most teachers do not bother to follow these stages due to lack of knowledge about symbols. Symbol use is then seen not so much as something to be mastered, but as a constituent part of the mathematical practices in which students come to participate (Cobb, 2002). Dienes (1963) identified two challenges connected with the use of symbols, namely, the process of symbolization and the use of symbols once symbolization has been established. He asserts that there is a dearth in knowledge whether the use of symbols facilitates or hinders conceptual understanding. Teaching activities solely pitched at the iconic and symbolic levels need to be restricted considerably, and concrete modes of instruction should be explored first. English and Halford (2012) recommended that teachers should move from concrete manipulatives to semi-abstract representations such as pictures, diagrams and finally to abstract mathematical symbols. Abstract mathematical symbols should be introduced informally and learners should be allowed to use their own informal symbols. Transition to formal symbols should allow learners to map new symbols onto their existing understanding of the concept through a series of experiences during problem solving.
Methodology

Research Design

In order to find out how mathematical symbols influences learners’ understanding of maths concepts a descriptive survey methodology was utilised. A descriptive study is one in which information about a specific topic is collected without changing the environment (van Wyk, 2012). The purpose of this design is to describe a phenomena and looking for specific relationships or correlating variables. It is used to obtain information concerning the current status of the phenomena to describe "what exists" with respect to variables or conditions in a situation. In survey method research, participants answer questions administered through interviews or questionnaires. After participants answer the questions, researchers describe the responses given. A descriptive survey design suits this research since the idea was to describe a situation, which are learners’ experiences with mathematical symbols. However, descriptive surveys are not very informative research designs because, "…descriptive surveys basically inquire into the status quo; they attempt to measure what exists without questioning why it exists". (Jackson, 2009:89). To overcome this drawback, interviews in the form of group discussions with learners were held. Learners were allowed to discuss difficulties they encountered in using maths symbols in an atmosphere of freedom of expression and one that would ensure that they were also free to criticize their teachers or their textbooks.

Sampling

Participants for this study were drawn from Sekhukhune District in Limpopo Province. This district was selected because the researcher had taught there and observed learners experiencing problems with the use of mathematical symbols. Permission to conduct the study was sought and granted by the Sekhukhune District Department of Education. All the secondary schools in the district were listed alphabetically and numerical codes were assigned to represent the schools. A simple random selection procedure using a random digits table was utilised to select participating schools. Participants were drawn from grades 10-12 classes together with their teachers. Since the study was about learners’ experiences of understanding of mathematical concepts through the use of maths symbols, an unbiased study sample had to be chosen by controlling the ability factor. Thus learners were drawn from three ability cohorts: best, average and poor performance in Mathematics. The sample included 110 learners comprising 73 females and 37 males and 7 maths teachers.

Data Collection

A self-administered structured questionnaires were administered to learners and teachers. The questionnaire for learners consists of questions involving both open and closed ended statements on whether mathematical symbols hinder or facilitate learners’ understanding of mathematical concepts. The closed ended items had a rating scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree) with pre-determined response options. The items were derived from the literature
review. The last section consists of open-ended questions which sought to solicit information about the teaching and learning approaches that are currently utilised in classrooms. The questions in this section were mainly designed to check whether current instructional strategies reduce or eliminate barriers to conceptual understanding due to unfamiliar notations. Interviews were also conducted with the learners to allow the researcher to probe deeply into the problems to uncover new clues, to open up new dimensions of a problem, or to secure vivid, accurate and detailed accounts that are based on the personal experience of the participant with mathematical symbols. The questionnaire for teachers comprised of open ended questions which explore teachers’ experiences, challenges and obstacles, encountered with regard to the use of mathematical symbols when teaching mathematical concepts. The questionnaire also solicited information about the teaching and learning approaches that are utilised in classrooms.

Results and Discussion

Thematic analysis was used to analyse the data from questionnaire and interview responses. Thematic analysis emphasizes pinpointing, examining, and recording patterns or "themes" emerging from the data (Braun & Clarke, 2006). Themes are patterns across data sets that are important to the description of a phenomenon and are associated to a specific research question. After going through learners’ responses from both questionnaires and interviews the following themes related to learners’ difficulties with mathematical symbols emerged: textbooks and problem-solving, informal vs formal mathematics, context and multiple meanings, and instructional strategies.

Textbooks and problem-solving

The main theme that emerged from this category of questions was that textbooks do not fully provide thorough explanations pertaining to how the symbols are used to develop mathematics concepts and problem solving procedures. Learners indicated that they are not capable of using conventional mathematics symbols that they have learned in class to represent problem solving situations, procedures and concepts. Learners also indicated that there are many symbols to learn in a single topic and sometimes they forget others. Learners expressed limited ability to initiate a mathematical expression or symbol as demanded by a mathematical problem. Hence a limited symbol sense.

Informal vs formal mathematics

Participants indicated that they make attempts to foster connections between their informal ways of thinking and the actual mathematical symbols. One of the core concepts in all dynamic views on mathematics is the concept of a symbol. Symbols function as means for regulation of the thinking process. However, participants indicated that they do not think in connection with mathematical symbols and pay little attention to their meanings during mathematics lessons. Learners’ informal ways of thinking about mathematical symbols were also evidenced from their responses on the role of mathematical symbols in the learning of mathematical concepts. Common responses to this question were that symbols make learning easier and shorten the amount of writing. None of the responses were formal.

Context and multiple meanings
Learner participants indicate that mathematical symbols assume different meanings in different contexts. Symbols carry different meanings in different topics. To be confident when using these symbols, a learner needs to observe the following: the context, in which we are working, or the particular topics being studied. For example, if we see the + symbol written in the sum 3+5, we understand that the context is one of adding the two numbers, 3 and 5, to give a sum of 8. When studying directed numbers the symbol (+5) shows the position of 5 on a number line. Thus the (+) sign can be regarded as an addition sign in the first context and as a position sign in when studying directed numbers.

**Instructional influences**

One of the questions requires learners to suggest instructional strategies that teachers employ to reduce the negative influences of the challenges posed by mathematical symbols. Participants suggested that teachers should teach mathematics concepts in ways that promote retention and link symbols with their references. Another interesting response from the participants was that they do not see the relevance of some symbols to what they are learning and it makes difficult for them to think in terms of such symbols during problem solving.

Participants blamed educators for quoting and substituting into formula without explaining the meanings of the symbols that make the formula. Participants confirmed that the current textbooks use familiar symbols and notation though the teacher is needed to offer clarification on some of the unfamiliar symbols. Learners indicated that textbooks symbols and notations are relevant after the teacher explanations. It is therefore crucial that teachers emphasise and develop learners’ abilities to understand and connect meanings to mathematical symbols. Teachers should desist from concentrating on teaching learners what to do (procedure) when they see certain symbols. Meaningful teaching requires teachers to help learners to construct concepts for spoken mathematical words and written symbols. It is common practice amongst teachers to ask learners to use symbols very early while they are still trying to understand a topic. Mathematical symbols are a highly abstract way of communication. The symbols are associated with numerous mathematical words, so teachers need to guide the learners to become familiar with the mathematics vocabulary and references associated with them. Most mathematical concepts in these grade levels are modelled at the abstract level using only numbers and mathematical symbols. Learners should be provided with a variety of opportunities to practice and demonstrate mastery at the abstract level before moving to a new math concept/skill. As suggested by Clement (2004) teachers should introduce symbols after learners have had opportunities to make connections among the other representations, so that the learners have multiple ways to connect the symbols to mathematical ideas, thus increasing the likelihood that the symbols will be comprehensible to learners.

**Teachers’ views of mathematical symbols and their pedagogical implications**

After going through learners’ responses from both questionnaires and interviews the researcher identified the following categories of themes: challenges of symbolism in a new topic; three mathematical skills; signifier and signified connection; symbolisation and conceptual understanding.

**Challenges of symbolism in a new topic**
Teachers indicated that learners take time to familiarise themselves with mathematical symbols. They also indicated that there is a big gap between the senior and Further education and training (FET) phase in terms of content, level of abstract concepts and symbol-rich mathematical concepts. One participant cited geometry and trigonometry as topics that have challenging abstract symbols. Teachers revealed that the learners have many misconceptions in the use of symbols in these topics which have a bearing on their learning of concepts. Teachers claimed that mathematical symbolisation problems encountered by the learners have connection with their lack of conceptual knowledge and are a result of the teaching they experience in lower grades. Other mathematics teachers blame textbooks for not presenting content in an elaborate way that provides sufficient room for learners to develop their relational knowledge and conceptual understanding.

**Three mathematical skills**

Teachers indicated that they cater for learners who struggle to verbalise, write or read symbols in the various mathematical activities but some of the problems have their roots in the learners’ prior experiences which cannot be corrected or learned at FET phase. Some educators argued that these skills must be taught at primary school level. Teachers also suggested that learners experiencing challenges with mathematical symbols and concepts should be identified and encouraged to engage in discourse during classroom deliberations. Mathematics is construed through the use of the semiotic resources of mathematical symbolism, visual display in the form of graphs and diagrams, and language. In both written mathematical texts and classroom discourse, these codes alternate as the primary resource for meaning, and also interact with each other to construct meaning. From the findings of the study, there is evidence that most learners fail to interpret or understand the meaning of mathematical symbols due to the way by which they are taught to read, pronounce and use them.

**Signifier and signified connection**

Mathematics teachers indicate that learners often fail to make signifier- signified connections during learning sessions. Meanings of mathematical concepts emerge in the interplay between signifier/signified systems and objects/reference contexts. In a general sense, to endow mathematical signs with meaning, one needs an adequate reference context. Using language and symbols to communicate is the ability to exchange information, experiences, and ideas through many modes, including written and spoken language, symbols, movement, gesture, body language and images, in order to make meaning and to create and maintain relationships with the goal of building a common understanding. Learners should be competent language and symbol users through activities that allow them to see how language and community are inextricably related. Teachers can foster the effective use of language and symbols through opportunities for learners to create, analyse, interpret, and reflect on ideas presented in written, oral, visual, and digital forms; for informative and imaginative purposes; and both formally and informally within literacy, mathematical, scientific, social and artistic contexts. Another issue that emerged from teachers’ observations was that many learners think of mathematics as a collection of symbol manipulation rules, plus some tricks for solving rather stereotyped story. They do not adequately link symbolic rules to mathematical concepts.

**Symbolisation and conceptual understanding**
Teachers confessed that learners face the challenge of simultaneously learning two things in a mathematics lesson: symbolic language of mathematics and the concept represented by those symbols. Teachers usually combine the two in their teaching; a new mathematical concept is introduced using unfamiliar symbols. Learners often memorise mathematics facts and manipulate symbols without having a deeper understanding of the concepts or processes involved. Memorisation of symbols, rules and mastery of computation are not the same as true knowledge of mathematical concepts and ideas. Teaching instruction must first ensure that learners’ conceptual understanding is deeply embedded. When learners have truly mastered a concept, they should be able to show all detailed steps in a process.

Symbolisation and problem solving

Participants confirmed that the symbolic structure of some the problems directs and influences their goals. Learners’ goals in problem solving are determined by their prior experiences with the symbols in the problem. Learners’ problem solving ability is determined by what they are “seeing” in the symbolic structure of a problem. This observation is similar to finding in the study conducted by Kenney (2009) who observed that learners have preconceived ideas about what math symbols are supposed to represent, and often base their interpretations on these experiences. This difficulty has its origins in learners who apply personal and informal meaning to symbols. Thus good teaching entails the ability to foster connections between the learner's informal symbols and the formal abstract and arbitrary system of symbolism.

Conclusions and Recommendations

The purpose of this pilot study was to gain insight on how mathematical symbols influence secondary school learners’ understanding of mathematical concepts so as to inform the broader study. The study also explores teachers’ perspectives on how symbolism influences their pedagogical practices. Thematic analysis of the findings of the study provides evidence that mathematical symbols hinder most learners to understand mathematical concepts. Mathematics teachers also indicate that the use of mathematical symbols to construct mathematical is a serious setback in their attempt to teach for conceptual understanding. This study has also concluded that learners fail to grasp mathematical concepts because of the dynamic nature of symbols. In one context symbols represent mathematical objects while in another context they represent ideas and processes to do mathematics. According to the themes emerging from learners’ questionnaire responses, textbooks and the teachers seem to be unreliable sources of conceptual understanding. Textbooks were blamed for changing symbols too often and use the same symbol to represent different ideas or processes or different symbols to represent the same idea or process. Symbols change meaning in different topics, hence learners cannot use their prior knowledge to learn new concepts. The object-process nature of mathematical symbols was also identified as a possible cause of confusion. Teachers’ pedagogical strategies were also blamed for resorting to symbols before learners grasp the concept.

References


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Prospective Mathematics teachers’ circle geometry technological content knowledge in a GeoGebra-based environment

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In this paper I draw on a research project that aimed at exploring the prospective teachers’ circle geometry technological content knowledge in the context of a GeoGebra-based environment. The investigation was conducted by probing into the prospective teachers’ thinking as displayed in their solutions to the technological content knowledge-based tasks. The major focus was to characterize the technological content knowledge the prospective teachers displayed. I examined what do the GeoGebra constructions reveal about the PTs’ competence in constructing geometry diagrams within a GeoGebra environment. The construction produced was expected to reflect the PTs’ ability to transform the statements from a static environment to a dynamic construction employing GeoGebra as a construction tool. I examined what the prospective teachers could or could not construct with GeoGebra. Data sources were the GeoGebra algebraic view, the GeoGebra graphic view, the construction protocols and the screen-cast recordings. The prospective teachers did not utilize the affordances and constraints of GeoGebra when making connections between the construction and geometric principles. The PTs’ had technical constraints and not geometrical constraints.

Introduction
Researchers such as Larborde, Kynigos, Hollebrands, & Strässer (2006); Mishra & Koehler, (2006) have studied the use of technology in teaching and learning. The most common findings are that teachers are either reluctant to use technology or use it ineffectively. The reluctance of practicing teachers to integrate technology into teaching mathematics after undergoing professional development has recently led researchers to expose the complexities of the phenomenon (Drijvers & Gravemeijer, 2007). This exposure has been emphasized through focusing research on designing and examining technology-based activities that are purported to enhance mathematical thinking. I concur with Angeli (2005 ) that the task of preparing prospective teachers (hereafter referred to as PTs) to become technology competent is difficult and requires many efforts for providing them with ample opportunities during their education to develop the competencies needed to be able to teach with technology. In unison, researchers acknowledge that mathematics methods courses provide a meaningful context within which the integration of technology can be pedagogically situated in the teaching of subject matter (Angeli, 2005 ; Niess, 2005).

I argue that integrating technology requires teachers to experience specific content areas in relation to specific technological tools. Thus it remains a matter of serious concern that there is need for research-based models on how PTs relate to technology to construct their mathematical knowledge. There is need for more research on instrumental genesis within the Dynamic Geometry Environments (DGE) context. More specifically how do DGE tools such as GeoGebra influence the teacher content and pedagogical knowledge of school geometry in teacher preparation programs. How is PTs’ knowledge of circle geometry transformed as they work on tasks developed within a GeoGebra-rich environment? How is knowledge constructed in the contexts of re-learning school mathematics, learning mathematics with technology and planning to teach mathematics with technology? What characterizes such knowledge? This paper focused on mathematical thinking processes of the PTs as they learn or re-learn school geometry in the GeoGebra based environment by examining what characterizes the prospective teachers’ technological content knowledge.
Research context
The project purposefully focused on gaining in-depth understanding of the aspects of the PTs’ technological pedagogical content knowledge (hereafter referred to as TPACK) with regard to circle geometry. Hence the PTs were the primary participants were enrolled in a second-year undergraduate mandatory mathematics methodology course that the researcher taught at an urban South African university. The Bachelor of Education (B.Ed) second year mathematics education course is a theoretically and practically oriented mathematics methods course that deals with the teaching and learning of mathematics, develops prospective teachers’ didactical knowledge, and incorporates aspects of mathematics teaching that challenge student’s mathematical thinking (Ramatlapana, 2011). All students in the course were introduced to GeoGebra in their first year of study. GeoGebra was integrated into the second year methodology course structure. A learning trajectory was developed that engaged students in activities that enhance their geometry content knowledge, geometry pedagogy content knowledge and knowledge of learning geometry with GeoGebra.

Research questions
What do the GeoGebra constructions reveal about the PTs’ knowledge of circle geometry constructed in a GeoGebra environment?

Theoretical framework
The exploration of mathematics prospective teachers’ circle geometry technological content knowledge is premised on the claims that, firstly, learning mathematics is profoundly influenced by the tasks, by the learning context and by the tools that are used in mathematics instruction. This claim is extended to all domains of mathematics. I contend that PTs’ geometry thinking is derived from experience, for which I conjecture that PTs’ knowledge is influenced and framed by PTs practical experiences with tasks, tools and the PTs’ learning context. Secondly, that PTs’ geometry knowledge is developed through the relation produced by the interaction between content, pedagogy and technology knowledge. The TPACK is a prerequisite to effective integration of technology in education. Mishra and Koehler (2006) explicited that TPACK is the interaction of content, pedagogy and technology bodies of knowledge, both theoretically and in practice, to produce the types of flexible knowledge needed to successfully integrate technology use into teaching. I employed the TPACK framework to study the teacher knowledge of circle geometry as proposed by Mishra & Koehler (2006).

Method
This case study purposefully focused on gaining in-depth understanding of the aspects of six (6) PTs’ circle geometry technological content knowledge. I designed the tasks, facilitated the implementation of tasks and conducted individual interviews a week after the implementation of the tasks. There were two categories of tasks, written tasks and GeoGebra-based tasks focusing primarily on eliciting the three knowledge domains of pedagogy, content and technology in the context of circle geometry. With regard to the GeoGebra-based tasks, the participants individually worked on the tasks in the researcher’s computer. The PTs’ GeoGebra constructions were recorded using the screen-casting software, UltraVNC Addon, which was downloaded in the researcher’s computer.

PTs’ technological content knowledge (hereafter referred to as TCK) was examined when PTs responded to circle geometry tasks that incorporated the use of technological tool, GeoGebra. Among the six major written tasks were GeoGebra-based sub-tasks. The GeoGebra-based tasks were technological-based tasks that required the use of GeoGebra to construct and/or interpret GeoGebra-constructed geometric diagrams. Screen recording was employed to capture actual computer work activity by tracking the user’s thinking processes. The cursor movements were then exported as videos. The interview focused on PTs’ explanations about the solution processes for all the tasks.

The criteria for the rubrics were rigorously scrutinized for both content and construct validity by critical readers. The use of written tasks, screen recording and interviews were considered as multiple
sources of data collection that can ensure reliability and validity. The PTs responses were scored according to the analytic rubric that I designed to capture TPACK-related evidence. Therefore, the rubrics were thus referred to in this study as the TPACK rubrics. The development of the TPACK rubrics was drawn from Miheso-O’Connor (2011), who employed the use of rubrics, to measure pedagogical content knowledge proficiency in teaching mathematics. As such, the design of the rubric was guided by the question “What would the participant need to know or be able to do to successfully respond to this task?” Inter-rater reliability was considered when establishing the reliability and consistency of rubric scoring. The tasks and the rubrics were rigorously tested for coherence, reliability, and validity during this process. The task item analysis process involved examining item format, item performance scoring and item wording. This effort resulted with improvements in the performance level criteria and the holistic scoring of the rubrics and the elimination of some sub-tasks.

**Results and discussions**

The TCK construct was conceptualized as the knowledge of how circle geometry concepts may be represented with GeoGebra. The circle geometry TCK required for the successful completion of the TCK tasks was a construction of geometric diagrams with GeoGebra. Figure 1 presents the Task 1. Task 1 (c) was classified as a TCK task since it elicited knowledge of GeoGebra constructions and reasoning.

**TASK 1**

The diagram below shows a circumscribed circle with centre S. Triangle ABC has AB = AC. Angle A is acute and AB is extended to K. AS extended cuts BC at M and the circle at H. BE bisects \( \angle CBK \). BE meets AS produced at E. AB when produced, is perpendicular to EK.

(a) Write down and label all the geometric figures that you see in the above diagram. Eg. \( \triangle ABC \)

(b) Which triangles are congruent? Explain.

(c) Use GeoGebra to construct the diagram.

**Figure 1: Task 1**

The critical component of Task 1 (c) was the ability to reproduce a pencil-and-paper diagram in a GeoGebra environment. The construction was expected to reflect the PTs’ ability to transform the pen-and-pencil diagram and verbal statements from a static environment to a dynamic construction on GeoGebra. When interacting with GeoGebra, the PTs were expected to do the following not necessarily in this order: (i) construct a circumscribed triangle ABC where AB=AC; (ii) construct line AS which when extended cuts line BC at M and the circle at H; (iii) to construct line BE which bisects angle \( \angle CBK \); (iv) to construct line BE which meets line AS produced at E; and (v) to construct line AB which when produced is perpendicular to line EK. I draw on the notion that PTs should have the competence to visualize, construct and reason to reflect their knowledge and understanding of geometry (Duval, 1995; Gagatsis et al., 2010; Larborde, 2004). Task 1(c) required cognitive
apprehensions to deal with the knowledge of how to represent circle geometry properties within a GeoGebra environment. Apprehension in this context refers to the several ways of looking at a drawing or visual stimulus (Duval, 1995). Task 1(c) particularly required a perceptual apprehension of the diagram followed by a sequential apprehension in order to construct the diagram in the GeoGebra environment.

A summary of the PTs’ scores within the task is presented in Table 1. The analytical rubrics were employed to qualify the responses. A general overview of the table indicates the task was attempted, with 0 as the lowest score and 3 as the highest performance score attained in the task. Four PTs (Nkosi, John, Wisdom, Lesedi) scored 0.

Table 1: Scoring of the PTs responses across and within the TCK tasks

<table>
<thead>
<tr>
<th>PT</th>
<th>Rubric scores (/4 for each sub-task)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nkosi</td>
<td>0</td>
</tr>
<tr>
<td>John</td>
<td>0</td>
</tr>
<tr>
<td>Wisdom</td>
<td>0</td>
</tr>
<tr>
<td>Lesedi</td>
<td>0</td>
</tr>
<tr>
<td>Bonolo</td>
<td>1</td>
</tr>
<tr>
<td>Thabiso</td>
<td>3</td>
</tr>
</tbody>
</table>

The overall mean and standard deviation were 0.667 and 1.211 respectively, indicating that two PTs (Bonolo and Thabiso) scored above the mean and rest of the PTs scored below the mean. The overall performance of the PTs indicates that the variation of scores is low, suggesting that the PTs were of a similar ability with faulty knowledge of circle geometry TCK. The conclusion is based on the contention that the ideal average performance for the TCK tasks should be 4 (teachers should be able to do tasks without error) but the attained average is 0.667, signifying weak knowledge of the construction of diagrams with GeoGebra. The rubric scores in the descriptive summary (Table 1) above provide statistical features of the PTs’ individual performance. However, an interpretation of the scores within tasks provided an insight into the PTs’ TCK.

The PTs’ constructions produced within the GeoGebra user interface were studied for the TCK evidence. As such, I examined the PTs’ constructions as represented in the GeoGebra algebraic view and the graphic view. The algebraic view illustrates the text input in the construction processes whereas the graphic view provides the visual component of the construction. I also examined the PTs’ construction protocols for the step-by-step construction processes and the screen-cast recordings for the thinking processes. These different data sources are discussed in the subsequent sections.

Analysis of the algebraic view

One of the affordances of GeoGebra, to both learner and researcher, is the multiple representation of an object. A GeoGebra default screen shot shows an algebraic view and graphic view. See Figure 1. An object can be represented in algebraic form on the algebraic view window. The algebraic view contains the numeric and algebraic representations of the constructed objects presented in alphabetical order but not necessarily according to the order of construction. Table 2 shows a summary of the PTs’ constructed objects as represented in the algebraic view. The expected number of constructed objects according to the model solution, in the graphic view of the ideal construction was: 2 angles, 1 conic figure, 3 lines, 8 points, 2 rays and 5 segments.
Table 2: Summary of PTs’ objects representations on the algebraic view of Task 1 (c)

<table>
<thead>
<tr>
<th>PT</th>
<th>angle E=2</th>
<th>conic E=1</th>
<th>Line E=3</th>
<th>point E=8</th>
<th>Ray E=2</th>
<th>segment E=5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nkosi</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>11</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>John</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>8</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Wisdom</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td>8</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Lesedi</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>14 (6)</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Bonolo</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>11 (3)</td>
<td>2</td>
<td>8 (2)</td>
</tr>
<tr>
<td>Thabiso</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>9 (1)</td>
<td>2</td>
<td>7</td>
</tr>
</tbody>
</table>

Note: (i) number in brackets represents the number of objects deleted in the graphic view but visible in algebraic view; (ii) E is the expected number of constructed objects to be represented in the algebraic view

Generally there were variations between the number of expected objects and the actual number of objects the PTs constructed as seen in the algebraic view. Much variation occurred in the number of lines, points and segments presented in the PTs’ constructions. The expected number of lines was three but the number of lines that the PTs constructed ranged between 1 and 5. The expected number of points in the construction was 8 but those of the PTs ranged between 8 and 14. However, some PTs (Lesedi, Bonolo and Thabiso) had 9 or more points in the graphic view but there are indications that some points were later removed in order to meet the construction requirements. See Figure 2 for Lesedi’s algebraic view and graphic view.

Figure 2: Lesedi’s Task 1(c) GeoGebra construction

The algebraic view allows for objects to be removed from the window provided these objects are free objects that are not dependent on other objects. For instance, Lesedi’s algebraic view showed that she plotted 14 points which she later trimmed to 8. The output of the construction illustrates that all the PTs except Wisdom constructed the expected number of points. There was also some variation realized in the number of segments drawn by the PTs.

Task 1 (c) required a construction of two angles, acute Angle A and Angle BKE which is 90°. The table shows that all the PTs except Wisdom constructed only one angle, Angle BKE. Wisdom did not construct this or any other angle. The algebraic view shows an object when it is constructed in the
graphic view. Thus it could be seen that the acute Angle A was not constructed but was visible by default in all the constructions. The PTs did not confirm the acute angle through its measurements. My conversation with Nkosi sheds light into the failure to construct Angle A.

Nkosi: I didn’t consider that…if you just gave me this and don’t give me the description?
Kim: Yes
Nkosi: Yes, I would just look at the diagram.
Kim: you’d just look at the diagram? But suppose you’d also looked at the description, what would you have changed in your construction?
Nkosi: the accuracy.
Kim: Because your only concern was the 90 degree
Nkosi: yes because that’s the only one I could see from the diagram
Kim: suppose it was mentioned in the diagram that AB=AC, would you have made sure that they were accurate?
Nkosi: yes, then I was going to make sure that they were accurate.

Since the accuracy of measurements of Angle A was not given in the diagram, the PTs concluded that this angle did not warrant due construction but can be visually recognized and classified as acute.

All the PTs constructed one conic figure as expected but that cannot be said about the lines. The task required a construction of three lines: angle bisector BE, angle bisector AE and a perpendicular to AB produced. The PTs produced between 1 and 5 lines which were not necessarily the required lines. For instance, as will be discussed in the next section, none of the PTs constructed the angle bisector BE. Overall, there were two rays in the model diagram. Half of the PTs constructed the two expected rays whereas John and Wisdom did not construct the rays at all.

Analysis of the graphic view
The graphic view of the GeoGebra user interface provides a visual component of the construction or drawing. The geometric objects are displayed in this view where the objects can be drawn or created and modified using the construction tools. Table 4 shows a summary of objects the PTs constructed in order to meet the construction requirements of Task 1 (c).

<table>
<thead>
<tr>
<th>PT</th>
<th>Circle S</th>
<th>Triangle ABC</th>
<th>Angle bisector BE</th>
<th>AB produced, when AB = AC is perpendicular to EK</th>
<th>AB = AC</th>
<th>Points A, B, C passing dragging test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nkosi</td>
<td>√</td>
<td>√</td>
<td>X</td>
<td>√</td>
<td>X</td>
<td>No point</td>
</tr>
<tr>
<td>John</td>
<td>√</td>
<td>√</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>No point</td>
</tr>
<tr>
<td>Wisdom</td>
<td>√</td>
<td>√</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>No point</td>
</tr>
<tr>
<td>Lesedi</td>
<td>√</td>
<td>√</td>
<td>X</td>
<td>√</td>
<td>X</td>
<td>No point</td>
</tr>
<tr>
<td>Bonolo</td>
<td>√</td>
<td>√</td>
<td>X</td>
<td>√</td>
<td>√</td>
<td>one point (A, B, or C)</td>
</tr>
<tr>
<td>Thabiso</td>
<td>√</td>
<td>√</td>
<td>X</td>
<td>√</td>
<td>√</td>
<td>any two points (A, B, or C)</td>
</tr>
</tbody>
</table>

Note: √ indicates construction requirement met; X indicates construction requirement not met

Generally, some construction requirements were met to produce the objects. At a glance the graphic view shows that all the PTs constructed circle S and triangle ABC. One given property of triangle ABC was that AB = AC, implying that triangle ABC is isosceles. Table 4 demonstrates that despite the PTs constructing the triangle, their construction did not satisfy this property. Only Bonolo and Thabiso constructed the two congruent sides AB and AC indicating that these PTs successfully
constructed the required triangle. Although the algebraic view suggests that the PTs constructed at least one line, none of these lines could be classified as the angle bisector BE. However, 4 of the 6 PTs constructed the line perpendicular to AB produced. Thabiso noted that the point E was the intersecting point of the perpendicular and the angle bisector. He asserted that

**Thabiso:** what I don’t see… it’s I don’t see the relationship that if I have this perpendicular line then I have the angle bisector then I have already sorted out this one. So am trying, I think am trying to get the perpendicular bisector you see, …

All the PTs struggled to construct the perpendicular to AB produced as acknowledged by Thabiso in this excerpt affirming that the PTs could not exploit the technical affordance of GeoGebra.

**Analysis of construction protocols**

The construction protocol of the GeoGebra user interface provides a textual representation of the order and steps of construction or drawing of geometric objects. The construction protocol was employed to analyse how the constructions and drawings were organized. This analysis provides an insight into how the constructions and drawings were sequentially apprehended. A sequence has to be followed using GeoGebra in order to make the construction. Table 4 provides a summary of the PTs’ construction protocols for Task 1 (c). The table considers the sequence of construction, the number of construction steps and the time each PT took to construct the diagram. When analysing the sequences of construction, I draw on Duval’s (1995) position that the order of construction depends on either the mathematical properties that are represented and / or the technical limits of the tools which are used. I considered how the specific properties that should be extracted from the static diagram were sequenced in the construction. The order of construction was corroborated with the examination of the videos of the screen recording. This strategy was essential in addressing the limitations of a construction protocol. A construction protocol does not show steps that are deleted during the construction process. The implication is that the construction protocol provides some but not complete access into understanding PTs’ geometrical thinking.

The model construction with a short accurate protocol and the points A, B, C passing the dragging test was 2 minutes long with 20 construction steps. The model sequence of construction depended on the geometric object properties and the GeoGebra construction tools. This sequence was ideal in that it provided a short sequence by exploiting the affordances of GeoGebra. The sequence of the objects for construction was as follows: (1) \( \Delta ABC \) where \( AB=AC \); (2) Circle \( S \); (3) AS extended cuts BC at M and circle at H; (4) BE bisects \( \angle B \); (5) AB extended to K. (6) AB produced perpendicular to \( EK \); (7) BE meets AS produced at E.

I will use Nkosi as an example to illustrate the construction protocol and its constructed diagram. See Figure 3 for his construction protocol and Figure 4 for the GeoGebra construction. Table 4 presents the Nkosi’s construction processes.

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Definition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Point A</td>
<td></td>
<td>( A = (3.76, 1.5) )</td>
</tr>
<tr>
<td>2</td>
<td>Point B</td>
<td></td>
<td>( B = (-0.38, 2.66) )</td>
</tr>
<tr>
<td>3</td>
<td>Circle c</td>
<td>Circle through B with centre A</td>
<td>( c: (x - 3.76)^2 + (y - 1.5)^2 = 18.49 )</td>
</tr>
<tr>
<td>4</td>
<td>Point C</td>
<td>Point on c</td>
<td>( C = (-0.46, 2.35) )</td>
</tr>
<tr>
<td>5</td>
<td>Point D</td>
<td></td>
<td>( D = (2.4, 1.76) )</td>
</tr>
<tr>
<td>6</td>
<td>Ray a</td>
<td>Ray through C, D</td>
<td>( a: 0.59x + 2.86y = 6.43 )</td>
</tr>
</tbody>
</table>
Figure 3: Nkosi’s Task 1(c) construction protocol created with GeoGebra

The objects as named in the construction protocol correspond with the objects in the Algebraic View as seen in Figure 4. The Algebraic View lists the objects in alphabetical order but not necessarily in the order in which they were constructed. Definition refers to the description of the geometric properties of object in relation to other objects. For example, in Step 3, the Circle C is defined in relation to centre A and point B.

Figure 4: Nkosi’s Task 1(c) GeoGebra construction

Nkosi’s construction protocol had 21 steps done in 4 minutes 53 seconds. He first constructs the circle with centre A through point B (sequence 1). In sequences 2 and 3, he draws ray a through C and D and ray b through C and E. He constructs line d through FD and a segment e through C and H followed by a construction of segment f which connects I and H and segment g which connects H and J (sequence 4). In sequence 5 he makes a manual construction of a 90° angle through C, F and G. Next, he constructs K which is the intersecting point of line d and ray a. He finally constructs segment i
which connects I and K (sequence 6). Nkosi did not construct the angle bisector. He used his own labels instead of the labels given in the diagram.

Table 4: Summary of PTs’ construction protocols for Task 1 (c)

<table>
<thead>
<tr>
<th>PT</th>
<th>Number of construction steps (expected N=20)</th>
<th>Time taken to construct (expected T=02:00)</th>
<th>Sequencing of construction objects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Circle</td>
</tr>
<tr>
<td>Nkosi</td>
<td>21</td>
<td>04:53</td>
<td>1</td>
</tr>
<tr>
<td>John</td>
<td>20</td>
<td>04:51</td>
<td>1</td>
</tr>
<tr>
<td>Wisdom</td>
<td>20</td>
<td>21:07</td>
<td>1</td>
</tr>
<tr>
<td>Lesedi</td>
<td>27</td>
<td>08:56</td>
<td>1</td>
</tr>
<tr>
<td>Bonolo</td>
<td>25</td>
<td>11:55</td>
<td>1</td>
</tr>
<tr>
<td>Thabiso</td>
<td>22</td>
<td>04:29</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: N is the expected number of steps; T is the expected time taken to construct; 1, 2, 3, 4, 5, 6 is the order of construction of the objects; - means object not constructed

Table 4 shows that the number of construction steps for the five students ranged between 20 and 27. The time taken, as seen in the screen recording, to construct was not consistent with the number of steps. Wisdom produced 20 construction steps as shown in the construction protocol but took the longest time to complete the construction, indicating that he took longer to manipulate his construction. The recording included the times when the PT was thinking and not necessarily interacting with GeoGebra.

The sequence of constructions in Table 4 shows that all the PTs constructed the circle first and BE last. When quizzed on the reasoning about constructing the circle first, different versions were given. Nkosi explained that “because it’s easier to draw this quadrilateral because it’s a cyclic”. Wisdom alluded that “because everything is being done inside the circle” he had to start with the circle. Lesedi lamented that

Kim: what was your intention? Why start from the circle, why not the triangle
Lesedi: I wanted to start with the circle so that I can draw the diameter first, If I start with the triangle first without a circle I wouldn’t know where will my centre will be…
Kim: your centre will be? Oh. Ok. So your concern was the centre?
Lesedi: yes

Clearly Lesedi was thinking about the affordances and constraints of GeoGebra. She is aware that GeoGebra does not have a diameter construction tool so one needs to construct a line through the centre of the circle in order to draw a diameter. Later on she mentions that “I dragged H down, then I had to drag to make sure that the circle pass through centre S”

Thabiso’s sequence of construction was the shortest with well executed linking of GeoGebra affordances with geometric principles. Although he could not construct the angle bisector, he is the only PT that used the perpendicular line construction tool to produce a perpendicular EK.
John’s sequence of drawing/construction was similar to Thabiso’s. However the difference was in the execution John’s drawing/construction did not pass the drag test and the perpendicular EK was drawn rather than constructed suggesting a limitation on the knowledge of the affordances of the GeoGebra tools.

Point E is the intersection of the angle bisector and the perpendicular. None of the PTs constructed the angle bisector, suggesting that the point E was not plotted in the correct position.

Analysis of screen recordings
The PTs were screen-recorded whilst they were performing the construction tasks. Screen recording captured the actual drawing/construction by tracking the movements of the mouse and the PTs’ interaction with the GeoGebra construction tools and the GeoGebra menu. I examined the transcripts of the videos of the screen cast recordings. As mentioned earlier, the screen recording corroborated the construction protocol. I was determined to find a connection between the PTs’ knowledge of geometric properties and the affordances and constraints of GeoGebra in representing these properties. As such, since the indicators for TCK were the ability to produce and describe a construction of a diagram with GG, the actions made during the construction process were employed as analytical tools for the screen recordings. A deductive approach was utilized to identify and classify the actions.

### Table 5: PTs’ actions during the construction process

<table>
<thead>
<tr>
<th>PT</th>
<th>selects</th>
<th>draws</th>
<th>inputs</th>
<th>drags</th>
<th>deletes</th>
<th>renames</th>
<th>total</th>
<th>Time taken to construct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nkosi</td>
<td>9</td>
<td>9</td>
<td>7</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>30</td>
<td>04:53</td>
</tr>
<tr>
<td>John</td>
<td>18</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>4</td>
<td>8</td>
<td>50</td>
<td>04:51</td>
</tr>
<tr>
<td>Wisdom</td>
<td>53</td>
<td>25</td>
<td>22</td>
<td>22</td>
<td>21</td>
<td>0</td>
<td>143</td>
<td>21:07</td>
</tr>
<tr>
<td>Lesedi</td>
<td>23</td>
<td>11</td>
<td>11</td>
<td>5</td>
<td>2</td>
<td>7</td>
<td>59</td>
<td>08:56</td>
</tr>
<tr>
<td>Bonolo</td>
<td>28</td>
<td>14</td>
<td>20</td>
<td>0</td>
<td>16</td>
<td>1</td>
<td>79</td>
<td>11:55</td>
</tr>
<tr>
<td>Thabiso</td>
<td>13</td>
<td>14</td>
<td>6</td>
<td>0</td>
<td>1</td>
<td>7</td>
<td>41</td>
<td>04:29</td>
</tr>
</tbody>
</table>

**Select actions**

In order to construct or draw, the PTs had to select the tools that were appropriate for the construction/drawing of a particular object and/or make selections from the GeoGebra menu. I classified each selection as a ‘select action’. Students should have selected the object based on the properties of the objects. On some occasions the PTs selected a wrong construction tool. This action was reversed by selecting the un-do icon in the GeoGebra menu. A correct construction of the diagram on GeoGebra, according to the memo, required 19 construction tools selections. Table 5 shows that Nkosi made the least number of selections at 9 in less than 5 minutes whereas Wisdom had the highest selections at 53 in about 21 minutes. Table 5 suggests that the PTs who took less time made fewer tools selections.

**Draw actions**

The drawing action focussed on the construction/drawing of segments, lines, rays and circle in the graphic view. A correct drawing/construction of the diagram on GeoGebra required 11 drawing actions. The PTs’ drawing actions were just about the same as the required number of drawing actions except for Wisdom who made 25 drawing actions. Worthy of mentioning is that the GeoGebra allows for a selected construction tool to be used several times on the graphic view. Therefore the selection actions do not in any way determine the number of drawing actions.

**Input actions**
The input action refers to actions required for plotting the points and inputting the angle in the construction. The requirements were that 8 points had to be plotted and an $90^\circ$ angle to be inserted in the diagram. The PTs had either more inputs (John, Wisdom, Lesedi, Bonolo) or less inputs (Nkosi and Thabiso).

**Dragging actions**

GeoGebra allows for dragging of objects in the graphic view to show how these objects transform. Just like any Dynamic Geometry Environment, dragging a geometric object (e.g., point, line) in a GeoGebra interface indicates or confirms whether its properties are maintained or not. I called the drag test utilized by the PTs the ‘drag action’. The objects were dragged to explore and check if the object maintained the geometric properties and whether the dynamic diagram had all the properties of the static diagram. The model construction required at least 1 dragging action. In the model construction, the perpendicular $EK$ had to be dragged to intersect with angle bisector $EB$ at point $E$. But Table 6 demonstrates that dragging occurred or did not occur at all in some constructions. John, Bonolo and Thabiso did not employ the dragging affordance of GeoGebra. Nkosi, Wisdom and Lesedi construction recordings show that dragging actions were performed. Wisdom had the most dragging actions. Although he was determined to re-produce the static diagram, Wisdom was aware of the potentials of GeoGebra for confirming that indeed the construction was correct. He asserts that

\[ \text{Wisdom:} \quad \text{I wanted to see whether, it would, I wanted to answer this question whether when you drag it changes shape so I saw “kuti” eeh if I drag it changes, when you drag any point right it changes so I wanted to make sure that it doesn’t change.} \]

Clearly, Wisdom wanted to confirm the relationship between the whole figure and its figural components in a GeoGebra environment. To accomplish this PT required a good knowledge of the properties of the diagram. He was not concerned about the time it took him to do the construction but instead explored with the drag tool to investigate the geometric objects in the GeoGebra platform.

**Delete actions**

The delete actions were employed to clean up the construction of extra and unwanted objects. The objects deleted were lines, angles, points, rays and segments. Wisdom had the most delete actions at 21 followed by Bonolo with 16 delete actions. Nkosi made no delete actions.

**Rename actions**

In order to reproduce a pencil-and-paper diagram on a GeoGebra environment the PTs had to rename the object labels as given in the static diagram. GeoGebra assigns name labels to construction objects but renaming of labels is permissible. There were 9 input actions expected to be performed. Table 6 shows that the Nkosi and Wisdom used the GeoGebra-assigned labels and did not rename the objects.

**Conclusion**

This project aimed at understanding the PTs’ competence in constructing geometry diagrams within a GeoGebra environment. The construction produced was expected to reflect the PTs’ ability to transform the statements from a static environment to a dynamic construction employing GeoGebra as a construction tool. I examined what the PTs could or could not construct with GeoGebra. Data sources were the GeoGebra algebraic view and the GeoGebra graphic view, the construction protocols and the screen-cast recordings.

The PTs’ quality of responses for the construction task was poor, with most scores at performance level 0. The observed and expected patterns validate that indeed the PTs’ geometry TCK was considered to be below average. The PTs’ TCK was hypothesized as the knowledge of circle geometry in the context of a GeoGebra environment. The interplay between the two knowledge domains requires that when determining the quality of the response, I consider if the PTs’ incorrect figure is due to weak geometry knowledge or to weak knowledge of GeoGebra or both.
The PTs identified and extracted from the static figure the objects to be constructed. The required objects were not all constructed as expected implying that not all constructions requirements were met. The construction protocol showed how the constructions were sequentially apprehended with more dependence on GeoGebra. Such dependency indicates that the PTs did not utilize the affordances and constraints of GeoGebra when to make connections between the construction and geometric principles. The PTs’ had technical constraints and not geometrical constraints. They know the properties and can identify the figures and figural units as evidenced in the CK tasks and in their discussions about the TCK tasks. But they do not have the technical knowhow to construct the diagram on GeoGebra. The PTs did not advantageously employ features of the technological tool, which Artigue (2007) and Noss (2001) propose invites the user to undertake an action such as dragging upon it.

Analysis of TCK was focussed on the sequential apprehension and operative apprehension with the perceptual apprehension back-grounded deliberately. Duval’s four cognitive apprehensions of geometric reasoning were required in the construction and description of GeoGebra-based diagrams. The PTs’ inability to produce a GeoGebra construction of a pen-and-pencil diagram indicates a weak sequential apprehension. Hence, the results show that the PTs’ encountered difficulty merging the cognitive processes of the construction and the reasoning when responding to the TCK tasks.

References


Measuring of Attitudes of Learners towards Mathematics

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The scholastic achievement of South African students in internationally bench marked tests reveal a steady decline in the standards of teaching and learning of the gateway subject mathematics. In the light of the above, an inventory in the form of a questionnaire was designed to measure students’ attitude towards mathematics, in particular after 12 years of schooling and to get an insight of the problems experienced by students. An empirical study was done using an inventory that comprised 42 questions and was administered to 344 students of the University of Johannesburg. Learners were requested to respond to the questionnaire to indicate their degree of agreement or disagreement to each of the items on the questionnaire, on a 5 point Likert-scale type of evaluation from Strongly Agree to Strongly Disagree. The variable descriptors in this survey were comprised of 7 distinct mathematics related attitudes, namely: Societal Implication, Sense of Security, Career Interest, Motivation, Value, Leisure Interest and Perception of the Teacher. These descriptors were then analysed statistically for means, standard deviations and variances. Also the data was analysed for its reliability and consistency through the use of the Cronbach Alpha coefficient, which in this case gave an acceptable value of $\alpha = 0.74$ for this study. However, discarding some items from the questionnaire may yield a higher value Cronbach alpha coefficient. The results of this investigation yielded mixed perceptions on almost all attitudinal descriptors, except for 2 closely related attitudes; namely Motivation and Value. The mean values for the latter 2 descriptors are 23.60 and 22.58, respectively. This means that if it is found that change has occurred in the learners’ attitude, then there will be a change in attitude towards mathematics. It must, however, be mentioned that this instrument is an ideal tool to measure attitudes of learners towards mathematical studies.

Introduction

It is regrettable that so much has been written about the abysmal performance and weakness of learners in mathematics. Subsequent to this there is focussed attention on “grade” improvement only. It is reported that only 6% of the entire cohort of grade 12 learners have obtained more than 60% in their final mathematics mark (Prew, 2013). Focussing only on grade achievement as a primary aim is an incorrect trajectory. However, other psychometric entities such as attitude towards mathematics deserve equal attention. Attitude plays a crucial role in determining one’s behaviour to a situation. Attitudes can shape ones’ behaviour; a positive attitude leads to a favourable response while a negative attitude leads to an unfavourable response (Tanveer et al., 1997). According to Tapia (2004), students’ attitude towards mathematics, is the single most important determining factor for success, thus much attention should be focussed on attitude changing to prevent unnecessary failures in the subject. Improved performance and achievement in the subject of mathematics can only be achieved through attitudinal change and a positive belief in oneself.

According to Wikipedia (2015 and the references cited within), attitude is defined as “a psychological tendency that is expressed by evaluating a particular entity with some degree of favour or disfavour”
Attitude can be classified into 3 important categories: Cognitive component, Affective component and Behavioural component.

(a) Cognitive component

The cognitive component deals with one’s belief and thoughts about the attitude object. According to Kirton (2003), there are 3 cognitive functions (this function focuses on problem solving and individual learning), namely: cognitive affect, cognitive resource and cognitive effect (Tanveer et al. 1997).

1. **Cognitive affect**: Cognitive affect focuses on the aspect of motivation, needs and wants, and values with the desire to achieve something. It focuses on the learners’ capabilities and learning ways.

2. **Cognitive resource**: Cognitive resource focuses on the learners’ ability, knowledge and experience.

3. **Cognitive effect**: Cognitive effect focuses on the learners’ capabilities and learning ways.

All these cognitive disciplines are the key pillars on which the mathematics inventory instrument was designed. Cognitive component of attitude is a perception of mathematics in terms of its practicality and usefulness in society (Tanveer et al. 1997). In behavioural sense the students’ reaction towards mathematics as a subject conjures mixed emotions and feelings.

(b) Affective component: This component of attitude deals with the aspect of feelings or emotions of an object. According to Ayub (2005), when one studies mathematics, “affect means optimistic or pessimistic feelings towards mathematics”. For those students that show anxiety for the subject have less affection for the subject and are more likely to display negative attitude towards the subject (Ho et al., 2000), and for those that are achieving good grades in mathematics would be more optimistic towards mathematics and would exhibit a positive attitude towards the subject.

(c) Behavioural component: The behaviour aspect deals with how learners cope with situations due to past experiences. In this situation, the learner will display a certain behaviour which is reminiscent of the behaviour when a similar event occurred in the past. Differential behaviours are observed for the learner either when they obtain poor, excellent or average grades for a test. In this respect, self-efficacy is influenced through the achievement of excellent grades (Lopez et al., 1997; Tanveer et al., 1997). Students persistently obtaining good or bad grades will ultimately affect their behaviour towards the subject. The behaviour of the teacher can also influence the behaviour of the learner. If the teacher perpetually displays a positive attitude towards mathematics, this will also stimulate a favourable behaviour in the learners (Tanveer et al., 1997) with a concomitant positive attitude towards the subject. Having a positive attitude towards a subject means that they are enjoying the subject and have full confidence in their ability to solve more complex problems (Farooq & Shah, 2008). A teacher that is always negatively inclined or see no real value of mathematics in the real world will also likewise elicit negative perception from the learner about mathematics. The value of the teacher/parent as role models is of paramount importance to the learner. The learner will likewise mimic such exemplary behaviour in keeping with the moral set by their role models.
The role of the parent in the educational paradigm of the learner cannot be overlooked. Parents themselves that have either done well or badly in mathematics will replicate such emotions (feelings) or practices to their children. The rippling effect of this is that the learners will either a high esteem or a low esteem of themselves in the classroom situation. The sum total of the learning environment will dictate as to what the learner will replicate in his/her mathematical world. According to Tanveer et al. (1997), that in order for the learner to achieve maximum learning in the classroom, there should be an environment, where student feel comfort, motivation, and experimentation in the classroom.

This regard, attitude will have a positive impact on student motivation, which will eventually produce the desired results. Thus learner behaviour, the environment and the various cognitive function are the key ingredients for changes in attitudes towards learning mathematics in school and beyond (Tanveer et al, 1997).

Positive attitude towards mathematics, according to Tapia (2000), Terwilliger and Titus (1995), has an inversely proportional relationship to anxiety. This means that if the anxiety levels are high then the attitude levels are low and vice versa. Anxiety can be attributed to a myriad of factors. The teacher is the most important person as far as this aspect of change is concerned. Instilling confidence in the learner will go a long way in changing the attitude of the learner towards mathematics. Only changes in attitude can bring about changes in performance and achievements of the learners.

Research into attitudes of learners towards the mathematics inventory is our focus of investigation. In this respect an instrument, using modified versions of 2 extant questionnaires of Fraser et al. (1993) and Tapia & Marsh (2008) was used to develop a psychometric questionnaire aimed at measuring attitudes of learners towards mathematics, with the hope of gathering more information on the changes that occurs in the students’ attitude. This investigation describes the 7 distinct attitudinal descriptors, its measurement and the impact it has on the students’ attitude towards mathematics. Statistical methods have been used to analyse the data. Analysis of results is based on the means as well as on the standard deviation values only. Further, the Cronbach alpha coefficient has been calculated to determine the reliability and the internal consistency of the questionnaire items of the survey. This factor is important especially when designing questions which do not show similarity or connectivity.

**Method and procedure**

The following methods and procedures were adapted for this study:

(a) Population size

The participants who formed part of this survey were 344 first year university students who had recently completed their schooling career. The reason for choosing these students was to get a holistic perspective of the students’ attitudes towards mathematics after 12 years of schooling. The survey was conducted during the orientation week of the University of Johannesburg induction programme. A heterogeneous group of students from a wide range of socio-economic backgrounds formed part of this survey. In particular Engineering students that were enrolled for Engineering Mathematics MAT 1 formed part of this cohort.
(b) Instrument for the Study

Students’ attitudes were measured using an inventory that consisted of 42 statements. The instrument that was used for the compilation of this inventory was the adapted versions of 2 extant questionnaires; namely, the first being the Test of Science-Related Attitudes (TOSRA) handbook by Fraser et al. (1993), while the second was an instrument designed to Measure Mathematics Attitudes by Martha Tapia (2008). Prior to the commencement of this investigation, permission was sought from both authors to use some part of their questions and the rest of the questions were modified by the author of this paper. Permission was also sought from the subject lecturers and students before administrating this questionnaire. Participation in this study was strictly voluntary to a specific Engineering group, which represented the largest group pursuing mathematical studies of an engineering nature. The present format of this inventory has been adapted and modified to give it an appropriate South African flair.

The survey inventory consisted 7 subsections specifically designed to measure attitudes towards mathematics on a broader scale. These subsections comprised of the following parameters (descriptors): societal implications of mathematics, development of career interest in mathematics, motivation for pursuing mathematical studies, values installed for pursuing mathematical studies, development of interest in following a mathematical field of study and the perceptions of the teacher in the students’ mathematical journey throughout their schooling career.

The item for the inventory was constructed using the Likert-format scale comprising of 5 alternate responses: Strongly Disagree (SD), Disagree (D), Neutral (N), Agree (A) and Strongly Agree (SA). Responses for the scoring of these statements were as follows: 1, 2, 3, 4 and 5, respectively for appropriately designated positive responses. Likewise for negative responses, the scoring was reversed for the following as follows: SD, D, N, A and SA with an appropriate score of 5, 4, 3, 2 and 1. The collected data was analysed by using appropriate statistical methods such as means, standard deviations, and the internal consistency reliability factor for which the Cronbach Alpha coefficient ($\alpha$) was used.

An inventory, as given in table 1, describing 42 items entitled: ‘Attitudes towards mathematics inventory” has been administered to students. Instructions were provided on the answer sheets and students had to choose their responses accordingly. For reliability of the survey students had to answer every question on the questionnaire. A blank space will be awarded a score of 3.

**Attitudes towards mathematics inventory**

This inventory consists of statements relating to attitudes towards mathematics. There are no correct or incorrect answers. Please answer each question according to the number code indicated in the table grid provided. Every question needs a response.

**Table 1:** Attitudes of learners towards mathematics inventory

<table>
<thead>
<tr>
<th>1- Strongly Disagree (SD)</th>
<th>2- Disagree (D)</th>
<th>3- Neutral (N)</th>
<th>4- Agree (A)</th>
<th>5- Strongly Agree (SA)</th>
</tr>
</thead>
</table>

224
1. Funding by government and other agencies for the improvement of mathematics in South Africa is worth it
2. Mathematics is one of my most hated subject in school
3. I would dislike being a mathematician after I leave school
4. I have really enjoyed studying mathematics at school
5. Mathematics is a useful and necessary subject to study at school
6. I would love to belong to a mathematics club
7. My mathematics teacher inspires me to solve harder problems
8. Mathematics is hated by most people in society
9. Mathematics does not scare me at all
10. Working as a mathematician must be an inspiring way to earn a living
11. Mathematics is dull and boring
12. I am scared of answering questions in a mathematics class
13. I hate doing mathematics homework
14. My mathematics teacher gets confused when he/she solves a problem
15. Government money towards mathematics upliftment has been wisely spent
16. My mind goes blank when working in a mathematics class
17. A career as a mathematician is dull and boring
18. I believe studying mathematics helps you in every other area of your life.
19. Mathematics develops and broadens the mind and teaches a person to think
20. I frequently meet my friends over the weekends to solve mathematics problems
21. My mathematics teacher can solve any problem in mathematics
22. This country is investing too much time and money on mathematics upliftment
23. I solve most mathematics problem with very little difficulty
24. I would like to teach mathematics when I qualify as a mathematician after school
25. I would avoid taking any mathematics courses at university
26. Mathematics Literacy is a better option than studying mathematics
27. I would prefer to write an essay in any subject than to do an assignment in mathematics
28. My mathematics teacher is always angry and shouts a lot
29. Curriculum changes in mathematics is a good thing
30. I feel a sense of insecurity when I solve mathematics problems
31. I dislike becoming a mathematician because it requires too much education
32. Studying advance or additional mathematics is exciting
33. I like studying mathematics because it develops my mathematical skills
34. Getting a mathematics book or equipment as a present is exciting
35. My mathematics teacher is always available to help me with my problems
36. The government should spent more money on the training of mathematics teachers
37. My self confidence in studying mathematics is high
38. A career in mathematics must be exciting
39. I believe I have a lot of weaknesses in mathematics
40. Success after school is not dependent on mathematics
41. I get bored watching mathematics programs on the educational channels on T.V.
42. My mathematics teacher has got no time for weak students

Table 2 shows how the 42 items from the inventory table 1 are allocated to the 7 different variables (descriptors) and items are indicated as either (+) or (-) for the purposes of scoring.

**Table 2**: Scale allocation and scoring for each item in the questionnaire.

<table>
<thead>
<tr>
<th>Societal implication</th>
<th>Sense of security</th>
<th>Career interests</th>
<th>Motivation</th>
<th>Value</th>
<th>Leisure interest</th>
<th>Perception about the teacher</th>
</tr>
</thead>
</table>
Scoring are obtained as follows: For positive items (+) in the questionnaire, such as: SD, D, N, A, and SA, the following scores are allocated 1, 2, 3, 4 and 5 respectively. On the other hand for negative items (-) in the questionnaire such as: SD, D, N, A, and SA, the following scores are allocated 5, 4, 3, 2 and 1, respectively. Scores for each the 7 variables listed horizontally (containing 6 items vertically) are added separately. The maximum possible vertical score for each of the variables in table 2 could be: 6 x 5 = 30. Likewise, the minimum possible vertical score for each of the variables in table 2 could be: 6 x 1 = 6. There is an equal distribution of positive and negative descriptors in the 42 item questionnaire i.e in each of the seven scales there are 3 positive and 3 negative descriptors (or 21 positive and 21 negative) that requires either positive or reverse scoring.

Results and discussion

The discussion below is based on the statistical results of the analysis from the questionnaire entitled: “Attitudes Towards Mathematics Inventory”. Table 3 gives a statistical description of such a data.

Table 3: Statistical Description of the questionnaire data

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Sample Mean Total</th>
<th>Standard Deviation</th>
<th>Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SD</td>
<td>D</td>
<td>N</td>
<td>A</td>
</tr>
<tr>
<td>Societal Implication</td>
<td>1.77</td>
<td>1.84</td>
<td>3.97</td>
<td>4.19</td>
</tr>
<tr>
<td>Sense of security</td>
<td>4.17</td>
<td>4.57</td>
<td>4.65</td>
<td>4.67</td>
</tr>
<tr>
<td>Career Interest</td>
<td>4.76</td>
<td>4.75</td>
<td>4.08</td>
<td>4.41</td>
</tr>
<tr>
<td>Motivation</td>
<td>5.21</td>
<td>4.11</td>
<td>3.98</td>
<td>4.72</td>
</tr>
<tr>
<td>Value</td>
<td>5.38</td>
<td>3.27</td>
<td>2.54</td>
<td>4.17</td>
</tr>
<tr>
<td>Leisure Interest</td>
<td>5.94</td>
<td>4.52</td>
<td>3.85</td>
<td>3.70</td>
</tr>
<tr>
<td>Perception about Teacher</td>
<td>5.55</td>
<td>4.36</td>
<td>3.93</td>
<td>4.68</td>
</tr>
</tbody>
</table>

Table 3 shows the means, the sample mean total, the standard deviations and variations of the students’ attitude for each variable of the subscale (dependent variables) and the independent
variables being the scales of the inventory such as SD, D, N, A and SA. In table 3, the mean scores for each of the seven scales as well as the overall mean are indicated.

In Figure 1, the sum total of the mean scores ranges from 17.01 for the descriptor “Societal Implication” to 23.60 for the descriptor “Motivation”. It might appear at the onset that the learners are fully motivated when involved in mathematical studies or that they place a high Value in the subject mathematics. Unfortunately, these results reveal otherwise; students are undecided in their responses. In a sense they have given reasonably equal responses to “Strongly Disagree” and to “Strongly Agree” for both the descriptors. For the other descriptors, the rating appears to be differential. Societal Implication has the lowest score, yet they are in Strong Agreement with most of the items of the sub-descriptor. Although Career Interests does not feature high in the mean profile, their preference for “Strongly Agree” is the lowest in the table of scales. It appears that the role of the teacher cannot be overlooked when attitudes towards mathematics are mentioned (mean value of 22.45) and which calls for a high level of discussion, as will be discussed below.

Statistical descriptors and interpretation

(a) Societal implications

Mathematics plays an important role in shaping the lives of individuals in various spheres such as civic, social and private (Mensah et al, 2013; Anthony & Walshaw, 2009). Thus the necessity for them to go through various stages of mathematical development from primary to secondary schooling. The role of educational practitioners, society and the government is of paramount importance in this regard. For the preparation of mathematically literate citizens of society, the government needs to make adequate financial resources available for the upliftment of mathematics. To be in par with technological innovation, it is a pre-requisite for the curriculum to undergo reformation. Coupled with this, learning outcomes can only be achieved if the learners are in the hands of competent and capable teachers. It is the responsibility of the government, the school, the
governing body and other stakeholders to ensure that the teachers are adequately prepared to meet the challenges of the 21st century competences. Having addressed these issues will go a long way in the upliftment of the moral of the teachers and the concomitant change in the attitude of these teachers. Armed with this predisposition of positivity, the attitude of the learners will likewise change.

The problem of shortage of suitably qualified teachers could be as a result of the unpopularity of mathematics as a subject in society by and large (Sam, 2002). This means that more teachers are choosing easier subjects such as humanity and languages to teach at school. The fact that mathematics is dull and boring subject could be stem from the negative perception (or image) of mathematics in society. Students develop a negative attitude about mathematics due to them repeatedly failing the subject. The rippling effect of this is that these learners as adults will portray negativity and low confidence about mathematics to their children, thereby perpetuating the negative image of mathematics in a vicious cyclic effect. The stigma of mathematicians being few odd and anti-social people will certainly discourage people from venturing into any mathematical or related careers (Sam, 2002). Today many people are scared of mathematics. The negative image portrayed by many people about mathematics is that it is (Sam, 2002):

- difficult, cold, abstract, and in many cultures, largely masculine (Ernest, 1996).

Others describe mathematics as (Sam, 2002):

- fixed, immutable, external, intractable and uncreative (Buxton, 1981).

Mathematicians and scientists are the building blocks of the country’s scientific and economic structure. Having a poor supply of them will have a damaging effect on technological advancement. The mean scores in this category ranged from 1.77 for “Strongly Disagree” to 5.24 for “Strongly Agree”. Most students are in agreement of the overarching role of the government in its primordial task of uplifting and maintaining a high level of mathematics in society.

(b) Sense of Security

This topic highlights the feelings and security of the learner when attempting to solve problems in class of a mathematical nature. If they detest the subject with a passion, they will naturally blank out when immersed in such an environment and display negative tendencies. In this respect, their self-confidence, self-efficacy, self-belief and morals will be low and unsustainable to maintain. They will be rebellious with the teacher and disrupt the class when any opportunity arises. Unfortunately this kind of teacher-pupil relationship is not ideal under such prevailing conditions. On the other hand, if they have a positive attitude towards the subject, their achievement levels would be high and their confidence would also be high to solve more complex problems. These learners will display a sense of security and will be able to achieve maximum learning and develop a more positive attitude towards mathematics in a climate that foster ideal teacher-learner relationship (mutual). This positive attitude will shine and their motivational levels will be high to a point that only achievement and progress will be the order of the day for these learners. This prevailing attitude can be infectious and uplift the moral of other learners as well. In terms of the mean scores, the students are in high affirmation for “Strongly Disagree” (mean score of 4.17) as opposed to “Strongly Agree” (mean score of 3.08). Most students by and large have low levels of security when attempting to work or study in
a mathematics class. Some of the reasons could be: large classes, teachers not passionate about the subject they are teaching, teachers are not well remunerated, learners not at their appropriate grade level, lack of support from the department, lack of standardisation in subject material (textbooks) and tests, etc.

(c) Motivation and Value

It is interesting to note that students’ response on the aspect of “Motivation” is equally divided between “Strongly Disagree” to “Strongly Agree”. In parallel to this, the aspect of “Value” shares a similar trait in their dichotomy of choices for extremes. Mean scores of 5.21 were recorded for “Strongly Disagree” concurs with the mean scores of 5.58 recorded for “Strongly Agree” on the aspect of Motivation. Likewise, a similar mean score of 5.38 recorded for “Strongly Disagree” and a slightly higher mean score of 7.22 for “Strongly Agree” is recorded for the aspect of “Value” in mathematics. The “Value” of mathematics as a necessary subject to study at school in terms of development of skills cannot be over-emphasised. Many students through coercion by their teachers are opting for an easier option by choosing Mathematical Literacy instead of Mathematics. The ramification of this is that they will be limited in terms of career choices. Many students are of the belief that that success after school is not dependent on the subject mathematics. However, students’ strong self-belief and values, their motivation to learn and their attitude towards mathematics is a strong predictor of success in school and beyond. Every attempt is made by students to stay away from any advanced courses in mathematics, such as Advance Mathematics or Additional Mathematics. It appears that these courses are reserved for the elite few. The belief by many students is that mathematics is a “Dull and boring subject”. This stems from the fact that they do not have the confidence to do mathematics problems. Fear of failure is the driving reason for their inability to do so. Thus if the aspect of Motivation and Value in mathematics is changed, this could lead to a change in attitudes towards mathematics, leading to an improvement and success in mathematics. Motivational changes in the learner are brought about by changes in self-esteem, self-regulation, self-concept and self-efficacy (Mata et al, 2012).

(d) Leisure Interest and Career Interests

On the aspect of Leisure Interest in mathematics, students have displayed little interest on issues such as: belonging to a mathematics club, showing enthusiasm and interest in doing mathematics homework, meeting outside the school environment to solve mathematics problems or watching programmes on television explicitly screened for mathematical enrichment. Learners do not take doing their mathematics homework seriously enough to understand why it is given. Some learners are least impressed of getting a mathematics book or mathematical instruments (or calculators) as gifts. In this respect, mean scores for these items on the questionnaire ranged from 5.94 in favour of “Strongly Disagree” to 3.51 for “Strongly Agree” as a negative underlying dimension construct of students’ attitude towards mathematics. There appears to be an inter-correlation between the mean scores of the scales of Career Interest and Leisure Interest in mathematics. Those who enjoy studying mathematics are more inclined to have a career interest in mathematics. Students appear to have little career aspirations of becoming a mathematician. Some do not see their mathematics teachers as role models or that working as a mathematician can be an inspiring way to make a living. Some students may regards such vocations as high paying and respectable, but they do not see themselves as
candidates for such careers because of negative stereotyping associated with the peer culture (Tapia, 2000). This would imply that career choices in the field of mathematics would be limited for the select few. Could this be due to the changes in the curriculum (or poor teaching at school-level), where higher emphasis is placed on problem-solving rather than simple drill and practical applications in mathematics? In this respect a mean score of 2.63, the lowest on the scale has been their response. If in any way their attitudes can be altered, progress can be made in their mathematical performance and a long term progression towards career development in this area would be fruitful proposition (Tapia, 2000).

(e) Perception about Teacher

There is empirical evidence that points to a harmonious relationship between the teachers’ attitude and the students’ performance in mathematics (Mensah, 2013). This means that if the teacher radiated positive confidence in the learner, the students likewise themselves develop a positive attitude towards the learning of mathematics. The psychological characteristics in respect of the positive attitudes of the educator in the students’ mathematical progression is contingent on the following factors: inspiration of the teacher to move the students into a higher echelon of problem solving and with the confidence to do so, exuberance of the teacher’s ability and competence to solve complex problems and the availability and the willingness of the teacher to facilitate learning by truly caring about them to engage in mathematics with the hope of creating the right atmosphere that enhances student learning (Mensah, 2013; Noddings, 1995). Negative teacher attitudes that impinge on the learning of mathematics are: teacher struggles to solve basic mathematics problems; teacher displays outbursts of emotional tantrums (tense and threatening classroom atmosphere) and the unavailability (after school or during breaks) and unwillingness of the teacher to help weak students understand the fundamentals in mathematics. Thus the role of the teacher is irrefutable in radiating positivity and confidence in the learner. In this respect, the mean scores for teacher perception is heavily weighted towards “Strongly Disagree” (mean score of 5.55), while a mean score of 3.93 is allocated for “Strongly Agree” for this aspect of the variable.

Standard Deviations

The means and standard deviations are shown separately in Table 3. Most values of the standard deviation ranged reasonably from 0.60 to 0.88 for most of the descriptors, except for the Societal Implication and Value which had values of 1.37 and 1.65, respectively. It might be useful to note that if these descriptors are removed, the reliability of the measuring instrument could have a higher Cronbach coefficient and a better reliability index.

Cronbach Alpha (coefficient) as a measure of reliability of results

In determining the Cronbach’s alpha coefficient, the following formula as well as the data from Table 2 (derived from the questionnaire) was used (Zaiontz, website retrieved 2015):

\[
\text{Cronbach alpha coefficient } (\alpha) = \frac{k}{k-1} \left(1 - \frac{\sum_{j=1}^{k} x_j^2}{\text{var}(x_0)}\right),
\]

where k represents the number of items in the descriptors. The rest of the data is in table 2. Cronbach’s alpha is useful in that it provides lower bounds on reliability. Its value tends to increase if there are correlations between items in the questionnaire. Thus neglecting some parameters may yield a higher Cronbach alpha coefficient. Its
value ranges from 0 to 1, a value of 0.7 is acceptable, and if the value is above 0.8, means a good
degree of reliability. Our goal was to design instruments that show reliability and consistency for
meaningful contribution. On the other hand, if the value of the Cronbach alpha is above 0.95 means
that some items in the questionnaire are redundant and must be discarded. We have obtained an
acceptable value of $\alpha = 0.74$ for the Cronbach alpha coefficient. The error in the variance is obtained
as follows: $0.74^2 = 0.5476$, thus the error is obtained by subtracting this value from 1, giving an error
value of 0.4524 for the variance.

**Conclusions**

The items on the questionnaire show an acceptable degree of reliability from the value of the
Cronbach coefficient obtained ($\alpha = 0.74$). However, this value could even be higher if one of the
items on the descriptor sub-scale, societal implication, could be removed to improve the reliability of
the instrument. On the other hand, if this survey was done with learners from the schooling sector
may reveal a slightly better degree of reliability. If other variable descriptors such as gender, ethnic
background, and grade level were taken into consideration for this survey, then this survey would
have been more conclusive in its investigation (Tapia, 2000). Research has revealed that a similar
survey done at the beginning of the year and at the end of the year has led to attitudinal changes in
the learners.

The psychometric aspect attitude plays a pivotal role in any long-term trichotomy relationship
between a teacher, learner and parent. Attaining a harmonious relationship in this respect will sustain
long term changes in attitude of the learner. Too much attention on grade improvement only at the
expense of other pertinent issues such as attitudes of the learner towards mathematics can be
detrimental. However, addressing both these issues could be the key ingredients of success. The role
of the teacher, expertise and passion for the subject could alleviate the subjects’ rightfulness place in
society.

In respect of the responses from learners on attitudinal sub-scale descriptors, “Motivation” for the
learners to study mathematics and the “Value” they associate with studying mathematics, learners
was equally divided between assigning “Strongly Agree” to “Strongly Disagree” to the following
items on the questionnaire:

- I have really enjoyed studying mathematics at school; and Mathematics is a useful and
  necessary subject to study at school.
- Mathematics is dull and boring; and I am scared of answering questions in a mathematics
  class.
- I believe studying mathematics helps you in every other area of your life; and Mathematics
  develops and broadens the mind and teaches a person to think.
- I would avoid taking any mathematics courses at university; and Mathematics literacy is a
  better option than studying mathematics.
- Studying advance or additional mathematics is exciting; and I like studying mathematics
  because it develops my mathematical skills.
- I believe I have a lot of weaknesses in mathematics; and Success after school is not dependent
  on mathematics.
The following are major conclusions pertaining to the attitude about learners towards mathematics (which epitomizes some of the key issues (besides gender) to success in mathematics) (Tapia, 2000; Opachich, & Kadijevich, 2000):

- Mathematics achievement is closely related to self-concepts and attitudes towards mathematics.
- The effect of mathematics attitude on mathematics achievement is mediated by self-efficacy.
- Confidence and self-esteem are linked at higher levels to success in problem solving.
- Confidence of success in a math-related course is a stronger predictor of choosing math majors than either confidence to solve mathematics problems or to perform math-related tasks.
- There are no differences in mathematics achievement by gender, but males have higher mathematics self-concepts and self-perceived mathematics skills than females.

From the above, it is noted that self-efficacy is a key predictor of success in mathematics. Research in the area of attitudes towards learners needs to be ongoing so as to understand the level of Motivation of the learners from time to time. Instruments designed for that purpose needs to be continually optimised through modifications, guided by research, to get the best indicators of success.

References

Analysing Annual National Assessments to improve both teaching and assessment practices

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Working in a South African national context where investments have been made in the design, administration and collection of standardised assessment data in the form of the Annual National Assessments (ANAs), we ask: How can these investments be leveraged to focus attention on better learning, better teaching, and also better assessment? To stimulate debate relating to this question, we draw on an empirical base of Grade 3 ANA data from two public schools. We offer a descriptive account of how attainment in mathematics ANAs was analysed quantitatively and then qualitatively so that school managers and teachers in these schools could make decisions relating to improving their teaching. Further we present the results of a more sophisticated analytical technique (Rasch analysis) which was used to further make use of the ANA evidence to identify problematic aspects of the assessment process.

Introduction

Annual National Assessments (ANAs) have been introduced into the South African basic education system since 2011 as a means of assessing learning in languages and mathematics in Grades 1 to 6 and at Grade 9. Since their introduction, the administration of these national assessments have been met with criticisms or concerns from various parts of the research community. For example, concerns have been raised about the expense of administering such assessments (Kanjee, Sayed, & Rodriguez, 2010), the lack of common items across years which mitigate against annual comparisons (Kanjee 2011), concerns about lack of invariance particularly with translation of test items into different languages (Dampier, 2014), the linguistic complexity of mathematics test items (Sibanda & Graven, 2015), and concerns and inconsistencies in the mathematics marking framework (Graven & Venkat 2014). Graven and Venkat (2013) reported on primary teachers’ experiences of administering the mathematics ANAs and raised concerns about the language of the ANAs and language fluency of learners, the amount of time spent in primary schools administering these tests, the anxiety of learners, inaccurate and inappropriate marking memoranda, and the inappropriate timing of the ANAs at the end of the third term (and not at the end of the academic year).

Furthermore, the ANA process is criticised as being a system of ‘recording and reporting’, where reporting and recording of assessment information are privileged over the effective use of the information to improve learning and teaching practices (Kanjee & Croft, 2012). Kanjee and Sayed (2013) argue for greater use of ‘assessment for learning’ practices, and identify the lack of capacity of teachers and support to teachers in making effective use of assessment to inform teaching. Kanjee and Moloi (2014), identified ‘the single most critical challenge to address pertains to supporting teachers and schools in enhancing their use of assessment results to improve learning in all classrooms’ (p.109).

In this paper, we aim to make a contribution to better support teachers and other stakeholders to make use of the ANA data that teachers collect in their schools to reflect on and inform teaching, and also
to improve the assessments. This research differs from previous research conducted on ANAs as it reports on empirical data from two public schools in South Africa to demonstrate how teacher marking of ANA scripts; as well as qualitative analysis of learners’ responses to particular ANA questions was supported in order to for this data to be used timeously to inform teaching. This research is important as it offers potential ways of making use of ANA data – at school level - to guide mathematics instruction; and so inform mathematics teaching. As such, our work is framed in relation to the following overarching question: Working in a national context where large-scale investments have been made in the design, administration and collection of standardised assessment data in the form of the ANAs, how can these investments be leveraged to focus attention on better learning, better teaching, and also better assessment?

To suggest a possible response to this question, or at least stimulate further debate about answering it, we draw on an empirical base of Grade 3 ANA data from two Western Cape Education Department (WCED) public schools which were supported by a research intervention referred to as the *Focus on Primary Maths project* (2012-2014). We offer a descriptive account of how attainment in ANAs at the Grade 3 level was analysed quantitatively and then qualitatively so that school managers and teachers in these schools could make decisions relating to improving their teaching. Working at the micro-level of particular schools, and sensitive to the skills constraints amongst FoundationPhase teachers in relation to their use of computer programmes and quantitative reasoning, most of the analytical techniques used were deliberately simple and designed for use at the school level by the teachers who mark their learners’ ANA scripts. We reflect on the process of support which was necessary at these two schools for such ‘simple’ descriptive analysis to be undertaken. In addition, we present the results of a more sophisticated analytical technique (Rasch analysis) which was used by the research team in order to further make use of the evidence to further identify problematic aspects of the assessment process.

**The Focus on Primary Maths project**

The Focus on Primary Maths project (hereafter referred to as ‘the project’) was a focused intervention involving a consulting company with expertise in mathematics education, and the school leadership and teaching staff at Foundation Phase level in two schools in Cape Town: A township school and a suburban school. While the suburban school is affluent (poverty quintile 5) with an established track record of excellent attainment in mathematics and language, the township school is a relatively well-resourced school in a community of low socio-economic status (classified as a poverty quintile 3 and being a no-fee school). The township school is a relatively new school located in a poor township community which was performing below the provincial average in standardized assessments.

At the time of the project (2012-2014), both schools were relatively large primary schools with approximately 700 learners. The project aimed to:

1. Support ‘focus on maths’ teams, involving interested staff at each school, which focused on numeracy teaching and learning.
2. Provide staff professional development in mathematics education through:
   a. Offering mini professional development seminars on topics of interest related to mathematics education
   b. Seeking out appropriate professional development interventions for interested staff, and
c. Collaborative co-teaching interventions which enabled the ground work laid though training / professional development to be realised in classroom practice.
3. Identify areas of particular weakness as evident in the ANAs and systemic assessment results from each school, and work on classroom level interventions for these problem areas.
4. Share the lessons learnt and approaches used in trying to improve the numeracy results in the particular case study schools with a wider audience (through academic and/or practitioner publications and conferences, communities of practice, and other means as appropriate).

In this paper we focus specifically on the project activities pertaining to the third aim: Identifying areas of particular weakness as evident in the Annual National Assessments.

**Theoretical approaches and methods of analysis of assessment data**

In this section we explain the theoretical frameworks informing the way in which we analysed the ANA data and describe the methods adopted.

In carrying out an analysis of ANA data, there were two general approaches that we could take: we could use theoretical approaches based on classical test theory (CTT), or draw on methods based on item response theory (IRT) (Kline, 1993). CTT generally looks at four major concepts: item difficulty, item discrimination, reliability and the total score from the assessment (Weiss & Yoes, 1991). We made use of elements of CTT by making use of the total ANA scores of each learner. We reported on the mean results, standard deviation, maximum and minimum scores, as well as the percentage of learners passing the ANAs by grade and by class in each school (using 50% as adequate attainment). Over time, these descriptive statistics were compared on a year by year basis to the national means, so that teachers could reflect across each year on attainment of different cohorts in their grade.

We also made use of CTT by focusing on item difficulty. To do so, we captured learners marks on a per question basis which allowed us to calculate item difficulty, defined by Crocker (2006) as the ‘proportion of examinees who answered an item correctly’ (p.374). Considering the mark allocations for each item in the ANA, the total marks obtained by learners in a particular test item in a school were summed and expressed as a proportion of the total available marks. This gives a facility score per question which ranges from 0 (all learners got all aspects of the question incorrect) to 1 (all learners got all aspects of the question correct), and this can in turn be expressed as percentage. This offers a measure of the difficulty of a question in the test in relation to learners in each school.

Alternatively, in IRT, a probabilistic response model can be applied to assessment data in order to determine characteristics of the various items (Kline, 1993). There are a variety of IRT models that can be applied. In this study, the ANA data was analysed using Rasch analysis. Rasch analysis is a one-parameter IRT model, in which the probability of a person being successful on a given item is modelled in terms of a mathematical function involving the difficulty of the item and the ability of the person (Bond & Fox, 2007). This function is given by the following equation:

\[
P_i(\theta) = \frac{e^{(\theta - b_i)}}{1 + e^{(\theta - b_i)}} \tag{Equation 1}
\]

\(P_i\) is the probability of a person answering item \(i\) correctly, \(\theta\) is the ability of the person (measured in relation to their overall attainment in the test), and \(b_i\) is the difficulty of the item. Estimation methods are used to find the values for person abilities and item difficulties, and these are given on the same
The Rasch model can be used for dichotomous responses (e.g. right and wrong), or extended to cover more than two responses (Wright & Mok, 2004) including missing responses. Using a modified form of equation 1, items with different possible responses, for example dichotomous (0 or 1) for some items, and more possible responses such as 0, 1 and 2 for other items, can be catered for. This is known as the partial credit model (Wright & Mok, 2004), and this approach was utilised in this study. An underlying assumption of Rasch analysis is that the construct being measured is unidimensional in nature (Bond & Fox, 2007). A variety of software programs can be used to carry out Rasch analysis. In this study, WINSTEPS software was used to carry out this Rasch analysis.

A particular advantage of Rasch analysis is that it provides additional information (compared to CTT) in order to critically analyse the performance of items in the assessment tool being used (Boone & Rogan, 2005). For example, items that do not fit the Rasch model, and may therefore be problematic for measuring the particular ability under investigation, may be identified through ‘fit’ statistics obtained from the Rasch analysis. In estimating the ability of candidates and the difficulty of items in a given assessment, we can calculate the theoretical probability that a given candidate will answer a given item correctly, and we can compare this theoretical probability with the actual probability from the data collected. Based on this comparison of the theoretical model and the empirical data, residual values can be calculated (i.e. the difference between the empirical and theoretical probabilities), and the square of these residuals can be summed over all persons answering a given item to provide an item ‘fit’ statistic. The residuals can be unweighted in this process providing an ‘outfit’ statistic. Alternatively, as the outfit statistic is sensitive to responses from candidates who are much more or less able than the item difficulty, the summing of the residuals can be weighted to provide an ‘infit’ statistic (Wright & Mok, 2004). In this way, items where the empirical data seems to depart excessively from the theory, i.e. items that do not seem to fit the Rasch model, and may therefore be problematic for measuring the particular ability under investigation, may be identified through these ‘fit’ statistics. For these fit statistics, Bond and Fox (2007) recommend that the mean square values should be within the recommended range of 0.7 to 1.3, otherwise the items can be considered to be problematical.

In addition to fit statistics, we can also critically examine the performance of items using differential item functioning (DIF). DIF is used to detect bias in items, i.e. where an item is favouring a particular group of respondents over others, and is defined as “an item shows DIF if individuals having the same ability, but from different groups, do not have the same probability of getting the item right” (Hambleton, Swaminathan, & Rodgers, 1991, cited in Kanjee, 2005, p.63). In Rasch analysis, DIF statistics are calculated by fitting separate functions for different groups for the same item, and calculating the estimated item difficulty from each function. If the item difficulty for each group is significantly different (this difference being referred to as the DIF contrast), then this suggests that the item is behaving differently for different groups and therefore biasing against groups of respondents. Zwick, Thayer, and Lewis (1999) suggest that values of 1.5 or more for the DIF contrasts suggest items with possible bias.

In the following analysis of the ANA assessment data, in addition to the CTT approach, Rasch analysis will also be used, in particular the estimation of fit and DIF statistics, to identify problematical items in the assessment.
Analysis of the results
Beginning with the classical approach to test analysis, tracking of the learning gains made by learners at the two schools as part of the project was carried out using the ANA results. Although not in focus in this paper, it should be noted that analysis was also conducted on standardised assessments (using Early Grade Mathematics Attainment interviews) and the results from WCED systemic assessments were used alongside ANA analysis.

General descriptive statistics
We report first on the Grade 3 attainment using the following measures: mean results per school, and the percentage of learners passing the assessment (using a 50% attainment as the adequate attainment mark).

![Figure 5: ANA mathematics (percentage passing)]](image)

Improvements were considered only with regard to comparison to the national mean, and the ANA assessments did not include anchor questions which would allow school-level comparison year on year. The suburban school maintained excellent results over the project intervention period. From a low baseline of 25% of learners passing in 2011, the township school saw annual improvements in mathematics attainment in relation to the percentage of children passing. From 38% of Grade 3 learners passing in 2012, there was an improvement of 37 percentage points in 2013, and a further improvement of 9 percentage points in 2014.
The improvements in ANA attainment were also evident in the improving mean results for the ANAs. While the suburban school showed small improvements from an already very high baseline, the township school improved by 23 percentage points in 2013 and a further 5 percentage points in 2014. In so doing, the township school moved from below the national average to well above it. The improvement seen by the township school was steeper than that evident from the national improvements for both percentage passing and the mean. Having access to comparative data (from the district, the province, and the whole country) allowed for comparisons to be made between the attainment at the school and the attainment in these bigger populations. Without comparison to the national mean, it would not have been possible to claim improvements by the school (as the later scripts may have been easier question papers than those used in previous years; and the absence of common items made comparison impossible).

Using the mean results for each grade in each school provided an indication of year-by-year attainment in the ANAs by each school. In addition, we reported to the schools some basic descriptive statistics on attainment in the ANAs by class. We provide an example of this kind of reporting, making use of the township schools’ Grade 3, 2014 data.

Table 6: Township school Grade 3 mathematics ANA data 2011-2014

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade average</td>
<td>25%</td>
<td>37%</td>
<td>60%</td>
<td>65%</td>
</tr>
<tr>
<td>Percentage passing</td>
<td>7%</td>
<td>38%</td>
<td>75%</td>
<td>84%</td>
</tr>
</tbody>
</table>

Table 7: Township school Grade 3 mathematics ANA data by class 2014

<table>
<thead>
<tr>
<th>2014</th>
<th>3A</th>
<th>3B</th>
<th>3C</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number writing</td>
<td>26</td>
<td>27</td>
<td>27</td>
<td>80</td>
</tr>
<tr>
<td>Minimum</td>
<td>20%</td>
<td>0%</td>
<td>15%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Figure 6: ANA mathematics (mean)
<table>
<thead>
<tr>
<th>Mean</th>
<th>68%</th>
<th>70%</th>
<th>57%</th>
<th>65%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>93%</td>
<td>90%</td>
<td>85%</td>
<td>93%</td>
</tr>
<tr>
<td>Std deviation</td>
<td>17%</td>
<td>17%</td>
<td>17%</td>
<td>17%</td>
</tr>
<tr>
<td>Number passing</td>
<td>23</td>
<td>26</td>
<td>18</td>
<td>67</td>
</tr>
<tr>
<td>Percentage passing</td>
<td>88%</td>
<td>96%</td>
<td>67%</td>
<td>84%</td>
</tr>
</tbody>
</table>

Such reporting was used in the project to reflect on the class groupings, and to highlight areas of possible need relating to teacher support for particular teachers. For example, as a result of the reporting of the descriptive statistics to the school (and including the national and district trends), the township school made changes to their class groupings. In 2012, ability groupings were applied to classes; in 2013, a combination of ability groupings and mixed ability classes were trialled; in 2014 there were three mixed ability classes. The school management team in the township school therefore used the ANA results (and the provincial standardised assessments) to inform their decision making relating to the efficacy of their class selection practices. The 2014 ANA results in mathematics further informed the school management team’s decisions relating to staffing for 2015 (specifically, which teachers were allocated to which classes and grades) and professional development (for example additional mathematics professional development and support to the teacher of the 3C class in 2014 was recommended).

In reflecting on the use of the ANA results to support the schools and the teachers, it is also worth reporting briefly on how the analysis of the ANA results changed in these two schools over the project period (2012 to 2014).

In 2012, the ANA scripts were marked by teachers and the reporting and recording of marks was sent to the district. Only after this process was complete did the project team review the ANA scripts at each school and attempt to capture marks on a question by question basis. Two issues emerged through this process: firstly, by using a spreadsheet template, errors in the calculation of the total marks (conducted by the teachers) become evident; secondly, inconsistent marking and at times inappropriate application of the memorandum were observed. In some cases, learners’ answers that were marked as incorrect were found to be correct; in other cases the allocation of marks for working were awarded inconsistently between different teachers. Such errors in the application of the marking framework were only for a small minority of question items (but such problems were reported as more widely occurring in related research; see Graven and Venkat (2014) and Graven and Venkat (2013)). This put into question the quality of the data reported to the district, and suggested a need for tighter moderation and support of the marking process.

In 2013 both schools agreed to schedule an afternoon when teachers would come together for each Grade to mark their scripts. A project support person was allocated to each Grade team. As teachers marked, the project support person captured the results using a spreadsheet template. The spreadsheet template was developed from the previous year’s experiences and included the list of learners’ names and surnames per class. The template allowed for a question-by-question capture of the marks for each script. The template made use of simple calculation functions such as the ‘sum’ function to check addition of marks in the scripts, and the use of the ‘average’ function to calculate the class mean and grade means; and the use of ‘count if’ for percentage passing. The teachers therefore got immediate feedback on their class results (which had not been the case in previous years where they
waited for the district report to obtain this information). Marking groups by grade took place after school hours on the day of administering the ANA script with learners. Discussions about the application of the marking memorandum could then be held with all of the teachers in a Grade, with the aim of applying the same approach to all of their marking.

In 2014, a similar process was adopted. At this point in the project, the teachers now seemed to be more secure about their mathematics knowledge and discussed issues of interpretation of the memorandum within their Grade teams.

**Analysing and responding to item difficulty**

With the learner responses captured item by item, it was also possible to calculate the difficulty levels of each item. Teachers had been requested by their district to complete forms (their ‘record and report’ function) to the WCED. In 2011, this was done by the head of Foundation Phase who gathered the information by asking the teachers ‘which were the questions where your learners did not do well?’ The teachers were therefore reporting to the district on areas of common difficulty based on their subjective experience and recollection of marking the scripts, and not based on the learner marks for each question. With the question by question data available, from 2012, it was now possible to identify the 5 to 10 questions with the poorest attainment, and to order these in terms of level of difficulty. What was reported to the district was now based on empirical data from the learners’ marks across the grade.

Comparing the two schools, the items of particular difficulty for learners differed from school to school. By way of example, while ‘money’ emerged as a topic area where learners required intervention in the township school, in the suburban school, questions on ‘analogue time’ were found to be the most poorly answered. Teachers in each school were given a list of the questions (and related topics) requiring additional support and intervention, with the intention that these were revisited with their classes in the fourth term (before their class progressed to the next grade). Having the ANAs administered at the end of the third term was viewed as an opportunity to allow for focused remediation in the fourth term. In addition, lesson study interventions (comprising joint planning, teaching and then reflection on the teaching of these topics within a Grade team in a school) was planned for ‘money’ and ‘fractions’ at the township school, and for ‘analogue time’ at the suburban school.

**Rasch analysis**

In addition to this school level analysis using the CTT approaches, the project team also carried out a more sophisticated analysis of the Grade 3 ANA data, to illustrate how the analysis of assessment data across schools could be carried out, for example at district, provincial, or national levels. In this study, we are of course restricted to the analysis across the two schools in the project only. Therefore, the item by item scores in the spreadsheets from the analysis above was now imported into the WINSTEPS program for Rasch analysis to be carried out.

Rasch analysis can provide a whole range of statistics relating to the ANA assessment and the individual items in the test. For example, item difficulties could be calculated to provide similar statistics to that of the analysis above. Also, the Rasch analysis provided a reliability measure for the assessment, where the Cronbach α score was estimated to be 0.86, showing that the Grade 3 ANA
assessment was working well as a reliable instrument overall. However, we could also have calculated reliability through CTT approaches. Therefore, we will focus here on measures which we can only calculate through IRT approaches, namely the misfit statistics and the DIF analysis results.

We began by identifying the misfitting items from the Rasch analysis. Table 4 shows all the items with infit/outfit values outside of the recommended range.

**Table 8: Misfitting items**

<table>
<thead>
<tr>
<th>Item</th>
<th>Infit Mean Square values</th>
<th>Outfit Mean Square values</th>
</tr>
</thead>
<tbody>
<tr>
<td>19. Mum shared 42 sweets equally amongst her 3 children. How many sweets did each child get?</td>
<td>3.06</td>
<td>3.68</td>
</tr>
<tr>
<td>22. Calculate 489 - 256 by using the ‘breaking down’ method.</td>
<td>2.57</td>
<td>2.69</td>
</tr>
<tr>
<td>21. Calculate 245 + 153 by using the ‘adding-on’ method.</td>
<td>2.03</td>
<td>1.94</td>
</tr>
<tr>
<td>26. Calculate 42 ÷ 2.</td>
<td>1.82</td>
<td>1.71</td>
</tr>
<tr>
<td>18.1. In the toy box there are 12 soccer balls, 12 rugby balls and 12 tennis balls. How many balls are there altogether?</td>
<td>1.8</td>
<td>1.63</td>
</tr>
</tbody>
</table>

To further illustrate the nature of responses to the misfitting items, and also from an item with good fit statistics, are plotted in in Figures 3 and 4 respectively.

![Figure 7: Empirical and expected ICC for misfitting item (suburban school)](image)
Each graph shows the item characteristics curve (ICC) for each item. The expected theoretical shape of the curve (central solid line) relates the expected relationship between the average score achieved (y axis) against the average ability of the respondents relative to the item difficulty (x axis). The line with crosses shows the empirical data obtained from the assessment. The thin lines either side of the central solid lines show the 95% confidence interval for the expected shape of the (ICC). It can be seen that for the misfitting item, more of the empirical data lie outside of the confidence interval for the expected ICC.

The misfitting items included two word problems (one relating to a division context of equal sharing of sweets, and another relating to an addition context of balls in a toy box). The three bare calculations related to a subtraction and an addition calculation where which calculation method to apply was specified in the question (subtract by ‘using the breaking down method’ and add by using the ‘adding on method’). The final bare calculation related to division (halving).

It was of interest that concerns about questions that specify which method to apply in a calculation have been criticised in prior research. Graven and Venkat (2013) argue for accepting a variety of methods in responses to ANA items, noting that teachers raised concerns that the ANA exemplar and paper memos did not accept alternative methods for working with calculations. This is problematic given the research evidence that multiple representations are an important part of mathematical learning. In practical terms it is also highly discouraging for teachers.
and learners to be marked down for answers that have been correctly produced (p.16)

A similar argument is put forward in Graven and Venkat (2014). The Rasch analysis in this small study suggested that accepting a variety of methods may be necessary to avoid questions being misfitting (and so not appropriately differentiating learners to assess what was intended). It stands to reason that assessing a learner on their application of a particular method to a calculation may not accord with assessing the same learner’s ability to correctly perform the calculation. This puts into question the rationale for expecting particular methods to be adopted for calculations.

In looking for other possible reasons behind the misfitting of these items, when we examined both the questions and marking memorandum for these questions, we found that all of these questions made use of 2 marks for marking (1 mark as for the correct answer, and another for the application of a method). We conjectured therefore that the items were misfitting may be a result of the different applications of the marking framework, where teachers were given some discretion in the allocation of the ‘method’ mark.

Following the identification of misfitting items, DIF analysis was also carried out, identifying items that seemed to be behaving differently when comparing the two schools in the project. Table 4 shows the items for which the DIF contrast values appeared to be large (> 1.5).

Table 9: Items with DIF contrasts greater than 1.5

<table>
<thead>
<tr>
<th>Item</th>
<th>Topic</th>
<th>DIF contrast</th>
<th>Possible bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>10. Draw only one line of symmetry on the following shape. (Hexagon)</td>
<td>Shape and space</td>
<td>-2.54</td>
<td>Against suburban school</td>
</tr>
<tr>
<td>8. Write down the name of the given object below. (Cylinder)</td>
<td>Shape and space</td>
<td>-2.05</td>
<td>Against suburban school</td>
</tr>
<tr>
<td>23.1 Which is the most popular pet? (Bar graph shown)</td>
<td>Data handling</td>
<td>-1.52</td>
<td>Against suburban school</td>
</tr>
<tr>
<td>24.2. Jack buys a trumpet and pays with a R50 note. How much change will he get? (Price of trumpet given in diagram)</td>
<td>Numbers: money</td>
<td>2.4</td>
<td>Against township school</td>
</tr>
<tr>
<td>25.1. Convert R3,50 = ________c</td>
<td>Numbers: money</td>
<td>2.13</td>
<td>Against township school</td>
</tr>
<tr>
<td>24.1. Which two musical instruments can you buy for exactly R38,50? (Prices given in diagram)</td>
<td>Numbers: money</td>
<td>1.97</td>
<td>Against township school</td>
</tr>
<tr>
<td>27. Draw the hands on the analogue clock to show that the time is 05:15.</td>
<td>Measurement: Time</td>
<td>1.91</td>
<td>Against township school</td>
</tr>
</tbody>
</table>

When interpreting the DIF contrast values, positive values indicate items that possibly bias against the township school, and the negative values items that possibly bias against the suburban school. The majority of the items identified as possibly biasing against the township school involved money. Two out of the three items biasing against the suburban school involved shape and space.
Qualitative analysis of learner responses
Reasons for the possible biases against each school were then further explored by examining the learner responses to the biased items in each school by undertaking a qualitative analysis of the scripts at each school.

The possible bias against the suburban school relating to the shape and space questions may be a result of less curriculum focus on the ‘Shape and Space’ and ‘Data handling’ topics within this school. The teachers in this school specifically focussed at Foundation Phase level on number and operations work, and little teaching time was spent on ‘Shape and Space’ and ‘Data handling’. In addition, the instructions to draw ‘only one line of symmetry’ was not followed by some learners at this school, and they were penalised for identifying more than one line of symmetry by the teachers in their school who marked their scripts.

We examined the money questions which seemed to be biased against the township school by examining the responses from each school and identifying common errors in the learner activity. The first question relating to money (24.2) was presented as following in the ANA script:

![Figure 9: Question 24 in Grade 3 ANA](image)

The common error for learners getting this question incorrect was in the calculation involving a decimal number. Learners correctly selected the price for the trumpet as R18,25. They also correctly identified the appropriate mathematical model for the calculation as the wrote down R50 – R18,75 as their number sentence. Their difficulties arose when performing this calculation:
Figure 10: Calculation errors in working with decimal notation in context of money

Difficulties in working with both Rands and cents in decimal notation were also evident for second money questions. The question was posed as follows

![Figure 11: Question 25.1 in Grade 3 ANA](image)

Some of the learners responses were completely incorrect (such as R3,50 = R1,50c), suggesting that they may not have understood the term ‘convert’. The most common error for the township learners as breaking up the R3,50 into possible combinations of coins:

![Figure 12: Learners breaking up R3,50 into cents and not ‘converting’](image)

This same error was evident amongst the suburban learners, but this was less common. As a result of this observation additional teaching intervention on working with the decimal notation in the context of money was prioritised in the township school. Explicit use of the term ‘convert’ was encouraged in all measurement contexts.

**Conclusion**

With regard to better teaching and learning this paper demonstrates that there are possibilities for the investments in ANAs to be leveraged to focus teacher attention on learning absences and using these to plan reflective interventions on their teaching. The project intervention supported Foundation Phases teachers to come together across each grade, and then together as a phase, to collaborate and
discuss their marking of scripts; record their learners’ marks on a question by question basis, and use this self-generated data to identify empirically-grounded areas of particular need. The identified areas of concern were then used to inform tightly defined ‘mini-lesson studies’ aimed at better teaching and better learning of the identified topic. This process was an important element of several project interventions which can be used to account for the better learning (evident in improved attainment in both ANA and WCED systemic assessments) in this township school evident over the three year project period. One aspect of the way we worked with the ANAs contradicts prior documented concerns raised by teachers about the timing of the ANAs in the third term (Graven & Venkat 2014). In the approach we adopted, the timing of the ANAs was thought to be valuable, as it was possible to interpret learner attainment in a particular class, and still remediate identified areas of common difficulty with the same class and same teacher in the fourth term. We are not arguing that this can be achieved in all South African schools in the absence of facilitation and its related instructional leadership. To the contrary, we think that school-level instructional leadership is essential for such a process to be successful. In this regard we concur with Brodie who argues that ‘the facilitator was central in creating possibilities for enquiry, collectivity, safety and challenge in the community’ (Brodie, 2014, p. 237).

With apparent growth in interest, and support for, professional learning communities amongst teachers; we urge school management teams, heads of department; teachers, subject advisors (as well as the teacher training and professional development providers) to support the schools in their care to take ownership of the local school-level data which teachers ‘record and report’ to government, and to reflect on whether there is any meaningful information which can be used to inform their actions at the school level. Drawing on the data and experiences of two WCED schools in attempting such a process, this paper has offered a way for schools (and potentially districts) to make use of the data which they are obligated to record and report, and use this as a source of evidence to inform their teaching. We think this small study offers a picture of possible with regard to ANA ownership and utilisation at school level, and that the basic descriptive statistics methods (conducted using a spreadsheet) and theoretical approaches utilised are not beyond reach and could be replicated in other public school contexts. When reflecting on possibilities for better assessment, the more sophisticated analytical approach of Rasch analysis becomes relevant. This is not work which we expect to see taking place at school level – but it is an approach that provincial research units; and the national Department of Education ought to consider in the utilisation of the ANA data for better assessment instrumentation in future.

Firstly, we concur with Kanjee (2011) that the ANA assessments ought to include common items (anchor questions) to allow year on year comparison. These anchor questions need not be invariant over time. The inclusion of anchor questions across grades would also improve the possibilities for comparing grade level performance. Secondly, for the ANA data to be meaningfully utilised, question-by-question reporting on attainment and schools should be required to submit their marks in this format. We conjecture that this would help to reduce misreporting and incorrect addition of marks; as the errors made would be evident in a mismatch between the spreadsheet and the script (as was the case in this small study). Thirdly, this small study coheres with prior research in early grade mathematics education which has raised concerns about ANA question items that expect learners to apply a specified method for a calculation or which are marked using a specified method (Graven &
Two of the misfitting questions identified expected learners to solve a basic calculation using a specified method.

Finally, issues relating to problems with the marking of questions by teachers in this small study, and noted previous in Graven and Venkat (2012) seem to be exacerbated when there is partial marking. This conjecture has been inferred since all the misfitting items on this study had the possibility of partial mark allocations in common. This suggests that Rasch analysis on bigger samples ought to be undertaken to establish whether such items are misfitting for the larger population of learners. To then improve the reliability and validity of the assessments, reasons why items are misfitting should be investigated. In addition, DIF analysis can be conducted to test for potential bias in particular types of questions which may help to reveal how inequalities, identified in patterns of attainment in the national system, play out at the micro-level of individual question items.

References
Technology Education (SAARMSTE): Mathematics, Science and Technology Education for Empowerment and Equity, Maputo, Mozambique:
Five years on: learning programme design for primary after-school maths clubs in South Africa

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Both globally and in South Africa, out of school time (OST) programmes are increasingly seen as ways to extend learning and bridge the gap between home and school contexts. Literature reveals that OST programmes with an academic focus that have sequenced, active, focused and explicit design features show positive findings. The purpose of this conceptual paper is twofold: 1) to describe the design of an academically focused primary after-school maths club learning programme that has been tested in a South African context over a five-year period in a development and research project and 2) to situate this design in the broader literature and context of other such programmes. The sharing of this design may be useful in terms of it having been tested in many clubs over the 5 years, providing a prototype for after school programmes of this type. Additionally it is a way of communicating the framework for expanding the sphere of influence of the club programmes beyond the immediate project. Furthermore, due to a lack of published research and publication into these types of programmes in our local context, this article calls for more of this kind of work in order to provoke discussion about the design of local OST programmes and their effectiveness.

Keywords: out of school time programmes, Vygotsky, after-school maths clubs, zone theory, zone of proximal development, learning metaphors, primary school, South Africa

Introduction, context and focus of the paper

As a member of the South African Numeracy Chair (SANC) project, I co-ordinate and facilitate a number of primary after-school mathematics clubs. Two Grade 3 after-school maths clubs formed the empirical field for my doctoral research. As the maths club co-ordinator I am responsible for the club-learning programme design and related facilitator training for the SANC project. My work within the SANC project is thus focussed on both development and research in the field of numeracy.

The challenges with mathematics education in South Africa are well documented (see for example Fleisch, 2008; Schollar, 2008) and I will not repeat them here. With these challenges foregrounded, one key strand of the SANC project development work is direct learner intervention activities. After-school mathematics clubs are the projects’ major regular learner intervention (Graven, 2011; 2012) and serve two purposes: firstly, they are a place where the SANC project team can directly influence what happens with learners and secondly, they provide the project research community with an empirical research field in which they can interact directly with the learners and thus be insiders to the learning process (Graven, Stott, Mofu & Ndongeni, 2014). Since 2012 the project has run 26 clubs for over 284 grade 2 to 5 learners and have supported another 16 clubs outside the immediate project.

The after-school clubs are conceptualised as informal learning spaces focused on developing a supportive learning community where learners can develop their mathematical proficiency, make sense of their mathematics and where they can engage and actively participate in mathematical activities (Graven, 2011). Individual, pair and small group interactions with mentors are the dominant practices with few whole class interactions. The clubs are intentionally designed to contrast some of the more formal aspects observed in the classrooms of the SANC project participating schools (Graven & Stott, 2012; Graven, 2011). Research findings from after-school clubs have been published elsewhere, see for example Stott (2014 and in press).

In an earlier publication, Stott and Graven (2013) reflected on how a pilot club in 2011 influenced the proposed design of the learning programme for my subsequent doctoral research clubs. The
emergent design discussed in this previous work was used for the two research clubs, which formed the empirical field for my doctoral study in 2012 but was as yet untested beyond the pilot and research clubs. In this conceptual paper, I build on this earlier work and specifically focus on two aspects. Firstly, I position this design in the broader out of school time (OST) field. Secondly, I document and share the actual club-learning programme design that has been tested over a five-year period in a range of research and non-research clubs. This design framework forms the basis of the project’s maths club model. In the last two years, the design framework has been communicated as detailed here to organisations beyond the SANC project that have started and run maths clubs using the project model.

The intention in sharing this design is to expand on both local and international research about such programmes and to stimulate discussion about OST programme design and effectiveness. In this conceptual paper, I discuss the theoretical framework underlying this design, review and connect the club design with relevant literature and then share the club-learning programme design.

Theoretical framework

Theoretically, a broad perspective of Vygotskian learning and development forms the basis of the club-learning programme design which additionally draws on Sfard’s (1998) early work with learning metaphors. Vygotsky (1978) conceptualised development as the transformation of socially shared activities into internalised processes in his “general genetic law of cultural development” arguing that higher mental functioning appears first on the social level and then on the individual level.

Every function in the child’s cultural development appears twice: first, on the social level, and later, on the individual level; first, between people ... and then inside the child. This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher [mental] functions originate as actual relations between human individuals” (Vygotsky, 1978, p.57).

Vygotsky saw this social and individual learning and development as dialectically linked and described the dialectical nature of learning and development thus:

learning awakens a variety of internal-development processes that are able to operate only when the child is interacting with people in his environment and in cooperation with his peers. … learning is not development; however, properly organised learning results in mental development and sets in motion a variety of developmental processes that would be impossible apart from learning. Thus learning is a necessary and universal aspect of the process of developing culturally organised, specifically human, psychological functions (Vygotsky, 1978, p. 90).

The relationship between social and individual learning and development in the Vygotskian perspective forms an important foundation for the design of the project club-learning programme as the clubs aim to encourage more participatory mathematical practices whilst at the same time promoting the development of individual learner mathematical proficiency. For the club design, Sfard’s 1998 work on the metaphors of learning extends Vygotsky’s theoretical ideas. She identified and described the differences between two metaphors for learning. She described the metaphor ‘learning as acquisition’ as implying that learning is the acquisition of something that is then stored in an individual. Learning as acquisition theories can be regarded broadly as mentalist in their orientation, with the emphasis on the individual building up cognitive structures. In contrast, she identified the ‘learning as participation’ metaphor as considering learning as a process of becoming a member of a certain community, which entails the “ability to communicate in the language of this

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8 It should be noted that more recently, Sfard has developed a theory of learning with an emphasis on discourse where learning and development are seen as changes in discourse. See for example her work entitled “Introduction to thinking as communication” (2008).
community and act according to its particular norms” (p. 6). Sfard noted, that often these two metaphors can be seen as being in opposition to each other. However, working within the broad Vygotskian perspective described above, the tensions between the two notions of acquisition and participation are nothing unusual as the genetic law already links them. Thus, I argue that the two notions complement rather than conflict with each other (Stott, 2014).

Drawing on Vygotsky’s work and on Sfard’s ‘metaphorical mappings’ (1998, p.7), the club design purposely incorporated both the Vygotskian ideas of individual and social learning and development and these metaphors of acquisition and participation. Figure 1 below gives a tabular comparison of the two metaphors described in Sfard’s article. Later I discuss how these have been specifically accommodated by the club-learning programme design thus using these theoretical ideas as the foundation for the design.

<table>
<thead>
<tr>
<th>Acquisition metaphor</th>
<th>Participation metaphor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual enrichment</td>
<td>Goal of learning</td>
</tr>
<tr>
<td>Acquisition of something</td>
<td>Community building</td>
</tr>
<tr>
<td>Recipient (consumer), (re-)constructor</td>
<td>Learning</td>
</tr>
<tr>
<td>Provider, facilitator, mediator</td>
<td>Becoming a participant</td>
</tr>
<tr>
<td>Property, possession, commodity</td>
<td>Student</td>
</tr>
<tr>
<td>(individual, public)</td>
<td>Peripheral participant, apprentice</td>
</tr>
<tr>
<td>Having, possessing</td>
<td>Teacher</td>
</tr>
<tr>
<td></td>
<td>Expert participant, preserver of practice/discourse</td>
</tr>
<tr>
<td></td>
<td>Knowledge, concept</td>
</tr>
<tr>
<td></td>
<td>Aspect of practice/discourse/activity</td>
</tr>
<tr>
<td></td>
<td>Knowing</td>
</tr>
<tr>
<td></td>
<td>Belonging, participating, communicating</td>
</tr>
</tbody>
</table>

Figure 13: Sfard’s (1998 p.7) Metaphorical mappings

Kilpatrick, Swafford and Findell’s (2001) strands of mathematical proficiency have been widely used in South African mathematics education circles (see for example Adler, Ball, Krainer, Lin, & Novotna, 2005). The power of this work is that it provides a rich and elaborated notion of mathematical proficiency that extends beyond a focus on procedural mathematics. Within the broader SANC project and specifically within the clubs, the project promotes the development of mathematical proficiency in all learners, drawing on Kilpatrick et al.’s definition, which comprises five intertwined and interrelated strands. Conceptual understanding - comprehension of mathematical concepts, operations and relations; procedural fluency - skill in carrying out procedures flexibly, accurately, efficiently and appropriately; strategic competence - ability to formulate, represent, and solve mathematical problems; adaptive reasoning - capacity for logical thought, reflection, explanation and justification and productive disposition - habitual inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one’s own efficacy (p. 5).

Literature review

In order to situate these project clubs in the literature, I approached this literature review as a narrative review to provide sufficient background for understanding the broader OST field, out of school time programmes as well as the features and effectiveness of such. I also provide an overview of zone theory as background for the final section of the paper, in which I share the tested design.

Out of school time programmes

OST refers to the hours in which school-age children are not in school where children are doing something other than activities required by school attendance. A wider definition includes summer schools, before school and weekend programmes, therefore after-school programmes can be seen as a specific sub category of OST programmes (Lauer, Akiba, Wilkerson et al., 2006). Much of literature pertaining to after-school programmes originates from the United States (US), where after-school programmes have been in existence for many decades. I draw on the US literature as the basis for this review as there is little academic literature on OST programmes to be found in the broader African and more specific South African context.
Afterschool programs are a critical first step in the process of changing not just how we educate our children, but how we come together, in partnership - school and community - to ensure their success (White, 2005, p. 8).

This quote suggests the importance of providing after care programmes for children. White suggests that when a neighbourhood or home context are “less than desirable” (p.3), after-school programmes can bridge the gap between these and the school. This is particularly pertinent to the South African context where many children (over 60%) live in poverty and where many home contexts can be seem as problematic (Fleisch, 2008). Durlak and Weisberg (2007) note that there is increasing evidence that the ways in which young people spend their out of school time hours can have important implications for their academic, personal and social development (ibid).

Many US OST programmes target at-risk children and the types of programmes range from basic school after-care, through academic development to specific social, sport and artistic programmes. One of the aims of the SANC project’s after-school maths clubs programme is to promote and potentially improve mathematical proficiency in local primary school learners; this can be seen as a focus on academic development as opposed to sports development for example. Hence the remainder of this review will look at OST programmes that emphasise academic development. In this regard, Beckett, Borman, Capizzano et al. (2009) highlight that “OST is an opportunity to supplement learning from the school day and provide targeted assistance to students whose needs extend beyond what they can receive in the classroom” (p.1). The SANC project club learning programme provides an example of how South African learners could supplement and extend school learning on mathematics and points to a possible way to address some of the cognitive backlog in our education system that Schollar (2008) refers to.

Research in the US centres on the impact and effectiveness of after-school programmes and Durlak and Weissberg (2007) summarise the positive effects of OST programmes as follows:

young people benefit when they spend time engaged in structured pursuits that offer opportunities for positive interactions with adults and peers, encourage them to contribute and take initiative, and contain challenging and engaging tasks that help them develop and apply new skills and personal talents (p. 5).

There are a number of ideas here that resonate with conceptualisation of the SANC project maths clubs which have a deliberate focus on increasing learner engagement, learner confidence and participation in mathematical sense making (Graven, 2011).

Lauer et al. (2006) concluded that OST programmes can have positive effects on achievement in reading and maths. However, they highlighted that future research and evaluation studies should document the characteristics of the OST programme and how the programme is implemented, as more evidence is needed of what characterises effective programmes. This final point is relevant to my work with clubs in the South African context, where effective OST programmes could be one way of addressing learner backlog. Additionally, for future sustainability of the project clubs and expansion of their sphere of influence, the characteristics of the project’s club-learning programme should likewise be documented and shared in the broader academic space.

**The benefits of and critical success factors in after-school programmes**

Papanastasiou and Bottiger (2004) described the advantages and benefits they found in voluntary middle school (grades 5 to 8) maths clubs held before school time as providing opportunities for students to develop personal self-esteem, inquiring minds, relatively close human relationships and a sense of belonging and purpose or usefulness and, as low stress environments, clubs enable students to learn about teamwork and of the importance of cooperation and mutual support. Similarly, Little, Wimer and Weiss (2007) listed the academic outcomes associated with participation in after-school
programmes as better attitudes toward school; better performance in school (as measured by achievement test scores and grades); improved homework completion and better engagement in learning. Amongst the social and emotional benefits, they included improved self-confidence, self-esteem; improved social and communication skills and/or relationships with others (peers, parents, teachers); improved feeling and attitude towards self and school and development of initiative.

There is some commonality in these findings particularly with regards to the development of self-confidence, attitudes towards school and learning, improved social and communication skills as well as improvement in academic performance. These findings cohere with Graven’s (2011) motivation for starting clubs as a fundamental SANC project intervention and with subsequent findings from the five-year SANC project. Graven (2015) reports that learners are shifting ways of participating and showing increased enjoyment of mathematics, willingness to discuss the methods they used to arrive at an answer, willingness to try maths problems without fear of being wrong and increased confidence. Stott (to appear) notes from her research clubs that they are “enabling spaces for both recovery and extension of mathematical proficiency in learners as these spaces are free from several contextual constraints that teachers face in their classrooms” (no page).

However, Little et al. (2007) raise concerns that not all research and evaluation studies of OST programmes have shown benefits. For them, a critical component of achieving high quality in after-school programmes is to intentionally develop programmes that “focus on promoting targeted outcomes through well-organized and engaging activities” (2007, pp. 12–13).

Durlak and Weissberg (2007) applied a number of criteria to a range of OST programmes to establish whether positive results emerged. They concluded that programmes that devote sufficient time to skill enhancement, being explicit about what they wish to achieve, use activities that are coordinated and sequenced to achieve their purpose, and require active involvement on the part of participants (‘SAFE’: sequenced, active, focused, explicit) show significant positive findings with regards to many of the outcomes discussed above such as improved feelings of self-confidence, positive social behaviours and improved school grades. In their 2010 work they note that these SAFE features can be applied to a wide variety of intervention approaches, which is the case in learning programme design described here as it has been intentionally designed by working from a strong theoretical base to echo a number of these features.

I noted that research literature on academically oriented primary school clubs is relatively limited, particularly so in Africa. Peer reviewed literature on school maths clubs in South Africa is largely non-existent except for Graven’s (2011) article referred to earlier. In the absence of formal academic research on OST programmes in South Africa, an Internet search for after-school programmes in South Africa reveals many programmes (some with a mathematical focus), many privately funded and run by NGOs. What is noticeably lacking from the public space is research on how these programmes are structured and whether they are effective in addressing some of the issues with mathematics education. Thus, additional motivation for writing this article is to encourage research and publication into these programmes in our local context, in order to provoke discussion about their design and what characterises their effectiveness.

Zone theory overview

The broader SANC project work is framed as a community of practice, particularly with regard to the teacher development programme (Pausigere & Graven, 2014). In searching for a framework around which to structure the maths club-learning programme, several considerations had to be taken into account. Designs and frameworks needed to cohere with the SANC project’s broader theoretical framework, be related to mathematics education, were recent in research terms, take the ‘SAFE’ features into account and be flexible enough to cope with changes as both my research and the SANC after-school club project moved forward over the 5-year period.
In connection with Vygotsky’s work on the zone of proximal development, Valsiner (1997) proposed zone theory as an “explanatory structure within the field of human development” (Galbraith & Goos, 2003 p.365). Galbraith and Goos (ibid) adapted Valsiner’s work for teacher-student relationships and have extended it further into teacher development. Their work on zone theory particularly resonated with these broader project considerations.

Valsiner suggested two additional zones in namely the zone of free movement (ZFM) and the zone of promoted action (ZPA) to further describe the structure of a child’s development in terms of the environment and relationships between the child and other people in the environment (Goos, Dole and Makar, 2007). The two additional zones are intended to give a better understanding of how the ZPD operates in a specific learning context and create a picture of the physical and cultural space in which the ZPD is situated. From this work, the ZFM, ZPA and ZPD can be seen as structures through which an adult or more knowledgeable other constrains or promotes the learner’s thinking and actions and as such the ZFM/ZPA combination interactively generates the environment in which that learner develops (Blanton, Westbrook, & Carter, 2005).

Althoughmuch of this is detailed in earlier work, for completeness I provide a brief overview of zone theory (ZT) as used in educational research. The ZFM describes what is allowed for the learner by the adult in a particular learning context. In other words, the way an adult organises the ZFM anticipates the nature of the child’s thinking about the concept being taught at the moment and in the future. In this sense, the ZFM ultimately channels the direction of learning development for the child, providing a framework for cognitive activity, learning and potential development (see Blanton et al., 2005; Galbraith & Goos, 2003) and for possible emergence of the child’s ZPD.

The set of activities available and promoted in the learning environment are the means by which an adult or more knowledgeable other attempts to persuade a learner to act in a certain way (Blanton et al., 2005). This is called the ZPA. The activities promoted in the ZPA should ideally be in a learner’s ZPD. In other words, the ZPA should promote activities that stimulate the emergence of the ZPD by being just beyond what the learners are currently able to do on their own (Blanton et al., 2005; Galbraith & Goos, 2003).

In educational literature, the ZPD is conceptualised in many different ways (see Stott, submitted). In ZT, the ZPD is described as the “set of possibilities for development that are in the process of becoming actualised as individuals negotiate their relationship with the learning environment and the people in it” (Goos, Dole and Makar, 2007 p.25). Elsewhere, I have identified and discussed how the zone of proximal development came to be the critical design concept for the clubs (Stott & Graven, 2013). For the purposes of this paper and this discussion of ZT, the ZPD is conceptualised as something that does not exist prior to the learning activity and is created (or not) through the social interactions with others during club activities. It depends on the active contributions of the learners as well as the mentor. The ZPD is as a symbolic space that encompasses the whole person. The emergence of a ZPD is encouraged by presenting activities that are meaningful to the learner, activities that can be accomplished with assistance, ones that allow the learner agency to benefit and take advantage of the assistance from others (Stott, 2014).

For the maths club-learning programme design, following Goos et al. (2007), zone theory is used in conjunction with a professional development framework which extends ZT to ensure that broader project concerns and processes are included in the design of related learning programmes. This extension is described in the next section.

**Overview of SANC project club-learning programme design**

What follows is the description of learning programme design framework used for the two case study research clubs in 2012 and for the on-going implementation of broader SANC project maths clubs over the last 5 years. Figure 2 below shows the final tested design framework. As will become clear...
As we progress through this section, there are a number of reasons why the framework as shown is useful. As a process it is easily explainable to others and contributes to ensuring that the maths club model is sustainable beyond the time frame of the project. The framework provides a process for setting goals, planning and evaluating the on-going learning programme in the clubs. As the process is iterative and cyclical it allows evaluation of what works and does not work on a regular basis and this can be used to plan and implement subsequent actions and activities in the clubs. This kind of evaluation process was undertaken after the pilot club in 2011 (see Stott & Graven, 2013).

Key areas on the diagram are numbered one to three. One highlights the shared vision of the broader SANC project across all its developmental activities in terms of the factors that enable learners to become mathematically proficient. The broader aims of the project are noted in the framework (see 2). For the specific club-learning environment, the inter-related components of zone theory define the structure of the learning environment in the club, the activities promoted and the relationships between the all participants in the club as well as foregrounding the possibilities for learning in the ZPD.

![Figure 14: Club-learning program design framework (adapted from Stott & Graven, 2013: 33)](image)

Based on the conceptualisation of the ZPD given earlier, the ZPD (see 3a) is highlighted as the critical design concept for the clubs and is shown as a larger circle. The ZPD is not portrayed as a fixed entity or as a fixed set of possibilities that are the same for each learner in the clubs. Using diagnostic assessment activities at the beginning of a club helps to establish what the set of possibilities may be but these possibilities can only be developed in subsequent club sessions. The ZPD is created (or not) by the social and dialogical interactions of each club session and as such is different for every child, in every session (Stott, 2014).

The zone of free movement (ZFM) (see 3b) explains the learner-environment relationship and how that environment supports the intended learning, thus playing a supporting role in the emergence of the ZPD. Specifically, for the club-learning programme, a number of connectionist teaching characteristics from the Effective Teachers of Numeracy study (Askew, Brown, Rhodes et al.,1997) are foundational to understanding the specific ethos promoted in the clubs. Of note are those that suggest that learners become numerate through “purposeful interpersonal activity based on
interactions with others” (p. 35) and that numeracy teaching is based on “dialogue between teacher and pupils to explore understandings” (p. 36). Specifically club mentors are active participants and co-learners and facilitate rather than teach, they encourage participation and engagement, promote the club ethos, provide flexible mediation to challenge and build learner confidence and encourage learners to feel comfortable both with mistakes and with hard work and struggle (Boaler, 2014). Thus the key features of the ZFM for the clubs are that all participants are active, including the mentor and peer and group work are encouraged, dialogue is foregrounded (for example talking about mathematical thinking and understanding) and as such the active characteristic of effective OST learning programmes is incorporated (Durlak and Weissberg, 2007).

The zone of promoted action (ZPA) (see 3c) describes the activities that are promoted in the club to facilitate development of mathematical proficiency in each club learner and describes the efforts of the mentor to promote this learning. It defines the diagnostic activities that enable a mentor to establish where learners are in their mathematical proficiency trajectories and activities that promote the development of the five strands of proficiency discussed earlier. The kind of activities that are promoted in each club are directly influenced by each learners “set of possibilities” for their ZPD. Consequently only the diagnostic assessment activities, which can be formal assessment tasks or simple card and dice games, are planned in advance. The data and reflections from these initial activities drive the subsequent activities for the club that are aimed at learning and development of mathematical proficiency for each learner with the hope of encouraging the emergence of ZPDs. The overarching intention for any activity promoted in the clubs is the fostering of sense making and flexible thinking using an interwoven approach to the development, where possible, of the five strands of mathematical proficiency (Kilpatrick et al., 2001). In terms of procedural fluency, focus is on developing efficiency, accuracy and flexibility in order to take the attention away from using traditional algorithms. In this way, the ZPA incorporates the sequenced, focused and explicit characteristics of effective learning programmes highlighted by Durlak and Weissberg (2007).

Earlier I spoke about the acquisition and participation metaphors (Sfard, 1998). From this examination of the ZFM and ZPA zones for the club-learning programme, it is clear that the clubs have a dual focus in that learner mathematical proficiency is promoted as well as mathematical forms of participation. This design framework addresses and accommodates the relationship between the acquisition and participation metaphors and Figure 3 shows how this dual focus is intentionally interwoven in the club design.

![Figure 15: Club-learning program design: metaphorical mappings (Stott & Graven, 2013:31)](image-url)
Individual learner progress and the acquisition of mathematical proficiency is shown on the left of the diagram and represents the acquisition aspect of the design. As mentioned, the ZPD is the foregrounded design construct that focuses on each individual club learner. The diagnostic assessment activities promoted in the ZPA establish and track where each individual learner is on their own individual mathematical proficiency trajectory, with the overarching aim of improving learner mathematical proficiency over time.

The right side highlights an intended focus on evolving forms of mathematical participation whereby the learners, mentors and other people in the club become participants in the club with increased sense making and communication in mathematics. Addressed through the ZFM, these participationist aspects. Additionally, the collaborative activities promoted in the ZPA extend the participationist aspect further by promoting activities that allow possible increased sense making and mathematical communication in a collaborative way.

**Concluding remarks**

Over the past five years, following on from the pilot study in 2011 and earlier publication, this design has been tested as the framework for all the clubs run both within and beyond the SANC project. The framework has been shared in varying forms of complexity with educators who are interested in starting and running their own clubs. On reviewing this model for my doctorate, one person commented that the model described in this paper contributes to an area of extra-curricula programming as it relates to contexts throughout the world where opportunities to enhance mathematics education of children is an on-going challenge.

I argue that the club-learning programme design communicated here enables the promotion of targeted academic outcomes (in this case, the development of mathematical proficiency) through well-organised and engaging activities and the ‘SAFE’ (sequenced, active, focused, explicit) design features. This learning programme has been purposely designed with a solid theoretical background based on Vygotsky and Sfard’s work, incorporating those theoretical concepts, zone theory and these SAFE design features and goes some way to contributing to research on how after-school spaces can benefit young learners.

Without such well-designed approaches to academic OST learning programmes, the maths clubs could merely be “more of the same” and may well simply be an extension of the maths classroom. The opportunity to promote specific practices (as described here) that intentionally contrast to those found in many of our South African classrooms would then be lost. Furthermore, in order to improve OST programmes both in South Africa and abroad, it is important that research is carried out on how they are designed and on what makes them effective. They may be an important aspect in addressing some of the educational challenges we face here on the African continent, particularly in bridging the gap between home and school contexts as research emanating from our project suggests that after-school maths clubs could be valuable spaces for changing foundation phase learner attitude and learning habits.

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**References**


Materials ‘borrowing’ and adapting: Overviewing ‘Big Books’ interventions in primary mathematics classrooms

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In this paper, we detail the reasons for the cross-national ‘borrowing’ into the South African primary mathematics landscape of the materials and pedagogic approaches presented within Askew’s ‘Big Books’ resources focused on additive and multiplicative word problems. Our attention is on two aspects: firstly, the ‘fit’ of the approach for some of the problems highlighted in prior research findings relating to primary mathematics education research; and secondly, the adaptations made both initially, and subsequent to the emerging findings from a sequence of intervention studies based on this approach that are feeding into the tailoring of this approach to the conditions and constraints of our context. A brief overview of current findings suggests that the approach, with initial adaptations in place, is showing promise in relation to learner performance on pre- and post-tests around the intervention lessons. These results suggest possibilities for larger-scale trials of the approach going forward.

Introduction

Cautions have been widely expressed in the education literature about the pitfalls associated with unquestioning ‘borrowing’ of policies, theories, curricula and textbooks across contexts in the hope of finding a ‘magic bullet’ to raise standards (Steiner-Kamisi & Walsow, 2012). In a context of increasing presence of international comparative testing with outcomes presented in the form of country rankings, policy advice, however, often focuses on taking on board curricula and textbooks, organizational forms and pedagogic practices seen in countries and regional and/or socioeconomic contexts where outcomes are ranked as ‘successful’. Those cautioning against this argue that the success of particular pedagogical approaches, artefacts and texts has to be considered in the light of the particular socio-cultural contexts that gave rise to these approaches and the dominant discourses within those contexts (Askew, Hodgen, Hossain, & Bretscher, 2012). Any playing through of these discourses elsewhere is viewed as unlikely to lead to sought-for improvements in its ignoring of the broader ecology in which curriculum enactments, organizational forms and pedagogic practices are located. Equally important are concerns over the politics of policy and practice borrowing and the effect on marginalized groups of the homogenizing effects of dominant discourses.

In this paper, we present an overview of an example of ‘materials borrowing’ that we have developed into an intervention model that has been used in a series of projects focused on solving word problems involving the four operations in primary schools. Our focus is on the particular problem in South African primary mathematics being addressed and our concomitant reasons for considering this borrowing in the first instance. This is followed by detail on instances of adaptations to the materials and our formulation of the materials into an intervention model that is contextually attuned. We conclude with a brief overview of outcomes from these intervention studies that have led us to consider the materials and the model as showing promise in supporting primary teachers to work with learners on word problems focused on number operations. Finally we return to the broader issues outlined above.
The problem with word problems

Some of the problems that the international literature highlights around the difficulties that learners have in working with mathematical word problems (Verschaffel, Greer, & de Corte, 2000) have extensive local parallels in South Africa. For instance, the 2014 ANA diagnostic report (DBE, 2014) includes the comment that:

‘The process of translating words to numbers and signs seems to generally be a problem.’ (p31)

Advice on dealing with these issues, however, stands, in some instances, in counterpoint to some of the approaches to word problems advocated in the research literature (see below). For example, the same report recommends an identifying ‘key words’ approach, rather than attending to representing the relationships between quantities:

‘Learners should be exposed to techniques of dealing with word problems by firstly underlining the key words in the written sentence; and,

Learners need to be taught how to translate the key words into correct mathematical operations (i.e. addition, subtraction, multiplication and division)’

For example:

There are 10 children in a class and 20 more joined them. Half of them are boys. How many learners are boys?

(10 + 20) \div 2

Learners need to know that “more” means addition, hence the “20” is added to the original 10. They must also understand that half means dividing by 2, hence the total of 10 + 20 must be divided by 2. (DBE, 2014, p32)

The issue of lack of sense making of problem situations is apparent in the problem noted above, and perhaps, entrenched, rather than addressed in such remediation advice. Thus the need for a pedagogy that promotes attention to structural relationships between quantities is writ large here, with theories such as the Dutch Realistic Mathematics Education (Freudenthal, 1983) suggesting the usefulness of beginning with an emphasis on learners’ informal models. In a similar vein, an influential body of work in the United States has noted that young children are, in most instances, able to ‘directly model’ orally presented situations using concrete resources, and use these direct models to produce the answer to missing number problems (Carpenter, Fennema, Franke, Levi, & Empson, 1999). Presenting problems in everyday language and located in familiar situations is viewed as critical to supporting the informal modelling that forms the basis of moves towards more formal standard models. Of interest in the complex multilingual terrain of many South African classrooms is the broad level evidence that children learning mathematics in their home languages generally perform at lower levels in exit examinations than those learning mathematics in English or Afrikaans as second languages (Howie, 2003). This finding suggests that large numbers of learners in South Africa show limited awareness of sense-making of texts even when these texts are presented in their home languages with this finding backed by evidence of gaps in learners’ comprehension skills, with widespread ‘rote’ reading occurring in the absence of focus on meaning (Bohlmann & Pretorius, 2008).

In our broader analyses, we have also noted difficulties within teachers’ explanations of problem situations, with transformations stated without justification (Askew, Venkat, & Mathews, 2012) and unknown quantities recruited within the assembling of representations and explanations (Mathews, 2014; Venkat, 2013). Within teacher development too, we have evidence that attending to expanding representational repertoires can concurrently support mathematical and pedagogic development (Venkat, 2015). These issues together with our reading of analyses of a range of conditions and problems in South African primary mathematics teaching and learning led us to believe that ‘borrowing’ the Big Books tasks and pedagogic approach developed in Askew’s (2005a, 2005b, 2005c) materials had the potential to be productive as the Big Books’ approach incorporated the
attention to models at the level of teaching and learning that have been found to be useful in international literature contexts and potentially in South Africa.

**The ‘borrowed materials’: The Big Books of Word Problems**

The ‘borrowed materials’ in this study are a series of grade-banded classroom texts – the Big Books of Word Problems - developed by Askew and containing sequences of word problem tasks relating to additive and multiplicative situations (Askew, 2005a, b & c). Three books (Years 1 & 2, 3 & 4, and 5 & 6) present a series of word problems that were developed in the context of England’s primary mathematics teaching. Each book contains a series of 24 lessons and each lesson is structured around a set of word problems focused on particular semantic categories of additive or multiplicative situations (see Carpenter et al, 1999). Careful variation (Marton, 2014) across the word problems in each lesson is intended to help develop learners’ awareness of classes of problems, rather than to treat every problem to be solve ab initio. In addition, the problem solving contexts were chosen in the expectation that children could relate to these and imaginatively enter into the narrative ‘world’ of a problem, thus supporting the emergence of informal models and solutions. Thus the pedagogic model suggested in the associated Teacher Guides focuses on initially asking children to imagine and create informal models of the problem situation. Contrasts between more and less efficient models and solution strategies can be discussed after each problem is solved, leading in to the class exploring how the learners’ models of the situation help in the selection of a calculation strategy and working out the answer.

Typically each lesson is structured around three problems and after the solutions to the three problems have individually been discussed, the teacher is encouraged to lead a discussion on the similarities across the models and solutions to explore the underlying connections in the quantitative relationships between quantities in the situation. For example, the three problems on a page may all have been structured around ‘subtraction as comparing’ situations. A follow-up task provides further situations of the same type for which children create their own ‘models of’ these situations, and then use these as ‘models for’ their choice of operations. A final discussion section again elicits structural similarities across the problem set, and the relative efficiency of some models and calculation strategies for deriving answers. In the middle and upper grades, an ‘odd one out’ problem situation is sometimes included in the individual work problem set, and problems sometimes include superfluous information, so that learners do not work ‘mindlessly’ (Langer, 1998) through the individual tasks. Across the series of lessons, semantic categories are largely dealt with separately (e.g. a lesson might focus predominantly on ‘compare’ additive relation tasks or a ‘rate’ type multiplicative relation tasks), but later lessons start to integrate tasks based on different semantic categories with the subsequent discussion attending to how to discriminate between different problem types.

Difficulties that have been written about widely in mathematics education – children’s difficulties with solving word problems, and the tendency to focus on the calculation required rather than structural relationships between quantities in the situation (Thompson, Philipp, Thompson, & Boyd, 1994) and the cue-based operation selections that we noted as being problematically advocated in the Diagnostic Report mentioned earlier have led to word problems gaining a certain amount of ‘bad press’: that they are artificial, do not lead to understanding and are poor pedagogic tools. Askew’s Big Books series was motivated by the need for improved attention to task design and pedagogic approaches that treat word problems not as key word or operation spotting exercises but mini-narratives that can support understanding. As discussed earlier, this approach rests on the bodies of research evidence for successful pedagogies based in encouraging children to act out and represent situations in informal models (Gravemeijer, 1999), attending to categorizing problems based on their phenomenological features (van Dooren, de Bock, Vleugels, & Verschaffel, 2010), extensive classroom discussions of emergent models and their advantages and disadvantages, and discussion of calculation strategies based on these models (Gravemeijer & Stephan, 2002). The resources were, therefore, strongly research informed, with problems contextualised in phenomena that were intended
to be familiar in a ‘real’ or ‘realistic’ sense to English primary age learners, where ‘real’ goes beyond the ‘everyday’ to embrace appeals to children’s imagination, for example, narratives involving superheroes or anthropomorphised creatures. The Big Books problems were also deliberately worded to confound the ‘key words’ approach (for example, ‘four people were on a bus. Some more got on. Now there are nine people on the bus. How many got on?).

The Big Books approach in the context of South Africa

The pedagogic emphasis on whole class discussion can provide possibilities for attention to moves towards increasingly standardized, generalizable and efficient models and strategies, addressing a need that has been highlighted widely in South Africa relating to lack of moves to more sophisticated calculation strategies (Ensor et al., 2009). Evaluation of learner responses is critical to recognizing the relative sophistication of these offers and then responding in ways that support movement towards more advanced ways of calculating. However, Hoadley’s (2006) work noted a frequent absence of evaluation of learner offers in Foundation Phase classrooms, pointing to a pedagogic ‘gap’ between the orientation of pedagogy in relation to learner offers in Askew’s approach and the ground in South Africa.

Some further issues noted in the South African terrain as problematic also sat somewhat at odds with the Big Books pedagogic model. Policy-oriented writing has pointed repeatedly to slow pacing within, and across lessons, leading to significant gaps in grade-specific curriculum coverage (Reeves & Muller, 2005). The policy response in recent years to this evidence has been set within moves to increasing prescription of content, sequencing and pacing of the curriculum – weekly plans in the national ‘CAPS’ curriculum statements (DBE, 2011a, 2011b), and daily scripted lessons in the provincial level Gauteng Primary Literacy and Mathematics Strategy (GPLMS). The Big Books approach, incorporating extensive discussion sections, worked somewhat against this overt attention to pacing, with intervention models needing to find ways of fitting into the increasing emphasis on standardization of curriculum coverage and pacing.

Adapting materials and intervention model for contextual fit

Four pilot projects have been conducted thus far based on the Big Books. All four projects thus far have been conducted by Wits Mathematics Connect-Primary (WMC-P) team members and affiliate part-time postgraduate students as the intervention lesson teachers with classes in partner schools; this allowed for trials of the materials in relatively favourable circumstances, and with extensive background reading and preparation for the teachers leading the intervention trials. Further, all of these projects incorporated the inclusion of pre- and post-testing of learners. In the light of this we identified the need for adaptations for contextual fit occurring at two levels: problem design and intervention lesson frequency across the pilot studies.

At the first level, the use-ability of the problems in Askew’s materials was considered in terms of familiarity of vocabulary and context for learners in the intervention class, and adapted tasks were devised if the original tasks were considered too unfamiliar for learners to develop informal models. In Takane’s (in process) study, located in a Grade 2 Zulu Home Language medium classroom in a township no-fee school, a series of Zulu language-based situations, driven by the need for familiarity for learners, were developed for an additive relations intervention sequence. In Dlamini’s (2014) Grade 6 study (and a follow-up Grade 5 study) on multiplication and Tshesane’s (2014) Grade 4 study on additive relations, both set in English medium classrooms in suburban fee-paying schools, minor editing of tasks was incorporated with attention in whole class discussion to dealing with vocabulary within task contexts that may have been unfamiliar to some learners in the classroom.

Secondly, intervention models that would work without disruption to the increasingly prescriptive content, pacing and sequencing in the curriculum coverage terrain had to be devised. In the
Intermediate Phase, this meant organizing six intervention lessons running either on a weekly or fortnightly basis, with other lessons balancing the content of the mandated CAPS, and in some schools, GPLMS, curricula. In Takane’s Foundation Phase intervention focused on additive relations – a topic that has extensive connections to several parts of the Foundation Phase curriculum, an intervention model involving 15 lessons, running twice a week, was agreed with the classroom teacher – who remained present across all intervention lessons.

Findings suggesting further adaptations

A range of interesting findings have emerged from the four trials that are leading to insights for how we might further tailor the intervention to fit contextual conditions and needs in broader trials going forward, and pointing to adaptations too, at the level of theorizing the pedagogic approach. A key example of this in Takane’s (in process) Grade 2 intervention was evidence suggesting initially, at least, that word problems constructed in order to be set in familiar contexts and offered in the learners’ home language, were not ‘automatically’ taken up and directly modelled by learners. This contrasted with Carpenter et al’s (1999) descriptions of learner working, and other constructivism-based theorizations working from the premise of learners’ sense making of the situation as largely ‘natural’ and ‘instinctive’. In Takane’s intervention model, this led to an early move within her pedagogic approach to defer attention to sophistication of models and strategies, and place more emphasis instead on encouraging discussion about making sense of the situation – beginning with physically acting out the problem, and then moving to represent it informally in pictorial images. This adaptation, while playing into and actually encouraging the more elongated unit counting models that have been described as so prevalent in the South African terrain, appeared to be required to ‘disrupt’ a mathematical culture in which sense-making appeared to be a relatively alien feature.

Retrospectively, given our own findings of lack of coherence in teachers’ explanations in Foundation Phase, coupled with broader evidence of highly ‘rote’ approaches to teaching and learning (Hoadley, 2012), Takane’s adaptation can be seen as a necessary step in order to establish a culture where making sense of a situation was viewed and evaluated as important, with discussions focused on communicating this as a classroom social norm (Yackel & Cobb, 1996). Takane’s initial analyses of pre- and post-test results suggest substantial improvements in learner performance, with moves to increasing sophistication coming in at a later stage in learners’ models and strategies. These results also show substantial gains for the intervention group in comparison to a parallel ‘control’ Zulu language of learning and teaching Grade 2 class who began with a very similar performance profile in the same school.

Different insights were gained from Tshesane’s Grade 4 additive relations 6-lesson intervention sequence. While overall performance gains in this intervention were small, a feature of interest in this study was that when the post-test was attempted without stipulation to use the number line model that had been widely discussed during the intervention lessons, the relative sophistication of models and strategies was substantially lower than the sophistication seen in the delayed post-test set more than a month later with no further intervention lessons, but with the stipulation that the number line should be used. Tshesane & Venkat (2014) report two important findings from this study: firstly, that by the middle of Grade 4, several learners had transitioned from using unit tally counts in the pre-test set early in Grade 4 to using column algorithms in the post-test, but that errors were frequently in evidence within this transition; secondly, that the number line, though not selected voluntarily by learners to model given problem situations, did support moves towards sophistication. Taken together, these findings have led Tshesane to a follow-up intervention study located in Grade 3 (before column methods are explicitly mentioned in curriculum documents), in which explicit attention to models is incorporated alongside attention to models as tools for representing situations and then for calculating solutions (Tshesane, in process). Thus we are also now considering when such interventions might be best enacted, as well as the nature of the interventions per se.
Dlamini, Venkat & Askew (2015) reported findings from two cycles of intervention studies focused across Grades 5 and 6. Substantial improvements in performance were seen between pre- and post-tests in both cycles, but with the performance profile lower, predictably, in Grade 5 in comparison to Grade 6. While the specific patterns of take-up varied to some extent, a common pattern seen across both of Dlamini’s intervention cycles was the take-up of a broader range of models of multiplication in the post-test than was seen in the pre-test, where – mirroring the broader SA evidence – unit counting and repeated addition methods were highly prevalent (Schollar, 2008).

Concluding comments

The findings presented in this paper are intended to provide both some of the key rationales for our borrowing of materials developed in a very different national policy and practice context to the South African situation, and some of the thinking behind the planned and more emergent adaptations. The South African Research and Development Chairs initiative was announced by the National Research Foundation with calls for proposals set explicitly within a linked research and development orientation in mathematics education across secondary and primary phases:

‘To research sustainable and practical solutions to the challenges of improving mathematics, numeracy and literacy education in schools’ (NRF, 2010)

Our sense of the Big Books materials and pedagogic approach, which the findings of studies overviewed in this paper provide some evidence of, is that they do provide materials developed on the basis of research evidence and set within a practical pedagogic approach that was feasible for trialing in South African primary school classrooms. But, as the cautions about policy and materials borrowing have noted, borrowing into a different context has necessitated further research cycles, and that in turn is provoking further theorization of the pedagogic approach in order to develop a contextually sensitive and constructive intervention content and approach.

The overall trajectory of this iterative research programme reflects, in many ways, the four-part methodological concerns of research related to policy borrowing described by Phillips and Ochs (2003) as involving cross-national attraction, decision, implementation and indigenization/internalization. With four trials now showing promise, alongside generating new insights, our next focus of attention is to look at a broader scale intervention based on the (adapted) Big Books materials as part of the indigenization/internalization phase. An important aspect of this phase will involve working with groups of teachers in schools as the intervention lesson teachers rather than postgraduate students. This will allow for an exploration of the practicality and feasibility of the intervention materials and model for teachers in the system. Smaller scale trials with a group of Honours level students teaching their own classes are also currently underway. In the process of these studies, we are learning how to adapt materials and pedagogic approaches in ways that are showing promise for addressing key issues with meaning making and problem solving in word problems in South African primary schools.

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Part B
Science
Long Papers
Evaluating the effectiveness of the Experimento programme: Insider accounts from Multipliers in Gauteng province

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Abstract

This paper explores the experiences of 23 Physical Science high school teachers who participated in a professional development (PD) programme coordinated by three Experimento multipliers. The Experimento programme is the name of a Siemens Stiftung international educational programme whose aim is to provide didactic and methodological approaches to classroom experiments using an inquiry-based approach to science education. Experimento multipliers are the facilitators of the PD. The main data source comprised teacher interviews, school visits to observe classroom enactment of activities using the Experimento 10+ box and the facilitators’ field notes. Findings suggest that there is a shift from the traditional approaches of science teaching to the implementation of inquiry-based teaching which was encouraged by the gradual formation of a community of practice; a reconceptualization of the term ‘practical activities’ as prescribed by the CAPS document; and the need for experiments which facilitate action-oriented teaching. The discussion highlights the implications of these findings for the practicing teachers’ professional development, and the problems of linking theory with practice in such development. The significance of this study rests in recommending more such interventions throughout the year to enable teachers to improve their skills of implementing inquiry-based teaching, content knowledge and science pedagogy as evidenced by analysis of their summative evaluation of the intervention.

Background and rationale

Participation in inquiry-based science education, which focuses on student-constructed learning, has been linked to academic success (Rooks-Ellis, 2014; Roehrig & Luft, 2006). Inquiry-based education involves engagement in the learning process, and challenges learners to question and explore concepts as they seek new knowledge (Brewer & Daane, 2002; Crawford, 2007). Different from traditional learning settings, inquiry-based education recognizes that learners engage with their experiences laden with preconceptions about the world and how things work. Inquiry-based education allows learners to seek evidence and construct solutions to support their reasoning (Gibson & Chase, 2002; Gillies & Nichols, 2015). Inquiry-based learning also emphasizes learners’ understanding of concepts rather than acquiring skills (Ramnarain & Schuster, 2014). It encourages “teachers to move away from the tradition in which knowledge is viewed as discrete, hierarchical, sequential, and fixed and towards an environment in which knowledge is viewed as an individual construction created by the learner” (Draper, 2002, p. 521). Furthermore, inquiry-based education provides learners with the opportunity to develop their meta-cognition skills and develop capacities to monitor and direct how they think and learn (Warner & Myers, 2008). The benefits of the application of this method have been well documented in the context of science education (Kanter & Konstantopoulos, 2010). Whereas the benefits of this type of science education are evident, access to such high quality science curriculum is not easily obtained (Ohana, 2004).
Implementation of inquiry-based learning in classrooms presents a number of significant challenges such as insufficient time for inquiry, learner expectations and abilities, concern about the potential of not accomplishing specified learning goals, overcrowded classrooms and fear of the unknown among others (Krajcik, Blumenfeld, Marx & Soloway, 1994). For example, in South Africa some learners have less access and fewer opportunities to engage in inquiry-based lessons due to insufficient apparatus and chemicals and teachers who lack relevant knowledge and skills to perform such lessons (Nompula, 2012). It is therefore critical to understand the implementation of inquiry-based teaching and the present study is designed to explore small-scale facilitation of such a process. This paper describes encounters and experiences of Experimento multipliers in one province which is running a professional development programme in facilitating small-scale implementation of inquiry-based teaching in various schools of South Africa. In this paper, experiences refer to practical contact with and observation of facts or events pertaining to content knowledge, didactics and pedagogy. Encounters, on the other hand, refer to unexpected challenges that multipliers’ face in facilitating inquiry-based learning.

Facilitation to support and guide teachers in facilitating small-scale implementation of inquiry-based teaching for the benefit of learners has grown in significance over the past two decades worldwide, including in South Africa (Pretorius, De Beer & Lautenbach, 2014). In the process of such facilitation, it is hoped that teachers develop their content knowledge, didactics and pedagogy (Holland, 2005). Facilitation is a process where support in providing professional development is delivered to classroom teachers and its focus is on particular subject matter content or pedagogical approaches intended to build their instructional skills (Yost, Vogel & Rosenberg, 2009). However, questions remain unanswered as to how facilitation is actually implemented and achieved in practice as it takes different forms (Waterman, Boaden, Burey, Howells et al, 2015). Moreover, little evidence exists on what it is that researchers do to support the implementation process and achieve in practice during facilitation (Waterman et al, 2015). Pretorius et al (2014) lament that professional development interventions in South Africa do not always address teachers’ needs nor do they necessarily result in better realisation of outcomes in science. Pretorius et al (2014) further argue that South African teachers’ learning of science and their emerging science pedagogy need urgent attention and that this paucity can be addressed through focused professional teacher development (PTD) programmes. This notion gives credence to the undertaking of this study given that South African teachers’ learning of science content and their emerging science pedagogy need urgent attention. This is attested by prior studies which found that teachers were more likely to change their instructional practices and gain greater subject knowledge and improved teaching skills when their professional development was directly linked to their daily pedagogical experiences, as well as aligned with curriculum standards and assessments (Holland, 2005).

Given this background, the purpose of the study was to evaluate the effectiveness and value of the use of the Experimento10+ Kits as well as assess the extent of use of cooperative learning methodologies by teachers who have been exposed to these by multipliers in science classrooms. Encounters and experiences of Experimento multipliers would then be ascertained in the process of this evaluation.

Research Question
1. To what extent are the teachers effectively using the Experimento10+ Kits to promote inquiry-based learning in their classrooms?

2. How are the teachers infusing cooperative learning methodologies exposed to them during the professional development programme to enhance inquiry-based learning?

3. What are the implications of this research for classroom practice and Science curriculum development?

Experimento - the international education programme of Siemens Stiftung

Experimento is the name of the Siemens Stiftung international educational programme. It provides didactic and methodological approaches to classroom experiments. The aim is interactive, real-world classroom instruction that inspires students to discover science and technology and improve their future career prospects. Experimento is being implemented with a regional focus on Africa (e.g. South Africa, Kenya), Latin America (e.g. Chile, Peru), and Europe (e.g. Germany). In order to meet the specific requirements for teaching and learning in each country, Siemens Stiftung works in close cooperation with local educational partners. “Experimento consists of three progressive modules for the age groups 4-7 (Experimento 4+), 8-12 (Experimento 8+) and 10-18 (Experimento 10+)” (Siemens Stiftung, 2011:2). Since it is an international project developed for teachers to put into practice the principle of discovery-based learning, the contents have been adapted to the specific needs and educational curricula of each country, in cooperation with teacher training institutes and local universities.

In South Africa, since the mid-1990s, curricula and teacher training, were strictly divided during the apartheid era but have been aligned step by step (Pretorius, De Beer & Lautenbach, 2014). Only recently have experiments become required in the curriculum (Department of Education [DoE], 2005). Experimento has been active in South Africa since 2011. It offers materials, methods, and guidance to educators and teachers based on the principle of experiment and discovery-based learning. The subject matter is tailored for local lesson plans by working with teacher training institutes and local universities. Currently in South Africa, around 270 teachers and over 20,000 pupils work with Experimento – a successful development that is steadily progressing. Four competence centres have been established and running in South Africa in four provinces namely, Gauteng (Johannesburg), Western Cape (Cape Town), KwaZulu-Natal (Durban) and Eastern Cape (Mthatha). In the last few months at the Science Competence Centre in Johannesburg, for example, teachers and student teachers have received training in the teaching tools of Experimento. “Experimento does not only connect conventional wisdom with modern teaching; but, it also supports interdisciplinary knowledge. It offers teachers and educators a practical and curriculum-oriented selection of topics in the areas of energy, health, and environment” (Siemens Stiftung, 2011:1). Seminars developed especially for that purpose provide educators with the relevant expertise in using Experimento. Specific instructions, methods and materials for experiments help to embed the programme successfully in teaching.

In 2011, two trainers came from Germany to train teacher educators and teachers who are branded as Multipliers. The multipliers would then later train more teachers on how to use the Experimento kits in their schools. The Experimento kits which are in form of boxes would be donated to schools for free. However, they would only be donated to those schools whose science teachers would have
undergone training. In five-day workshops, the trainers show teacher educators how to prepare exciting experiments with simple equipment and implement these in science and technology teaching in an educationally appealing way. Experiments enthrall not just children, but teachers too, as is evident from the frequency of missed coffee breaks and voluntary overtime once they get started with training. Many teachers first have to learn how to experiment themselves. In many cases, their training at school and university had few practical components hence the need for the one week workshop. By using simple, readily available materials and showing them interactive methods, the programme aims to take away teachers’ fear of experimenting in the classroom (Siemens Stiftung, 2011). The Experimento programme is ultimately only a catalyst. The methods imparted by the workshops encourage teachers to think beyond the instructions provided to them. New and creative approaches are born – a completely different type of teaching (Siemens Stiftung, 2011). This paper focuses on encounters and experiences of Experimento multipliers only in the Gauteng province when they were facilitating small-scale implementation of inquiry-based teaching using the Experimento 10+ box. The three Experimento multipliers run four workshops with each cohort of sampled teachers.

**Conceptual framework**

This study is guided by the literature on operationalization and categorization of constructivist descriptions of *inquiry-based teaching* (Warner & Myers, 2008) and *Professional Development* (Bell & Gilbert, 1996).

Inquiry is perhaps one of the most misunderstood approaches to teaching and learning. Often oversimplified as merely “asking a question,” and more often seen as a fad that denies central themes and content within the discipline, inquiry, by its very nature, seems to defy a consensual definition (Paulson, 2010). Part of the confusion rests in the term implying both a teaching strategy as well as a learning strategy, and part of the contested meaning rests within the diverse facets of its implementation within dissimilar disciplines (Neuby, 2010). In terms of interpretation, inquiry for school science has been a subject of contentious debate. However, scholarship agrees that the nature of inquiry for science teaching and learning is not fixed (Abell & Lederman, 2010). *Inquiry-based teaching* is a pedagogical approach that invites learners to explore academic content by posing, investigating, and answering questions (Centre for Inspired Teaching, 2008). Also known as problem-based teaching or simply as ‘inquiry,’ this approach puts learners’ questions at the centre of the curriculum, and places just as much value on the component skills of research as it does on knowledge and understanding of content (Marx, Ronald, Blumenfeld, Krajcik, et al, 2004).

Inquiry-based teaching requires learner engagement, most often manifested in terms of authentic, real-world experiences. Learners become immersed in solving problems, collecting data, and exploring primary and secondary sources. Duschel, Schweingruber and Shouse (2007) describe the importance of reflecting and connecting evidence to explanation, rather than assuming a scientific viewpoint to help learners understand not just the conclusions of science, but also how one knows and why one believes, then talk needs to focus on how evidence is used in science for the construction of explanations” (p. 188). Given this background, teachers play a vital role in adapting the inquiry process to the knowledge and ability level of their learners. According to Warner and Myers (2008), when using inquiry-based lessons, teachers are responsible for:

1. Starting the inquiry process;
(2) promoting learner dialogue;
(3) transitioning between small groups and classroom discussions;
(4) intervening to clear misconceptions or develop learners’ understanding of content material;
(5) modelling scientific procedures and attitudes; and,
(6) utilizing learner experiences to create new content knowledge.

Based on the objectives of the lesson and the abilities of the learners, teachers must decide how much guidance they will provide. Regardless of the amount of assistance that teachers provide, the fundamental goal of inquiry-based teaching is learner engagement during the learning process. This inquiry process fits well into Experimento’s aims as mentioned in the preceding section.

Professional development (PD) is the second phrase which needs operationalisation. According to Loucks-Horsley and Stiles (2001), designers of professional development can be guided by the extensive body of research on how effective change occurs in educational settings. Current research into the effective professional development of teachers indicates that this is nothing new but, the way in which it is structured and delivered needs to be reconceptualised (Kriek & Grayson, 2009). Dass (1999, p.2) reported that “traditional ‘one-shot’ approaches to professional development have been inadequate and inappropriate in the context of current educational reform efforts.” Ball and Cohen (1999, p.5) indicate that professional development of teachers is “intellectually superficial, disconnected from deep issues of curriculum and learning, fragmented and non-cumulative.”

Professional development that is of longer duration is more likely to contain the kinds of learning opportunities necessary for teachers to integrate new knowledge into practice (Brown, 2004). Recent findings suggest that multiple studies are necessary to determine what works in professional development, a view consistent with recent panels on scientifically-based research in education (Cummings & Worley, 2014). Penuel, Fishman, Yamaguchi and Gallagher’s (2007) findings are consistent with the view that studies of different curricula are likely to yield overlapping but distinct findings about what makes professional development effective.

In reviewing particular studies and synthesising findings across studies, the particular curricular and school contexts need to be taken carefully into account, as do the limits of generalisability of research findings. For example, Bell and Gilbert’s (1996) Science teacher development model emphasises three components:

(a) Personal development in which the teacher must be aware that there is a need for professional development and acknowledges the desire to acquire new ideas or strategies;
(b) Social development in which the teachers have opportunities to discuss ideas with other teachers, and to collectively renegotiate what it means to teach Science and be a teacher of Science; and
(c) Professional development in which the teachers are supported in implementing the new ideas and strategies in their classroom practice, drawing on the changes they make personally and socially.

These three components are viewed as essential to building teachers’ commitment to enacting change within their own classrooms and professional communities. Identifying teachers committed to personal development can be useful in selecting participants while social development and
professional development aspects of the model can be used in designing teacher development programmes. The three components emphasised by Bell and Gilbert’s (1996) Science teacher development model became the guiding principle of perceiving teachers as learners. The model achieved this by synthesising a range of accounts of teacher learning in the professional development intervention programme described in this paper.

**Methods and data sources**

As we were concerned with focusing on implementation, meaning and practice, we adopted an interpretative approach to explore encounters and experiences of three Experimento multipliers during and after facilitation of the Experimento intervention programme over a period of three (3) years. At this stage as the author I declare interest in the success of the programme. The author was involved in the project from its conception in South Africa in the year 2011 during which he was trained as one of the multipliers. The author and another multiplier were involved in data collection on behalf of the non-governmental organisation. The data were collected using validated instruments generated by the non-governmental organisation. The sample for the workshoped teachers is 37 from 37 high schools (3 workshops in total, first workshop had 13 teachers, second and third workshops had 12 teachers each) in Gauteng province of South Africa hence multipliers’ encounters and experiences are drawn from these for reflection. Of the 37 schools, 15 were former model C schools and 22 were township schools. Teachers from the first workshop were assigned code A (e.g. A3 for teacher 3) whilst those from the second workshop were assigned code B (e.g. B6 for teacher 6) and from the third workshop teachers were assigned code C (e.g. C5 for teacher 5).

Interpretive studies ‘are framed by descriptions of, explanations for, or meanings given to phenomena by both the researcher and the study participants rather than by the definitions and interpretations of the researcher alone’ (LeCompte & Preissle, 1993:31–32). Such an approach suggests that social research should capitalize upon the researchers’ ‘personhood’ (Stanley & Wise, 1983) and ‘reflexivity’ as ‘the human capacity for participant observation. We act in the social world and yet are able to reflect upon ourselves and our actions as objects in that world’ (Hammersley & Atkinson 1995:21). As the Experimento programme came to a close with each group of teachers, our experiences as facilitators fuelled questions regarding our own and the teachers’ roles, which we did not originally have in mind. The main data sources analysed in the study are questionnaire, semi-structured individual interviews with all 37 teachers who volunteered to participate in the PD programme, observations made during school visits to check on the state of the Experimento 10+ kit and researchers’ field notes. A group of teachers for training was selected by one of the multipliers after an open call was sent to all public and private high schools; 42 teachers initially responded, but five (5) withdrew for personal reasons.

Of the remaining 37 teachers, 24 were female whilst 13 were male who came from different schools in Gauteng province and whose professional experience ranged between four and thirty years. They were all teaching Physical Science at Further Education and Training (FET) level, that is, Grades 10-12, during the period of Experimento 10+ PD programme. The questionnaire was given to teachers to complete by two of the multipliers who conducted school visits. The questionnaire designed by Siemens Stiftung, which is also available on their website, was validated for face, content and criterion validity in several countries in three continents (Africa, Latin America and Europe). The reliability of the instrument was determined by calculating the Cronbach’s coefficient and $\alpha = 0.90$
was found, which is very high. According to Leedy and Omrod (2010), a good rule of thumb is that reliabilities should be 0.7 and above to be acceptable. The coefficient obtained for the instrument is well-above this recommended value suggesting the instrument was intervention programme over a period of three (3) years. At this stage as the author I declare interest in the success of the programme. The author was involved in the project from its conception in South Africa in the year 2011 during which he was trained as one of the multipliers. The author and another multiplier were involved in data collection on behalf of the non-governmental organisation. The data were collected using validated instruments generated by the non-governmental organisation. The sample for the workshoped teachers is 37 from 37 high schools (3 workshops in total, first workshop had 13 teachers, second and third workshops had 12 teachers each) in Gauteng province of South Africa hence multipliers’ encounters and experiences are drawn from these for reflection. Of the 37 schools, 15 were former model C schools and 22 were township schools. Teachers from the first workshop were assigned code A (e.g. A3 for teacher 3) whilst those from the second workshop were assigned code B (e.g. B6 for teacher 6) and from the third workshop teachers were assigned code C (e.g. C5 for teacher 5).

Interpretive studies ‘are framed by descriptions of, explanations for, or meanings given to phenomena by both the researcher and the study participants rather than by the definitions and interpretations of the researcher alone’ (LeCompte & Preissle, 1993:31–32). Such an approach suggests that social research should capitalize upon the researchers’ ‘personhood’ (Stanley & Wise, 1983) and ‘reflexivity’ as ‘the human capacity for participant observation. We act in the social world and yet are able to reflect upon ourselves and our actions as objects in that world’ (Hammersley & Atkinson 1995:21). As theExperimento programme came to a close with each group of teachers, our experiences as facilitators fuelled questions regarding our own and the teachers’ roles, which we did not originally have in mind. The main data sources analysed in the study are questionnaire, semi-structured individual interviews with all 37 teachers who volunteered to participate in the PD programme, observations made during school visits to check on the state of the Experimento 10+ kit and researchers’ field notes. A group of teachers for training was selected by one of the multipliers after an open call was sent to all public and private high schools; 42 teachers initially responded, but five (5) withdrew for personal reasons.

Of the remaining 37 teachers, 24 were female whilst 13 were male who came from different schools in Gauteng province and whose professional experience ranged between four and thirty years. They were all teaching Physical Science at Further Education and Training (FET) level, that is, Grades 10-12, during the period of Experimento 10+ PD programme. The questionnaire was given to teachers to complete by two of the multipliers who conducted school visits. The questionnaire designed by Siemens Stiftung, which is also available on their website, was validated for face, content and criterion validity in several countries in three continents (Africa, Latin America and Europe). The reliability of the instrument was determined by calculating the Cronbach’s coefficient and $\alpha = 0.90$ was found, which is very high. According to Leedy and Omrod (2010), a good rule of thumb is that reliabilities should be 0.7 and above to be acceptable. The coefficient obtained for the instrument is well-above this recommended value suggesting the instrument was reliable. Interviews were conducted after completing the questionnaire when the multipliers would have gone through the responses. Participants were informed of the reflective aim of the study and that the data would be available to the three facilitators for analysis and reflection. During the interview, teachers were asked
to narrate their experiences on their participation in the programme, from volunteering to participation to the whole process of experimenting in their classroom and interacting with the group of teachers they were trained with during the PD programme. They also expanded on their views on how often they conducted experiments using the Experimoto 10+ kit, critical reasons for conducting certain experiments, evaluation of aspects regarding the Experimoto-kits, evaluation of aspects regarding the Experimoto-instructions and cooperative learning techniques they used in their classrooms, PD and teacher professionalism among others.

Additional data used as supplementary in this paper included field notes written by the multipliers as they visited schools to observe the enactment of science activities in teachers’ classrooms and the status of additional apparatus and equipment the schools have besides the Experimoto-kits which were freely given to participating schools. Permission was sought and granted to use the Siemens Stiftung name in this paper hence ethical considerations were adhered to through the organisation’s informed consent (Corti, Day, & Backhouse 2000).

Results

The first research question asks to what extent teachers are effectively using the Experimoto10+ Kits to promote inquiry-based learning in their classrooms. To address this question, data was sought from the questionnaire, interviews and observations made during school visits. One question on the questionnaire asked what period of time lay between the training and the first usage of the Experimoto-set. Of the 37 teachers, 14 indicated that they used the Experimoto-set within a month, 20 teachers used the set within three months and three teachers used the set between three and six months. Teacher A3, during interviews said, “I immediately used the Experimoto-set after receiving it because I did not have any other apparatus and chemicals to use.” Observations made during school visits indeed confirmed that the sets were being used. However, acknowledging use of the Experimoto-set does not imply effective use of the sets. So other questions on the questionnaire sought to provide information on the efficacy of using the kits. For example, two other questions asked, how often teachers conducted experiments with the Experimoto-set. A follow-up question asked how often teachers used Experimoto materials for other experiments besides the prescribed ones. Contrary to expectations, 27 teachers responded by saying they frequently used the set whilst 10 teachers attested that they occasionally use the set. These figures were confirmed during interviews when school visits were embarked on to make observations.

Having determined the frequency of use of the Experimoto-set, the next question sought to establish how experiments are conducted using the set. In response to this question, 5 teachers indicated that they leave learners to experiment on their own, whilst 12 submitted that the learners watch them conducting the experiments(demonstration) and 20 penned that learners conduct the experiments under their supervision. Teacher B6 said, “I let the learners conduct the experiments under my supervision regardless of huge class numbers, which is what you taught us...” Linked to this question, all 37 teachers agreed the experiments can be conducted with a high number of learners, 24 teachers agreed that the experiments can be conducted by learners on their own and 13 teachers acknowledged that it is policy at their schools that learners should never do experiments on their own. Teacher C4 said, “I would have liked the learners to be on their own with the Experimoto-set when doing their science projects but school policy does not allow learners to be on their own when doing experiments.”
The questionnaire also asked teachers the critical reasons for them to conduct certain experiments. Of the 37 teachers, 26 responded by saying the curriculum dictates the topics on which experiments should be done, 22 acknowledge that experimenting allows action-oriented teaching, 7 teachers believe experiments can easily be conducted by learners on their own, 19 teachers wrote learners are motivated by the experiments, 14 hinted that the material for the experiments is readily available and 24 believe the learners’ autonomy is supported through this experiment kit. During interviews, teachers had a lot to say when probed on their responses. Teacher A10 said,

the material in the Experimento-set enables us to do some prescribed practical activities (PPA) with great accuracy. The thermometers are very sensitive and durable. I use them when doing water heating and cooling curves a prescribed experiment for Grade 10. Imagine we do the experiment in a test tube. The results are so good to the extent that all learners produce smooth curves. I have shown the procedures and techniques to nearby Physical science school teachers. They like it and say it works so well...

Asked to evaluate several aspects regarding the Experimento-kits, 24 teachers noted that there is sufficient material in the kit, all teachers highlighted that materials in the kit do not break easily but consumables had to be replenished and 25 teachers acknowledged that instructions in the manual are very helpful when setting up experiments. During interviewing, the teachers reiterated their views they had put on the questionnaire. Teacher C5 from a well-resourced school said, “There is sufficient material in the kit”, however, on the same point, teacher C7 from a poorly resourced school said, “Material in the set/kit is insufficient, we need more material” Regarding durability all 37 teachers interviewed confirmed the material does not break easily and is good.

The second research question related to how the teachers fusing cooperative learning methodologies exposed to them during the professional development programme to enhance inquiry-based learning.

Part of the Experimento PD programme entails equipping teachers with cooperative learning techniques as they implement inquiry-based teaching in their classrooms. Cooperative learning is the instructional use of small groups so that learners work together to maximise their own and each other’s learning. The first question on the questionnaire was asking the teachers to identify which cooperative techniques they were using in their classrooms. The majority of the teachers (34 out of 37) identified the group formation technique they learnt during the PD as the popular technique they were using. This was followed by 28 teachers mentioning assigning members of the group roles such as resource manager, time keeper, scribe, experimenter and so forth. Eight teachers noted that they were using both think-pair-share and placemat techniques. Seven teachers acknowledged they were using the gallery walk technique whilst six teachers attested to the idea of using the buddy book and only five teachers acknowledged still remembering and using the numbered heads technique. The second question was soliciting if teachers wanted more training in cooperative learning techniques. In response, 34 out of 37 confirmed that they indeed needed more training. During interviewing, all teachers said they needed some more training in cooperative learning techniques because they are so helpful. Teacher A9 said I have forgotten how to fold the buddy book but it is useful.

The third research question focuses on implications of this research for classroom practice and Science curriculum development. To address this question, interview data became handy. During interviewing, one teacher A7 said,
hands-on activities in real laboratories not only improved our teachers’ technological pedagogical content knowledge but also motivated us to include inquiry-based teaching strategies in science classroom practices. This was coupled with cooperative learning techniques which enabled us to ensure that all learners are involved during the learning and teaching process.

Another teacher B2 said,

the Experimento PD programme has helped my knowledge on how to strive to provide opportunities for learners to collaboratively build, test and reflect on their learning. I have gone on to implement what I have learnt from this programme and my learners are becoming confident and independent learners and are collaborating within and beyond the classroom.

It is interesting to note that during interviewing, teacher C5 reiterated aspects of inquiry-based teaching by saying,

...this training has helped me a lot. When doing practicals, my learners can now easily identify and test hypotheses within collaborative settings. The cooperative learning techniques I learnt are becoming useful. The learners are even acknowledging that my ways of presenting content of the subject have changed and they are developing deep understanding of content knowledge. The learners said there have been an improvement of ideas and knowledge and they can now solve problems or creating solutions easily...

Discussion

The results given in the previous section in addressing the question on the extent to which teachers are effectively using the Experimento10+ Kits to promote inquiry-based learning in their classrooms are moderately encouraging. There are several possible explanations for this result. Firstly, some schools had no science equipment at all and the Experimento-set enabled the teachers to conduct practical activities. This finding corroborates the ideas of Nompula (2012) who suggested that many schools in South Africa have insufficient equipment to perform practical activities and implement inquiry-based learning in the classroom during science classrooms. Another possible explanation for this might be linked to the frequency the teachers conducted practical activities and the way most teachers conducted these activities. Given that quite a number of teachers were still demonstrating some of the practical activities, these findings are rather disturbing. These results are consistent with those of Trautmann et al. (2004). This was despite of the fact that teachers were now having access to the Experimento-set which they could use to drive inquiry-based classroom instruction. The results of this study were successful in establishing the teachers’ priority areas as they were able to show that teachers are concerned mostly with prescribed practical activities negating the recommended practical activities which can be very useful in implementing inquiry-based teaching. These findings are in disagreement with Warner and Myers’ (2008), facets of inquiry-based lessons which include starting the inquiry process and promoting student dialogue among others.

Results regarding cooperative learning techniques were very encouraging. Despite some teachers dealing with huge classes, cooperative techniques at least enable all the learners to take part in the learning process. Aspects of inquiry-based learning as suggested by Warner and Myers (2008) such as transitioning between small groups and classroom discussions, the teacher intervening to clear misconceptions or develop learners’ understanding of content material as well as modelling scientific
procedures and attitudes are implemented in the process. This finding was encouraging. The combination of this study’s findings provides support and implications for classroom practice and science curriculum development for the conceptual premise that inquiry-based teaching strategies in science classroom practices utilises learner experiences to create new content knowledge through modelling scientific procedures which might influence learners’ attitudes. Some of the issues emerging from this study findings’ relate specifically to the fundamental goal of inquiry-based teaching which focuses on learner engagement during the learning process and more facilitation where support in providing professional development is delivered to classroom teachers (Yost et al, 2009) concentrating on particular subject matter content or pedagogical approaches intended to build their instructional skills and abilities.

Conclusion

The purpose of this study was to ascertain encounters and experiences of Experimento multipliers by evaluating the effectiveness and value the use of the Experimento10+ Kits as well as assessing the extent of use of cooperative learning methodologies by teachers exposed to them by multipliers in their science classrooms. Facilitating the implementation of inquiry-based teaching on a small-scale was a success. Teachers’ comments regarding didactic and methodological approaches to classroom experiments using an inquiry-based approach to science education provided some anecdotal evidence that was suggestive of their lack of awareness of the cooperative learning techniques. To a moderate extent teachers indicated they are effectively using the Experimento 10+ kits to promote inquiry-based learning in their classrooms. Cooperative learning methodologies exposed to teachers during the professional development programme to enhance inquiry-based learning proved useful as the teachers have begun to involve all learners in inquiry-based lessons regardless of huge class sizes in some of the schools. Given that this paper’s findings point in the direction of teachers implementing inquiry-based teaching to a moderate extent, future studies recommending such interventions throughout the year which might result in teachers improving their skills of employing inquiry-based teaching are needed. Further research should be done to investigate encounters and experiences of Experimento multipliers in other regions such as South Africa - the unexplored provinces and Kenya), Latin America (e.g. Chile, Peru), and Europe (e.g. Germany) where the Experimento programme is run differently from the one discussed in this paper given since curricula are different and the training is run differently.

References


The Influence of Gender, Teacher, and Scientific Practices on Students Engagement in Science Learning in Finland and the United States

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Abstract
The aim of this study was to uncover relationships between students’ reported use of scientific practices and these practices’ influence on situational student engagement in secondary science classrooms in Finland and the United States (US). The participating 12 teachers were trained to use certain scientific practices; then, project-based science units emphasizing scientific practices were designed in collaboration with researchers and teachers. Engagement data was collected during the science lessons via combining the experience sampling method (ESM) with smartphone technology. Altogether, 9,624 single engagement measurements were taken. The amount of times students were engaged in science were rare, occurring in about 17% and 15% of the learning situations in the US and Finland, respectively. In the US, students were most engaged when developing a model, asking questions, and analyzing/interpreting data, but this varied by gender and teacher. In Finland, students were most engaged when asking questions, developing a model, and constructing an explanation. These preliminary results emphasize the role of modelling and allowing students to ask questions in engaging students in science learning. In both countries, the average percentage of time students were engaged varied by teacher; therefore, science teachers may play a major role in promoting student engagement. In the US, males were more engaged in science learning than females. In Finland, there were no gender differences.

Introduction
Students’ declining interest in, motivation for, and engagement in science learning has received significant attention in the international science education research community (Osborne & Dillon, 2008; Zeyer et al., 2013) and has been highlighted in education policy documents, such as in the Programme for International Student Assessment (PISA) (Organisation for Economic Co-operation and Development [OECD], 2013). Finland and the US are attempting to address the importance of student engagement in science classes through the introduction of new science curricula/standards (Finnish Ministry of Education and Culture [FMEC], 2013; Next Generation Science Standards [NGSS] lead states, 2013). This provides a unique opportunity to compare how students currently experience their science classes as they relate to these new initiatives. The framework for the NGSS is a “three-dimensional” learning model: 1) scientific practices: eight behaviors and skills that emphasize inquiry in science; 2) cross-cutting concepts: seven ways of linking the different scientific disciplines; and 3) disciplinary core ideas: essential content knowledge across four domains of science: physical; life; earth and space; and the engineering, technology, and application of science (National Research Council [NRC], 2012). The first version of the new Finnish upper secondary school core curriculum was published in May 2015, and the collection of feedback was
organized during the summer of 2015. The new curriculum emphasizes acquiring relevant competences through familiarizing students with core scientific knowledge and practices. One way to teach using a “three-dimensional” framework is by engaging students in a project based science approach (Krajcik & Shin, 2013).

Objectives of the study

The objective of this study is to uncover relationships between students’ reported use of scientific practices and their influence on situational student engagement in secondary science classrooms in Finland and the US. Scientific practices are being introduced in new science curricula/standards in Finland and the US (FMEC, 2013; NGSS lead states, 2013) that emphasize the importance of active participation in specific learning situations that stretch knowledge acquisition individually and in a small group. These practices involve students, for example, in asking questions and defining problems; planning and carrying out investigations; analyzing and interpreting data; and developing explanations and designing solutions.

The research question is as follows: How does student engagement vary by gender, teacher, and the implementation of different scientific practices in the classroom?

Conceptualisation of the concept situational engagement

Much is known about interest and motivation and their influence on learning. For example, task-based interest could be created by choosing an appropriate teaching method, grouping students, using an interesting activity, or through offering students meaningful choices (Deci & Ryan, 2004). The role of context is emphasized as the starting point for the development of scientific ideas and interest (Bennett, Lubben, Hogarth & Campbell, 2004). Science-related engagement research emphasizes the differences in male and female students’ interest and the influence of the educational context on the development of interest. Many researchers argue that in general, girls are less interested than boys in physics, and that student interest in physics decreases as student age increases (Tytler, Osborne, Williams, Tytler, & Cripps, 2008).

Many research outcomes considering student interest and motivation are based on survey or interview data. However, surveys and interviews have limitations because they obtain retrospective measures of students’ reports on engagement experiences and their subjective feelings about them (Tuominen-Soini & Salmela-Aro, 2014). Although researchers agree that engagement is a changeable, malleable experience that occurs over time, existing studies pay limited attention to how students experience science-learning situations (Fredricks & McColskey, 2012). Moreover, basic assumptions that females are less engaged in science learning are based on surveys but not on measurements in real situations. Thus, measurements in real situations, like the experience sampling method (ESM) (Csikszentmihalyi & Schneider, 2000), could offer new insights on students’ engagement in science learning. Therefore, in contrast to those who have conceptualized engagement as a monolithic trend, we have specifically identified engagement as varying in intensity across different domains and situations, a characterization that fits closely with current definitions of situational interest in science education research (Krapp & Prenzel, 2011).

We approach situational engagement in the context of flow theory (Csikszentmihalyi, 1990) through three pre-conditions: interest, skill, and challenge. In order to be engaged, a student should experience elevated levels of challenge in a task but also feel equipped with the requisite skills to undertake the task. Skill is defined as a mastery of a set of specific tasks, and challenge is defined as a desire to persist in a science-learning situation (Eccles & Wigfield, 2002). Furthermore, a student must also experience situational interest in the task, as outlined by Hidi and Renninger (2006); Krapp and Prenzel (2011); and Lavonen, Juuti, Uitto, Meisalo and Byman (2005). Consequently, interest is defined as a psychological predisposition for a specific object. A student is considered to be engaged in a task when he or she simultaneously experiences elevated feelings of challenge, skill, and interest. Low levels of student engagement in science classes are a concern for both countries in the current study (OECD, 2007; OECD, 2013; President’s Council of Advisors on Science and Technology [PCAST], 2012). Research has found that too many schools in the United States (US) and Finland teach science superficially rather than encouraging integrated knowledge that allows students to draw upon their understanding to ask relevant questions, solve problems, make decisions, and learn new ideas (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014; Krajcik & Czerniak, 2013; Lavonen, 2013).

Need for engagement in science classes

Several policymakers and researchers have argued that school science should better represent real scientific practices and cater more effectively to the needs and interests of students (Andersson, 2007; European Union [EU], 2004; Tytler, 2014). Niemiec and Ryan (2009) argued that all humans would like to learn about their environment, and it should not be confused with external control. Therefore, scientific practices have the potential for promoting engagement in science learning. Engagement is not just an isolated and mechanistic phase in the beginning of the lesson that appeals to students’ curiosity, but it is built through employing scientific practices in a learning situation. One way to accomplish this is through the use of project-based science lessons. Therefore, these practices have the potential for guiding students toward situations in which they can employ their competences in challenging and interesting situations. However, there is not enough evidence on how engaging and to which students these practices are engaging in real science-learning situations.

Methods

This study presents the results from a collaboration between researchers in Finland and the US where secondary science teachers in both countries partnered with their local university to learn how to implement the scientific practices component of the three dimensional learning model in their classroom. As a part of this collaboration, a professional development intervention was implemented and scientific practices were introduced to six teachers over two consecutive days of workshops in both countries by a science education curriculum designer and researcher. After the workshops, the teachers designed a two-week intervention for upper secondary science lessons to be immediately implemented. These plans were developed in collaboration with the researchers. The intention of the intervention was to raise secondary students’ engagement in their science classrooms through employing scientific practices in different situations.

We gathered data in the US in five classrooms (three biology, one chemistry, and one physics) at three different time points across an academic semester. The US students were in grades 10 through
12, ranging in age from 15 to 18 years old. In Finland, seven classrooms were sampled (two biology, one chemistry, and four physics). The Finnish students were in grades 9 through 12, ranging in age from 16 to 19. In the US, a total of 103 high school students participated in the study from the Michigan area and provided over 3,500 responses, of which 1,300 were collected in science classrooms. In Finland, 167 high school students participated from the metropolitan area and provided over 14,000 responses, of which about 7,000 responses were collected in science classrooms. All of the students in both countries were given a background questionnaire to complete using items from the 2006 PISA survey, which asked about attitude, experiences, and future orientation toward science as a discipline in addition to demographic information. To validate the students’ responses, we also collected teachers’ lesson plan data on each day that the students were surveyed. We also observed lessons to watch for the use of scientific practices in the classroom to verify the fidelity of the measurements and implementation. It is important to note that these results are not intended to be causal. Within both countries, the samples were selected from convenience and cannot be generalized to the larger population.

In the Finnish schools, the number of science lessons varied between two and three per week and lasted for 75 minutes at a time. In the US, there was one 60-minute science lesson every weekday. In order to measure engagement in a science-learning situation, we have developed a system that uses smartphones with a special application that implements the Experience Sampling Method (ESM) (Csikszentmihalyi & Schneider, 2000) which is designed to capture in the moment affective feelings of the participants. During a two-week period, we randomly measured students’ level of engagement in specific science situations using the smartphone application. All of the students were given identical smartphones for the data collection period. The phones were adjusted to make a signal three times in science lessons and randomly during other lessons. Every phone was adjusted to make a signal at the same time, covering the first, middle, and the last part of the lesson. The time between two signals was 15 minutes, so the first signal went off 15 minutes after the beginning of the lesson.

This situational engagement was measured with Likert-scale items relating to situational interest, skills, and challenges (Csikszentmihalyi & Larson, 1987; Csikszentmihalyi, 2014) using questions such as “Is the activity interesting?” (1 = not at all to 4 = very much); “Your skills in the activity” (1 = low to 4 = high); and “Challenge of the activity” (1 = low to 4 = high). In the context of this ESM measurement, we operationalized engagement as a state of involvement in a learning task identified by higher-than-average individual states of interest, skill, and challenge (Eccles & Wang, 2012; Reschly & Christenson, 2012). Second, we asked qualitative questions such as “What are you doing?” and “With whom?” Third, the students selected the practice they were conducting in the situation from a list of scientific practices that we provided. The practices in the list included asking questions, developing a model, planning an investigation, conducting an investigation, analyzing data, solving math problems, constructing an explanation, using evidence to make an argument, evaluating information, and other. The practices were introduced to students in the beginning of the designed two-week intervention. Moreover, the teachers emphasized the name of the practice the students were conducting during the science lessons. We conducted several different analyses of the data in order to identify optimal learning moments. For example, we calculated person-level means across interest, skill, challenge, and differences in
optimal learning moments by gender using two-tailed t-tests. In addition, we used the person-oriented approach to identify different engagement/disengagement profiles (Raudenbush & Bryk, 2002).

**Results**

First, the data was filtered to contain only responses from when students were in their science classes. Then, the engagement measure was created as a dummy variable. A student response was considered engaged (= 1) when a student simultaneously reported high levels (Likert score of 3 or 4) of challenge, skill, and interest. If one or more of these emotions was not above a 3, then the response was counted as not engaged (= 0). Next, percentages of engagement were calculated by gender, teacher, and scientific practice (primary and secondary) within each country. Since the samples are not representative for either country, no between-country comparisons were made. In each country, tables were made that computed the differences in engagement by gender, by teacher, and by scientific practice (see Tables 1–3b).

Table 1. Engaged Responses in Science Class by Gender

<table>
<thead>
<tr>
<th>United States</th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Engaged Responses</td>
<td>1,407</td>
<td>1,506</td>
<td>2,913</td>
</tr>
<tr>
<td>Percentage</td>
<td>82%</td>
<td>85%</td>
<td>83%</td>
</tr>
<tr>
<td>Engaged Responses</td>
<td>317</td>
<td>274</td>
<td>591</td>
</tr>
<tr>
<td>Percentage</td>
<td>18%</td>
<td>15%</td>
<td>17%</td>
</tr>
<tr>
<td>Total</td>
<td>1,724</td>
<td>1,780</td>
<td>3,504</td>
</tr>
<tr>
<td>Percentage</td>
<td>49%</td>
<td>51%</td>
<td></td>
</tr>
</tbody>
</table>

Finland

<table>
<thead>
<tr>
<th></th>
<th>United States</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Engaged Responses</td>
<td>1,566</td>
</tr>
<tr>
<td>Percentage</td>
<td>85%</td>
</tr>
<tr>
<td>Engaged Responses</td>
<td>285</td>
</tr>
<tr>
<td>Percentage</td>
<td>15%</td>
</tr>
<tr>
<td>Total</td>
<td>1,851</td>
</tr>
<tr>
<td>Percentage</td>
<td>30%</td>
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Table 2. Differences in Engagement by Science Teacher in the United States and Finland

<table>
<thead>
<tr>
<th></th>
<th>United States</th>
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<th></th>
<th></th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Teacher 1</td>
<td>Teacher 2</td>
<td>Teacher 3</td>
<td>Teacher 4</td>
<td>Teacher 5</td>
<td></td>
</tr>
<tr>
<td>Not Engaged</td>
<td>730</td>
<td>770</td>
<td>262</td>
<td>684</td>
<td>467</td>
<td>2,913</td>
</tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>Percentage</td>
<td>84%</td>
<td>88%</td>
<td>90%</td>
<td>74%</td>
<td>86%</td>
<td>83%</td>
</tr>
<tr>
<td>Engaged</td>
<td>139</td>
<td>109</td>
<td>29</td>
<td>239</td>
<td>75</td>
<td>591</td>
</tr>
<tr>
<td>Responses</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage</td>
<td>16%</td>
<td>12%</td>
<td>10%</td>
<td>26%</td>
<td>14%</td>
<td>17%</td>
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<tr>
<td>Total</td>
<td>869</td>
<td>879</td>
<td>291</td>
<td>923</td>
<td>542</td>
<td>3,504</td>
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<th></th>
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<th></th>
<th>Total</th>
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<tbody>
<tr>
<td></td>
<td>Teacher 6</td>
<td>Teacher 7</td>
<td>Teacher 8</td>
<td>Teacher 9</td>
<td>Teacher 10</td>
<td>Teacher 11</td>
</tr>
<tr>
<td>Not Engaged</td>
<td>1183</td>
<td>406</td>
<td>417</td>
<td>532</td>
<td>1052</td>
<td>469</td>
</tr>
<tr>
<td>Responses</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage</td>
<td>89%</td>
<td>86%</td>
<td>84%</td>
<td>81%</td>
<td>86%</td>
<td>88%</td>
</tr>
<tr>
<td>Engaged</td>
<td>151</td>
<td>65</td>
<td>77</td>
<td>128</td>
<td>173</td>
<td>66</td>
</tr>
<tr>
<td>Responses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage</td>
<td>11%</td>
<td>14%</td>
<td>16%</td>
<td>19%</td>
<td>14%</td>
<td>12%</td>
</tr>
<tr>
<td>Total</td>
<td>1334</td>
<td>471</td>
<td>494</td>
<td>660</td>
<td>1225</td>
<td>535</td>
</tr>
<tr>
<td></td>
<td>Asking questions</td>
<td>Developing a model</td>
<td>Using a model</td>
<td>Planning an investigation</td>
<td>Conducting an investigation</td>
<td>Analyzing data</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>------------------</td>
<td>--------------------</td>
<td>---------------</td>
<td>--------------------------</td>
<td>----------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td><strong>Not Engaged Responses</strong></td>
<td>241</td>
<td>77</td>
<td>179</td>
<td>44</td>
<td>111</td>
<td>385</td>
</tr>
<tr>
<td>Percentage</td>
<td>79%</td>
<td>77%</td>
<td>83%</td>
<td>94%</td>
<td>85%</td>
<td>83%</td>
</tr>
<tr>
<td><strong>Engaged Responses</strong></td>
<td>63</td>
<td>23</td>
<td>36</td>
<td>3</td>
<td>19</td>
<td>80</td>
</tr>
<tr>
<td>Percentage</td>
<td>21%</td>
<td>23%</td>
<td>17%</td>
<td>6%</td>
<td>15%</td>
<td>17%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>304</td>
<td>100</td>
<td>215</td>
<td>47</td>
<td>130</td>
<td>465</td>
</tr>
<tr>
<td>Percentage</td>
<td>11%</td>
<td>4%</td>
<td>8%</td>
<td>2%</td>
<td>5%</td>
<td>17%</td>
</tr>
</tbody>
</table>
## Table 3b. Percentage of Engaged Responses in Finland by Scientific Practices

<table>
<thead>
<tr>
<th>Scientific Practice</th>
<th>Not Engaged Responses</th>
<th>Engaged Responses</th>
<th>Total</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asking questions</td>
<td>89</td>
<td>35</td>
<td>124</td>
<td>2%</td>
</tr>
<tr>
<td>Developing a model</td>
<td>106</td>
<td>42</td>
<td>148</td>
<td>3%</td>
</tr>
<tr>
<td>Conducting an investigation</td>
<td>67</td>
<td>45</td>
<td>112</td>
<td>1%</td>
</tr>
<tr>
<td>Planning an investigation</td>
<td>257</td>
<td>49</td>
<td>306</td>
<td>1%</td>
</tr>
<tr>
<td>Solving math problems</td>
<td>522</td>
<td>142</td>
<td>664</td>
<td>4%</td>
</tr>
<tr>
<td>Constructing an explanation</td>
<td>138</td>
<td>34</td>
<td>172</td>
<td>2%</td>
</tr>
<tr>
<td>Analyzing data</td>
<td>412</td>
<td>142</td>
<td>554</td>
<td>8%</td>
</tr>
<tr>
<td>Solving math problems</td>
<td>2062</td>
<td>427</td>
<td>2489</td>
<td>11%</td>
</tr>
<tr>
<td>Using evidence to make an argument</td>
<td>656</td>
<td>130</td>
<td>786</td>
<td>22%</td>
</tr>
<tr>
<td>Evaluating information</td>
<td>1397</td>
<td>140</td>
<td>1537</td>
<td>22%</td>
</tr>
<tr>
<td>Other</td>
<td>257</td>
<td>49</td>
<td>306</td>
<td>8%</td>
</tr>
<tr>
<td>Total</td>
<td>5838</td>
<td>1062</td>
<td>7035</td>
<td>83%</td>
</tr>
</tbody>
</table>

Percentage calculations based on total number of responses in each category.
Discussion

Overall, in science classes, students in the US reported being engaged about 17% of the time, while in Finland, this percentage was about 15% of the time. Although this level of engagement is low, it is higher than our earlier measurements in different situations. For example, according to our first data, collected in the spring of 2013 when there was no intervention present, only 13% of all observed 6,900 situations were recognized as being engaging in US secondary school. Moreover, only 9% of the situations during the science lessons were engaging for students (Schneider, Bruner, Judy, & Broda, 2014). These measurements were done in the same schools and using almost the same teachers as the measurements in the current study. The same schools and teachers were selected in order to compare the outcomes of the current study to previous study where the measurements were done in “traditional situations”. In this study the lessons were designed together with the teachers in order to have science practices during the lessons. Although the topics and students were not necessary the same we argue that the use of scientific practices in science learning could have an influence on student engagement in science learning compared to traditional approaches.

Our preliminary results suggest that there is a large amount of variation in student engagement between teachers in both countries in our sample. The average percentage of time students reported being engaged by teachers ranged from 25% to 10% in the US. The sample of teachers in Finland was slightly more consistent, with a range of 19% to 11%. Therefore, more research is needed to better understand the pedagogy used with scientific practices and the influence of different pedagogies on engagement. Why are some teachers more successful in making scientific practices more engaging than other teachers?

The difference in engagement varied by gender in the US. Male students were engaged about 18% of the time, compared with 15% for females. There were no gender differences in Finland. Therefore, our preliminary results do not support all of the outcomes that have been acquired with traditional surveys. It seems that gender differences are smaller when the measurements are done in certain situations. More research is needed on situational engagement in order to better understand the differences between males’ and females’ situational engagement in science learning.

With respect to scientific practices, in both countries, one of the most common practices students reported was “other,” which suggests that students were not always conducting scientific practices, or that they did not recognize they were doing them. In the US, 28% of the time, students reported doing something other than a scientific practice, which was the most common response, compared to about 22% of the time in Finland, where “other” was the second most common response. When students did identify that they were conducting a scientific practice, in the US, the most common responses were “analyzing data” (17%), “evaluating information” (16%), and “asking questions” (11%). In Finland, by far the most common response was “using evidence to make an argument (35%), followed by “evaluating information” (11%) and “analyzing data” (9%).
Frequency does not appear to equate with engagement in our samples. The most engaging scientific practices for students in the US were developing a model (23%), asking questions (21%), using a model (19%), and analyzing data (19%). In Finland, students reported that the most engaging scientific practices were asking questions (28%), developing a model (28%), and constructing an explanation (26%). In both countries, modelling and asking questions appeared to be the most engaging practices for both students.

Conclusions

This study looked at instances in which our participating teachers implemented a three-dimensional (project-based) science unit emphasizing scientific practices that were designed in collaboration with our research team and other teachers. This is significant work because each country is in the process of implementing new science curricula, of which scientific practices are a major part and our data is captured in the moment rather than with a survey which is subject to recall bias. Our preliminary results suggest that moments of student engagement in science are rare, occurring about 17% of the time in the US and 15% of the time in Finland. In the US, our gender findings are in line with much of the previous research, which showed that females were less engaged in their science classes. In both countries, the average percentage of time that students were engaged varies a great deal by teacher, suggesting that science teachers may play a major role in promoting student engagement. In both countries, students reported that they were most engaged when they were doing modelling and asking questions. Students in the US were engaged when they were analyzing data, while students in Finland were engaged when they were constructing explanations. While not causal or representative of either country, this study provides some of the first in the moment insight into the relationships between student engagement, teachers, and the use of scientific practices. Overall, this preliminary work suggests that how a teacher is trained in, and implements, project-based teaching may impact momentary student engagement. It also appears that modeling and allowing students to ask questions may engage students at a higher rate.

References


Csikszentmihalyi, M. (2014). Toward a psychology of optimal experience. In M. Csikszentmihalyi, Flow and the foundations of positive psychology, the collected works of Mihaly Csikszentmihalyi (pp. 209–226). Netherlands: Springer.


South African Curriculum and Assessment Policy Statement compared with selected international high school Science syllabi and their implications

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Abstract

The perennial underperformance in physical science at school and problems experienced in tertiary science necessitates a comparison of the Curriculum Assessment Policy Statement (CAPS) with international curricula. Document analysis is used to compare CAPS with similar documents used in Europe, America, the Commonwealth and Zimbabwe. CAPS is shown to have less rigorous content, little practical work and the content is not sequenced to promote cognitive growth in physics thought. A major revision of CAPS is recommended, to include practical paper in stake examinations, based on close comparison with similarly benchmarked standards in order to make the South African school graduate comparable to other countries. Also, teacher education programmes have to be revised to produce quality teachers who evince content command and best practice in the classroom.

Keywords: practical activity, rigor, sequence, cognitive, assessment.

Introduction

Performance in Physical Science education at South African matriculation level has been poor and inadequate, both at the level of content prescription and teaching (Cramer’s Engineering News, 2012; Mji and Makgato, 2006). The Curriculum and Assessment Policy Statement, (CAPS, 2012) in line with the Constitution of South Africa directs implementation in schools. However, how well does the CAPS compare with similar documents in other countries? While CAPS covers political nuances and pedagogical detail (CAPS, 2012) syllabi in other countries simply describe the content, sometimes suggest methodology and describe assessment objectives. This paper makes the hypothesis that CAPS does not offer enough academic content and methods to prepare candidates in the processes of science or for university entrance as compared to foreign physical science syllabi. The comparison is made of the cognitive demands of CAPS in theory and practical physics with Cambridge International Examinations (CIE), the Zimbabwe General Certificate of Education (ZGCE), European (EB) and the International Baccalaureate (IB).

Literature review

The ability of a curriculum to engender proficiency in the learners is a measure of its viability (Hunt & Lasley, 2010). This viability can be measured by power standards and power indicators. Power standards and indicators outline content, concepts and skills that are
essential within an academic discipline and at each grade level to ensure that all students have the opportunity to achieve proficiency (Keating, 2006). The standards are broken into logically sequenced instructional objectives that must be achieved through the years. Ideally, all curricula that lead to a pre-university certification such as CIE, ZGCE, EB, CAPS and IB should have comparable standards that allow graduates from each to enter and perform well in any university worldwide.

The performance of learners depends, among other things, on teaching and its alignment with the assessment and evaluation process (Burger, Bowie & Nyaumwe, 2010). Several researches have tried to explain the depressed performance in school Mathematics and Science in South Africa (DoE, 2001, Howie, 2003) and these researchers identify interalia: language of learning and teaching (Department of Basic Education, 2010), effect of large classes (Onwu & Stoffels, 2005), educational resources (Basson, & Kriek, 2012), alignment between subject assessment guidelines and the complexity of exams (Burger et.al., 2010) and coherence of the curriculum (Newmann et al., 2001). Learner and teacher factors, education system, syllabus and policy, all influence the ultimate performance in stake examinations. So, comparison of CAPS with selected international syllabi is necessary to evaluate its relevance, viability and power standards.

Ainsworth (2003, p. 2) defines the power standard of a curriculum as a subset of ‘prioritized standards that are absolutely essential for student success apart from those “nice to know” things. Learning standards are determined by educators at school level. Power standards help teachers to focus by teaching more depth in a narrower range of topics. The benefit of this approach is that learners are able to engage in high order reasoning skills that will remain through all their learning process rather than a shallow introduction to a wide range of topics which is not enduring beyond examinations. According to Reeves (2004) and Ainsworth, (2004) three criteria are used to set power standards:

- **Endurance** which prioritises the skills that the learner will use throughout life (beyond high stakes examinations, such as interpreting graphs, maps, currency value conversion etc.)
- **Leverage** prioritises skills that are useful in multiple disciplines (e.g. calculus in physics, chemistry, engineering, biology, finance etc.)
- **Readiness** for the next grade level (e.g. knowledge of algebra is necessary before calculus or geometry).

The instructional objectives of each grade level are thus aligned to the power standards determined for each locality. Curriculum coherence in each locality is achieved by vertical alignment, meaning what is learnt in one grade prepares learners for the next grade; horizontal alignment meaning the curriculum coverage in one grade level is common to all learners in that grade. Coherence helps teachers therefore to avoid repetitions, interruption of concept development and uncoordinated layering of concepts in different subjects. An example of lack of coherence is where a Physics teacher develops kinematics and dynamics using graphs before the Mathematics teacher has introduced graphs. In the same example, naturally consecutive concepts may not even be arranged sequentially. Thus, curriculum coherence achieves high order skills through deep content coverage which the learner can adapt to different disciplines and subsequent grade levels.
Objectives of the study

- To compare the requirements of CAPS in Mechanics with international syllabi for Grade 10-12.
- Identify knowledge gaps in South Africa (SA) CAPS in Mechanics that may be a source of poor performance of learners in national assessments.

Method

Document analysis was used to compare official physics syllabuses used in South Africa, United Kingdom, United States of America, Europe and Zimbabwe for the last three years of high school. Physics was chosen because it is regarded as difficult, and yet it underlies many science concepts in undergraduate science study.

The topic Mechanics is fundamental for most Physics concepts hence in this study it is used to measure the different syllabi. The comparison is in the following areas: Content depth, sequencing of concepts, amount and assessment of practical work and time allocation for it.

Results

1. Mechanics Concepts in CIE, CAPS, IB, ZGCE and EB

Physical Sciences includes Physics and Chemistry, implying a somewhat shallow level in each subject, than studying the two separately. CIE, IB, EB, ZGCE (Table 1) all take the initial two terms to cover foundational concepts of mechanics. Subsequent topics in Physics are built on the mechanics foundation. On the contrary CAPS takes three years to cover fewer foundational concepts of mechanics. CAPS prescribes Introduction to Vectors & Scalars and Motion in one dimension in Grade 10. Vectors in two dimensions and Newton’s Laws are only introduced in Grade 11. Momentum and Impulse are introduced in Grade 12. This is slow development and it is because half the time is dedicated to Chemistry section. This implies that learners will take three years to assimilate fewer issues in Mechanics than their counterparts in other countries studying single subjects. In addition, CAPS excludes fundamental concepts of mechanics (indicated by 0 in Table 1) implying that the South African school leaver will only meet these ideas at university unlike school graduates from elsewhere.

Table 10 Comparison of mechanics concepts offered by different school curricula

<table>
<thead>
<tr>
<th>Concept</th>
<th>CIE 2 yrs.</th>
<th>IB 2 yrs.</th>
<th>CAPS 3 yrs.</th>
<th>ZGCE 2 yrs.</th>
<th>EB 2 yrs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vectors and scalars</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>SI units</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Avogadro</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Orders of magnitude</td>
<td>✓</td>
<td>✓</td>
<td>0</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Dimension analysis</td>
<td>✓</td>
<td>✓</td>
<td>0</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Error Analysis</td>
<td>✓</td>
<td>✓</td>
<td>0</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Linear kinematics</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>--------------------------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Non-linear motion</strong></td>
<td>✓</td>
<td>✓</td>
<td>0</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Newton’s Laws</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Linear momentum</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Types of Forces</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Equilibrium</strong></td>
<td>✓</td>
<td>0</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Turning effects of forces</strong></td>
<td>✓</td>
<td>0</td>
<td>0</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Work Power Energy</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Work-Energy theorem</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Circular motion</strong></td>
<td>✓</td>
<td>✓</td>
<td>0</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Simple harmonic motion</strong></td>
<td>✓</td>
<td>✓</td>
<td>0</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Gravitational Field</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>- Potential</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>- Strength</td>
<td>✓</td>
<td>✓</td>
<td>0</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>- Kepler’s Laws</td>
<td>0</td>
<td>✓</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
2. Sequencing of mechanics concepts

Table 11 Excerpt from CAPS 2012 shows the disjointed development of mechanics.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 10</td>
<td>Introduction to vectors &amp; scalars; Motion in one dimension. Energy. 30 hours</td>
</tr>
<tr>
<td>Grade 11</td>
<td>Vectors in two dimensions. Newton’s Laws and Application of Newton’s .27</td>
</tr>
<tr>
<td>Grade 12</td>
<td>Momentum and Impulse. Vertical projectile motion in one dimension. Work, Energy &amp; Power. 28 hours</td>
</tr>
</tbody>
</table>

Comparative curricula EB, CIE, IB and ZGCE all develop mechanics first whereas CAPS develops mechanics in bits and pieces through three years (Table 2). This means that the student will get to the final year while still building the foundational concepts of Mechanics. Thus, students do not fully assimilate mechanics by the time they reach Grade 12. The international syllabuses complete Mechanics at the beginning of the course first. Tables 3 to 6 show mechanics concepts required in EB, CIE and ZGCE.

Table 12 Excerpt from EB syllabus for penultimate year of high school

<table>
<thead>
<tr>
<th>Section</th>
<th>Content</th>
<th>AS – Form 5 or (Gr 12)</th>
<th>A2 (Form 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I General Physics</td>
<td>1. Physical quantities and units ✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>2. Measurement techniques ✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>II Newtonian mechanics</td>
<td>3. Kinematics ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Dynamics ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. Forces ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Work, energy, power ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Motion in a circle</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8. Gravitational field</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>
Table 14 Content topics covered in the first half of Form 5 in ZGCE.

<table>
<thead>
<tr>
<th>1.0 Physical Quantities and Units</th>
<th>5.0 Forces</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Physical quantities</td>
<td>5.1 Types of force</td>
</tr>
<tr>
<td>1.2 SI Units</td>
<td>5.2 Equilibrium of forces</td>
</tr>
<tr>
<td>1.3 Avogadro constant</td>
<td>5.3 Centre of gravity</td>
</tr>
<tr>
<td>1.4 Scalars and vectors</td>
<td>5.4 Turning effects of forces</td>
</tr>
<tr>
<td>2.0 Measurement Techniques</td>
<td>6.0 Work, Energy, Power</td>
</tr>
<tr>
<td>2.1 Measurements</td>
<td>6.1 Energy conversion and conservation</td>
</tr>
<tr>
<td>2.2 Errors and uncertainties</td>
<td>6.2 Work</td>
</tr>
<tr>
<td></td>
<td>6.3 Potential energy, kinetic energy and internal energy</td>
</tr>
<tr>
<td></td>
<td>6.4 Power</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3.0 Kinematics</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1 Rectilinear motion</td>
</tr>
<tr>
<td>3.2 Non-linear motion</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4.0 Dynamics</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1 Newton's laws of motion</td>
</tr>
<tr>
<td>4.2 Linear momentum and its</td>
</tr>
<tr>
<td>conservation</td>
</tr>
<tr>
<td>4.3 Impulse</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>7.0 Motion in a Circle</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1 Kinematics of uniform circular motion</td>
</tr>
<tr>
<td>7.2 Centripetal acceleration</td>
</tr>
<tr>
<td>7.3 Centripetal force</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>8.0 Gravitational Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1 Gravitational field</td>
</tr>
<tr>
<td>8.2 Force between point masses</td>
</tr>
<tr>
<td>8.3 Field of a point mass</td>
</tr>
<tr>
<td>8.4 Field near to the surface of the Earth</td>
</tr>
<tr>
<td>8.5 Gravitational potential</td>
</tr>
</tbody>
</table>

3. Rigour
Comparison was made of the objectives on the modernised Bloom scale: Remembering, Understanding Applying, analysing, evaluating and creating (Draper, 2015). The number and level of objectives and criteria of practical skills show the degree of demand of the syllabus. All the syllabi examine mainly the lower level objectives but the practical work and examinations in the international syllabi examines creativity, evaluation and analysis. Frequent practical work also develops manual dexterity and high order thinking skills.

It is also important to notice that in CIE, ZGCE, and IB, all the mechanics is one topic in the introduction to physics. Whereas in CAPS, it is intermittently covered in three years. Thus in CAPS, one-dimensional vectors take most of the time in Grade 10 and two dimensional projectiles are not treated. In CIE, ZGCE, IB and EB, individual practical activities take much time, only one or two activities are recommended by CAPS and there are no terminal practical examinations in CAPS.
Rigour was measured by the number and level of content objectives set out by four curricula. CIE, ZGCE, IB all had 18 content objectives in the prelude to mechanics; Quantities Units and Measurement techniques. For CAPS such a prelude is ‘Skills for Physical Sciences Learners’ (CAPS, 2012 p.154) with no estimated time guide, which says ‘It is recommended that these skills be incorporated in lessons in Grade 10 appropriately in order to sharpen the skills that are necessary for successful teaching and learning.’ (CAPS, 2012 p.154). Therefore, the teacher must find an appropriate point to introduce measurement ideas in Grade 10. Different teachers can treat these skills differently. It is not scheduled like ‘Vectors and Scalars’ (4hrs in Term 3 Grade 10). CIE, ZGCE, IB and EB have more, deeper content objectives coupled with practical examinations, which is more rigorous than CAPS. The intermittent approach to one topic (covering it in three years) without practical examinations may not really demand cumulative experience with Mechanics. Meanwhile, practical work has distinct examinable criteria in international curricula: Design, Data collection and processing, conclusion and evaluation, manipulative and personal skills. These skills in the CAPS are not examined since there is no practical paper in matric stake examinations.

4. Practical work
Table 6 shows how CAPS prescribes one experiment in Grade 10 in term 1 and a second experiment in term 2. ZGCE, IB and EB in contrast, require that schools give each individual student, a three hour period for practical work each week, implying that such learners are exposed to more than ten experiments in a term.

Table 15 Prescribed and recommended practical activities for Grade 10 in the CAPS.

<table>
<thead>
<tr>
<th>Term</th>
<th>Prescribed</th>
<th>Recommended</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Heating and cooling curve of water.</td>
<td>Practical Demonstration (Physics)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use a ripple tank to demonstrate constructive and destructive interference of two pulses OR Experiment (Chemistry)</td>
</tr>
<tr>
<td>2</td>
<td>Electric circuits with resistors in series and parallel - measuring potential difference and current.</td>
<td>Investigation (Physics)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pattern and direction of the magnetic field around a bar magnet. OR Experiment (Chemistry)</td>
</tr>
<tr>
<td>3</td>
<td>Acceleration Example: Roll a ball down an inclined plane and use measurements of time and position obtain a velocity- time graph and hence determine the acceleration of the ball.</td>
<td>Experiment (Physics)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Roll a trolley down an inclined plane with a ticker tape attached to it and use the data to plot a position vs. time graph. OR Experiment (Chemistry)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reaction types: precipitation, gas forming, acid-base and redox reactions.</td>
</tr>
</tbody>
</table>
The following variations could be added to the investigation:

i. Vary the angle of inclination and determine how the inclination impacts on the acceleration

ii. Keep the angle fixed and use inclined planes made of different materials to determine how the different surfaces impact on the acceleration. One could also compare smooth and rough surface etc.

| 4 | Experiment (Physics)  
Conservation of Energy (qualitative) |

A demonstration does not give practice to individual learners and the degree of difficulty of the investigation suits Grade 8 or 9 in Natural Science.
Table 16  Sample instructions to teachers about Practical work from IB, ZGCE and EB.

<table>
<thead>
<tr>
<th>IB</th>
<th>ZGCE</th>
<th>EB</th>
</tr>
</thead>
<tbody>
<tr>
<td>On a practical level, the group 4 project (which all science students must undertake) mirrors the work of real scientists by encouraging collaboration between schools across the regions. p5</td>
<td><strong>C Experimental skills and investigations</strong> Candidates should be able to: 1. follow a detailed set or sequence of instructions and use techniques, apparatus and materials safely and effectively; 2. make observations and measurements with due regard for precision and accuracy; 3. interpret and evaluate observations and experimental data; 4. identify a problem, design and plan investigations, evaluate methods and techniques, and suggest possible improvement; 5. Record observations, measurement, methods and techniques with due regard for precision accuracy and units.</td>
<td>3. Teaching approach. <strong>There is no such thing as a non-practical science course:</strong> for the essence of scientific activity is to observe, relate observations one to the other, draw conclusions, make predictions and test these. Therefore the phenomena underpinning the cognitive knowledge of physics embodied in the course must as far as possible be observed in the laboratory or classroom, and it is highly desirable that pupils should themselves perform as much practical manipulation as the limited course time allows. In addition to this, pupils should learn to use traditional means (reference books and private study) to help themselves, as well as the methods which modern computing makes available to science. These include: - computerized gathering and logging of data - computerized data processing - simulation - use, where appropriate, of multimedia reference material and of resources offered by the Internet.</td>
</tr>
</tbody>
</table>

Note: The order in which the syllabus content is presented is not intended to represent the order in which it should be taught. p 7

CAPS however emphasises:  
**Step-by-step instructions:** following instructions is a good skill; manual dexterity is tested by requiring the students to perform very delicate motions and measurements.
Verifying information: CAPS (p. 64) asks to verify Newton’s Second law (In Grade 11) and verify the value of g (p. 99).

Alternative to Practical examinations:
These are questions that are based on a rendition of an experiment, sample data, and the candidate is required to analyse, infer and predict. The real advantage of such and examination is that the school is spared from buying equipment. However, training students for such an examination requires practical work experience in many experiments.

5. Time allocation for practical work in Physics
The CAPS document recommends teachers to give one formal practical assessment task. While several other practical activities are described, only one or two marks from practical work need be shown. Ostensibly these marks are for the district offices to keep record of continuous assessment (Kibirige & Teffo, 2014). There is thus no requirement to show development of practical skills and there is no terminal assessment of practical skills. While other curricula assess scientific process skills in practical examinations: designing experiments, handling data, drawing and communicating inferences. In international curricula, practical activity is primarily individual and frequent, with terminal examinations. The IB requires 40 and 60 hours of practical work for the Standard Level and Higher Levels respectively. CIE and ZGCE curriculum emphasises the importance of practical work as:

It should be stressed that candidates cannot be adequately prepared for this paper without extensive laboratory work during their course of study. In particular, candidates cannot be taught to plan experiments effectively unless, on a number of occasions, they are required:

• to plan an experiment
• to perform the experiment according to their plan
• to evaluate what they have done.

This requires many hours of laboratory-based work, and requires careful supervision from teachers to ensure that experiments are performed safely. (p. 47).

In 30 weeks of contact time in a year, learners spend 90 hours on individual practical activity. Learners master how to follow instructions, design experiments for accuracy and precision thus enculturating a practice of science. However, many public schools in South Africa have no laboratories and equipment enough to conduct frequent individual experiments (Mavhunga & Kibirige, 2015).

6. Assessment of practical skills
Assessment of practical skills takes several sessions but CAPS emphasises that one (1) or two (2) practical experiments can be done per term. Limited activities do not signal high standards requirement to teachers and learners. In two prescribed experiments, it is impossible to measure process skills criteria.
Discussion

The idea of Policy Statement

CAPS is a ‘policy statement’ being used in schools as a syllabus. The very description of a syllabus as a Policy statement may conjure a sense of political mandate. The fact that it is also authored by the Minister of Education, it appears as though the state machinery is brought into the classroom. All the other equivalent documents are defined as syllabi and not policy statements. Syllabi are designed by science curriculum developers, educators and examiners interpreting policy statements from government. For instance, a curriculum policy can state that science students must approach science like scientists. This would then be translated to a school syllabus that separates subjects and focuses on conceptual development, sequencing, content detail and laboratory practices for teachers and learners.

Mechanics Concepts

CAPS does not offer Physics as a separate subject. Grouping Physics and Chemistry into one subject has the obvious effect of making the coverage of either subject shallower than separate Physics and Chemistry subjects. CAPS (Physical Sciences) also lacks many core concepts in Mechanics e.g. dimensional and error analysis, Circular motion and gravitational fields. Lack of these skills diminishes the preparedness of undergraduate students in Physics.

The content detail and practical skills learners get at the end of CIE, IB, EB or ZGCE enable them to enter many universities in the world for a three year bachelor’s degree. On the contrary CAPS graduates are likely to qualify into four year bachelor degrees in South Africa. Research into academic needs indicates that CAPS graduates are un-prepared for university work also due to ‘lack of English proficiency, mathematical ability and effective study skills’ (Du Plessis & Gerber, 2012). Other social factors are beyond the scope of this paper. As a result of this academic deficiency, university education is found to be very demanding in the first and second years and up to fifty percent of black (historically disadvantaged) students drop out of university (Maqubela, 2012). In a related study, Student Retention and Graduate Destination, conducted in seven universities and Technikons in Western and Eastern Cape, one student’s reason for dropping out of college was ‘I battled to learn all the new
‘terminology and think in my chosen field of study’. Another was ‘I had no induction program to my studies, which made it difficult for me to cope right from the beginning’ (Letseka, Breier and Visser, 2012:34). This indicates inadequate concept development and mastery at high school. Students who cannot reason out issues at tertiary level resort to cramming to pass their degrees. When such people graduate as teachers, they are not confident and cannot even conduct experiments with their classes: instead teachers teach the way they were taught (Oleson & Hora, 2014).

**Sequencing**

The general sequencing of mechanics ideas come from the history of the fundamental laws of nature, and the general flow of learning from concrete experiences to abstract ideas (Settlage & Sutherland, 2012). Because learners are tacitly aware of fundamental concepts such as time, mass and length, these fundamental quantities form the basis of mechanics. The interconnectedness of time, length and mass is concrete in mechanics, everyone has tacit experience with them. Figure 1 outlines how the fundamental units of mass, length and time become interwoven into the higher concepts of Energy, Work and Power. A teacher can easily build on this conceptual fabric to show the inter-connectedness of concepts in physics. It is logical to develop all foundational mechanics concepts at the beginning of the physics course rather than build portions of mechanics foundation over three years as is currently the practice in the (CAPS) South African model. There is a natural continuity in physics thought in which students need to master and use the language, relationships and logic of classical mechanics concepts, to understand and apply to higher cognitive concepts such as oscillation, waves, electricity and modern physics. Figure 1 shows how the sequential progression from mechanics, builds a conceptualisation of Physics. The same foundation laid in Physics also supports any mechanics study that is done in mathematics and in technology. CAPS misses an opportunity to consolidate the curriculum coherence by arranging mechanics in a disjointed manner.

Sequence in Mechanics comes from three factors: historical development of the subject, progression from simple to complex ideas and the natural experience of the learner. The CAPS arrangement takes learners three years learning small unconnected bits of Mechanics. Immediately they move from mechanics to another concept, deep learning in mechanics is interrupted. An uninterrupted treatment of mechanics is necessary to study other concepts that will invoke force, energy, power, etc. Sequential arrangement helps learners to align fundamental concepts with other disciplines. Conceptual learners master the broader subject easier (Hobson, 2010; Hewitt, 2012)
Fundamental and derived quantities

![Figure 1](image)

**Figure 1** Quantities derived from mass length and time showing interconnectedness of Physics.

**Rigour**
CAPS has very well chosen objectives in Mechanics. However the content that is developed in those objectives does not offer deep learning in Mechanics. Elsewhere, there is much deeper and wider content selection and emphasis on practical work than in CAPS. This is missing in the CAPS Physical Sciences.

**Practical work**
Practical work in CAPS consists of infrequent activity that leads the learners to verifying established physics laws. This work is too little to train learners in the basic skills of experimentation and report writing and does not stimulate ‘thinking and designing solutions like a scientist (Prat, 2012; Harris, 2013; Krajcik, & Merrit, 2013). In Grade 12, CAPS requires the following in Physics and Chemistry:

1. Analyse the components of a properly designed scientific investigation.
2. Choose an experiment and determine appropriate tools to gather precise and accurate data.
3. Defend a conclusion based on scientific evidence.
4. Determine why a conclusion is free from bias.
(5) Compare conclusions that offer different, but acceptable explanations for the same set of experimental data.

(6) Investigate methods of knowing used by people who are not necessarily scientists. p.98.

It would however, take many more practical activities to develop learners to such a high level of scientific maturity. EB and IB guide to teachers sets a clear expectation and challenge to teachers and learners (and parents) that the learner must act as a real scientist and they are expected to use all facilities at their disposal such as computers and internet and smart phones. Modernisation and inclusion of information technology, computers are made part of the IB curriculum (IB syllabus).

**Time allocation**
Mechanics is easily developed practically, enough time needs to be allocated for it. The small amount of time allocated to practical work in CAPS gives learners a feeble grounding in the subject (Campbell & Prew, 2014). Proficiency in practical work requires time on task and independent thought (Woodley, 2010). Safety, accuracy and precision take time to develop. The small number of practical activities required by CAPS means that learners do not master practical skills. Research has found that teachers avoid practical work (Kibirige et al., 2014), are not confident and do not have enough experience to do practical science (Onwu and Stoffels, 2005). It can be construed that with little time allocated to a combined, Physics and Chemistry as Physical Sciences subject, there is inadequate preparation in the practice of science.

**Assessment of practical work**
In CAPS there are no terminal or stake practical examinations. The assessment of practical work is done through formal and informal continuous assessments. The two prescribed experiments are set a low standard of achievement for teachers and learners. Besides setting low standards, many South African learners are encouraged to use past examination marking guides or ‘memoranda’ to practice for examinations (personal observations). Thus, learners can actually pass by cramming procedures and answers from previous memoranda.

By comparison the other curricula set out to assess skills that nature the students through several practice sessions. While verifications are an important part of scientific work, the nature of questions set for examination by IB, CIE, EB and ZGCE go far beyond simple verification to test the scientific scholarship of the learner. Table 12 shows that 90% of the weight of the ZGCE practical examination assesses high order thinking skills of design, handling data and application, deductive reasoning and creation. So students who pass from ZGCE are capable of designing and conducting experiments on their own. Such skills make learners to perform well at tertiary studies in any country.

**Conclusion**
The paper aimed to compare South African CAPS and international syllabi. It compared the depth of content in Mechanics and the amount of practical work that is done by learners. Practical work is assumed to develop the learners in the processes of science, making them better prepared for university science courses. CAPS, however, prescribes a maximum of
two practical activities for assessment per grade whereas all the other syllabi require that much more time be spent on practical work (e.g. 40 to 60 hrs in IB at Standard Level ZGCE).

Dudu and Vhurumuku (2012) aptly observed that the ‘requirement that only two practicals are assessed per grade might be sending wrong signals to teachers, leaving open possibility of misinterpretation as ‘‘Do only two practicals’’

The small number of practical activities also implies low levels of conceptual growth, skill in data handling, inference and hence understanding of science. This is compounded by a disconnected concept build-up. One dimensional motion at the start of Grade 10 is followed by a little study of Vectors in two dimensions in Grade 11. In Grade 12 they revisit Mechanics only to learn about Momentum and Impulse, Projectiles, Work Power and Energy. This is rather slow progression in content, where all other syllabi cover all mechanics in the first term of one year. Thus, CAPS does not have rigour and its sequencing of content allows learners to forget content, and as such learners may not be well grounded in the subject.

**Recommendations**

This study recommends to increase content depth and include practical work that is examinable in the stake examinations. Schools that offer Physical Science and Biology need to equip laboratories and empower teachers to guide learners in conducting experiments, increase contact time and the number of practical activities. Teacher-training institutions need to enhance deeper in content and practical work than they are currently offering.

**Suggested content reorganisation in CAPS**

**Table 18** Suggested reorganisation of the CAPS Physics syllabus

<table>
<thead>
<tr>
<th>Grade</th>
<th>Suggested Content Syllabus</th>
<th>Individual Practical Experiments (One 90- minute practical session per week per student)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 10</td>
<td><strong>Mechanics</strong>&lt;br&gt;Kinematics&lt;br&gt;Dynamics, Work Energy Power&lt;br&gt;Gravitation&lt;br&gt;Oscillations&lt;br&gt;Shm, energy in shm, damped and forced oscillations&lt;br&gt;Waves&lt;br&gt;Transverse, longitudinal, reflection, refraction, diffraction, Interference&lt;br&gt;Sound, Doppler Effect</td>
<td>Kinematics&lt;br&gt;Dynamics- collisions&lt;br&gt;Oscillations- Simple pendulum&lt;br&gt;-Compound pendulum&lt;br&gt;-Mass-spring problems&lt;br&gt;-Optics experiments&lt;br&gt;-Interference&lt;br&gt;&lt;br&gt;Skills to be developed&lt;br&gt;-Use of measurement instruments&lt;br&gt;-precision and accuracy</td>
</tr>
<tr>
<td>Grade 12</td>
<td><strong>Magnetism</strong>. <strong>Electromagnetic induction</strong>. <strong>Alternating current</strong>. <strong>Charged particles</strong>. <strong>Nuclear Physics and Radioactivity</strong>. <strong>Quantum Physics</strong>. <strong>Electronics</strong>. <strong>Physics Project</strong>.</td>
<td></td>
</tr>
</tbody>
</table>

With rapidly expanding knowledge, access to information and interconnectedness of ideas, teachers can no longer rely on the content mastery they got in their basic training. There is a need for teachers to focus on single teaching subjects to keep the teachers knowledgeable and creative. A 1969 quote shows how far back we have had knowledge explosion “In almost every classroom, there are now children who know more about something than the teacher knows” (Howard, 1969). In 2016 it is much more imperative for teachers to be very knowledgeable in their field in order to help learners adequately. While specialisation has implications on the number of teachers, timetabling, equipment supplies, ancillary staff and buildings; it is worth investing in a long lasting solution than combining subjects into Physical Science or Combined Science. Specialization in teacher training would need to match the subjects in the school system. In all the countries compared with, teachers are trained in separate subjects, to allow deep treatment at school level.

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A case study on the incorporation of learners’ socio-cultural background in the teaching of Natural Sciences at three township schools in South Africa

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Abstract

In pursuit of quality and equity in science education, the South African NCS aims to ensure learner acquisition and application of knowledge and skills in ways meaningful to their lives. Based on that premise, this study is a part of a larger study which proposes that knowledge of learners’ socio-cultural background when teaching some NS topics enables science teachers to engage in multiple pedagogical and instructional strategies which make science more relevant. Consequently, three Grade 9 NS teachers from three different township schools were observed teaching for a period of six months while incorporating learners’ socio-cultural practices and beliefs. Video recordings of the lessons revealed that incorporation of learners’ socio-cultural background could be done through the use of: (1) prompt and open-ended questions that elicit learners’ pre-instructional knowledge; (2) argumentation and cooperative groups that promote class and group interaction; (3) authentic problem-solving activities and effective questioning techniques which promote the development of critical and analytical thinking skills in learners; and (4) resources, examples, experiences and language familiar to learners as useful tools to facilitate conceptual understanding. These research findings provide information that empowers teachers who strive to meet the challenges of making science more comprehensible to socio-economically and culturally diverse learners.

Introduction

In South Africa, the amended NCS Grades R-12: Curriculum and Assessment Policy (CAPS) for NS (Department of Basic Education, 2011), seeks to ensure that learners acquire and apply knowledge, skills and values in ways that are meaningful to their lives. In this regard, the curriculum promotes knowledge in both local and global contexts. The curriculum values indigenous knowledge systems, the rich history and heritage of the country as important contributors to nurturing of values. Accordingly, literature on culture and science instruction recognises the importance of the social context of science learning and the effect of the learner’s socio-cultural background on the teaching and learning of science as a prerequisite for meaningful learner achievement (Cobern, 1994; Jegede, 1995; Carter, 2007). It is detrimental therefore to downplay the influence of home and families on the education of learners (Solomon, 2003). Sadly, disadvantaged learners like township learners tend to receive the least interesting, most passive forms of instruction, and are given the least opportunity to participate actively in their own learning (Knapp, Shields & Turnbull, 1995).
Failure to incorporate learners’ socio-cultural beliefs and practices results in transmission of science content which Aikenhead and Ogawa (2007) refer to as “socially sterile, impersonal, frustrating, intellectually boring and/or dismissive of students’ life-worlds” (p. 886). Incorporation of learners’ socio-cultural background in science teaching helps to demystify science as a preserve for the elite (Okebukola, 1999). As such, success in science is dependent on how learners perceive the cultural difference between their lived experiences and the science classroom and how teachers help them to connect the two (Aikenhead & Jegede, 1998). Therefore, harmony between school and home culture promotes smooth transition of learners in the science classroom resulting in enculturation (Wolcott, 1991).

School culture comprises norms and ways of working, thinking, talking, valuing and behaving. If science teachers are not knowledgeable about learners’ socio-cultural experiences that guide learners’ behaviour and conception of science, they may either misinterpret or miss entirely what learners understand (Darling-Hammond & Friedlaender, 2008). As a result, failures of science learners from disadvantaged communities can be understood in terms of learners struggling to understand, gain access to, and find relevance in the culture and practice of science as framed by the school (Barton, 1998). Incongruence between home and the science classroom poses challenges to many urban township settings that serve culturally and linguistically diverse learner populations. As a result, schools are regarded as being in communities but often not of communities (Bouillion & Gomez, 2001). Therefore, teaching of science divorced from real community life makes it difficult for learners to discern the utility value of the skills they acquire at school.

The study takes the stance that knowledge of learners’ socio-cultural background when teaching NS is a key requirement for meaningful presentation of science in ways that are easily discernible to Grade 9 township learners. This is pertinent because educational reform in South Africa envisions schooling where all learners, irrespective of their background, have the opportunity to succeed (Frempong, Reddy & Kanjee, 2011). On that note research has shown that the way in which learners respond to school and other educational settings and benefit from the experiences presented is influenced by the socio-cultural environments in which they are socialised and schooled (McInerney, 2010). In situations where science teachers do not understand the cultural norms that guide their learners’ thinking and behaviour, they may fail to guide learners appropriately (Gay, 2000) with the result that some learners are fast-tracked from one topic to another without meaningful learning.

In the South African context township schools are in urban reserves established by the apartheid government as exclusive residential areas for Black people in South Africa. There is a diversity of socio-cultural, economic, political and religious backgrounds of learners in science classrooms, which is coupled with the influx of immigrant learners. This results in teachers and learners finding themselves in classes with learners from linguistic, cultural and educational backgrounds very different from their own.

In this regard, socio-cultural factors which include language used in the teaching and learning process, the learners’ prior experiences, their behaviour, attitudes and cultural values have been found to either facilitate or hinder learner interaction and active
participation in class (Appleton & Harrison, 2001; Wellington & Osborne, 2001). As a result, science teachers face daunting challenges which firstly include recognising and understanding diverse learners’ socio-cultural background in the classroom and secondly finding the most suitable ways to manage these differences for effective engagement of learners with science concepts. Figure 1 below shows how learners’ socio-cultural background is conceptualised in the study as including norms and values, religion and beliefs, socio-economic and political issues and indigenous knowledge.

Fig. 1. Conceptualisation of learners’ socio-cultural background

Learners’ socio-cultural background in science teaching

The study employs social constructivism as its theoretical framework in conceptualising the epistemological, ontological and methodological process (Cole, 2008), as well as in facilitating the interpretation of research findings (Crotty, 1998). Social constructivism places emphasis on the importance of a shared construction of meaning and knowledge through social interaction (Schwandt, 1994). The nature of scientific knowledge as being socially constructed and changeable calls for science teachers to foster a critical perspective on scientific culture among learners which emphasises the limitation of scientific knowledge and its application as social products (Lee, 2006). Therefore, emphasis on acquisition of knowledge and skills through content coverage does not guarantee understanding (Fraser, Tobin & Kahle, 1992). Instead, science teaching should help learners construct and modify knowledge in their mental schemes to allow understanding (Perkins, 1993).
Accordingly, social constructivists advocate for a teaching and learning environment that promotes meaningful learner-learner and teacher-learner interactions that result in co-construction and negotiation of ideas (Solomon, 1987). Barnett and Hodson (2001) assert that scientific ideas and their relationship to ideas learners already know, present different opportunities for the design of teaching and learning activities by science teachers as they encounter learners from diverse backgrounds (Lemmer, Meier & Van, 2006). Therefore the study asserts that knowledge of learners’ socio-cultural context should shape the teachers’ practice in terms of the kind of questions they ask, the ideas they reinforce, the tasks they assign to their learners and the teaching methods they employ. However, this demands schools to be inclusive and supportive of all learners, creating a system which ensures that learners’ success does not depend on their backgrounds. It is against this background that the following research question was formulated:

How do Grade 9 teachers incorporate learners’ socio-cultural background when teaching some Natural Sciences topics?

Methodology
The study employed a qualitative case study research design by exploring the processes and dynamics of teachers’ practices (Merriam, 1988; 1998) when incorporating learners’ socio-cultural background in some NS topics. The methodology shed light on what pedagogical approaches teachers employed and what activities teachers used (Gall, Gall & Borg, 1996). Using Patton’s (2002) notion of purposeful sampling, three Grade 9 NS teachers from three different township schools were selected. This study is part of a larger study where these teachers had been professionally developed on what constitutes learners’ socio-cultural background and identifying topics where the incorporation would be meaningful.

The schools
Zona, Kuhle and Pindi (pseudonyms) are three high schools located to the south-west of Johannesburg. The schools are located in almost the same community and enrol 1 360, 1 287 and 1 098 Black learners respectively, generally from the poor background of township and informal settlements. The schools are all non-fee-paying schools that depend on government support in terms of resources. Table 1 below shows the profiles of the three teachers who were involved in the study.

Table 1: Teacher profiles

<table>
<thead>
<tr>
<th>Teachers (pseudonyms)</th>
<th>Thuli</th>
<th>Peter</th>
<th>Nhlamulo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Female</td>
<td>Male</td>
<td>Male</td>
</tr>
<tr>
<td>Age</td>
<td>26</td>
<td>43</td>
<td>58</td>
</tr>
<tr>
<td>Ethnic Group</td>
<td>Sipedi</td>
<td>Zulu</td>
<td>Tsonga</td>
</tr>
<tr>
<td>Religion</td>
<td>Christianity: Jehovah’s Witness</td>
<td>Christianity</td>
<td>Christianity</td>
</tr>
</tbody>
</table>
Data collection procedure and analysis

The study was an in-depth exploration of classroom practices, using multiple forms of data collection (Creswell, 2005) to allow triangulation. Data collection involved lesson observations, post-lesson interviews and analysis of documents. Using Reformed Teaching Observation Protocol (RTOP) (Sawada et al, 2000), five lesson observations were made on each of the three teachers when teaching different sections on reproduction and sections on nutrition. RTOP was used as an observation and analytical instrument to provide a standard means of assessing how teachers incorporate learners’ socio-cultural background during NS teaching. Five target elements for observations were lesson design and implementation, propositional knowledge, procedural knowledge, communicative interactions and learner-teacher relationship (Sawada, Piburn, Falconer, Turley, Benford & Bloom, 2000). Table 2 shows areas taught by each teacher.

Table 2: Summary of lessons observed

<table>
<thead>
<tr>
<th>Lesson Number</th>
<th>Thuli</th>
<th>Nhlamulo</th>
<th>Peter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9 F: The male reproductive structure and circumcision.</td>
<td>9E: The male reproductive structure and circumcision.</td>
<td>9D: The male reproductive structure and circumcision.</td>
</tr>
<tr>
<td>2</td>
<td>9H: The female reproductive system and causes of infertility in humans.</td>
<td>9A: The female reproductive system and importance of reproduction.</td>
<td>9 G: The female reproductive system (structure and function).</td>
</tr>
<tr>
<td>3</td>
<td>9D: Use of science and research in solving infertility problems.</td>
<td>9A: Causes of infertility in humans.</td>
<td>9E: Causes of infertility in humans.</td>
</tr>
<tr>
<td>4</td>
<td>9 H: Surrogacy and socio-cultural implications.</td>
<td>9C: Surrogacy, research and ethical considerations.</td>
<td>9D: Structure of the respiratory system.</td>
</tr>
<tr>
<td>5</td>
<td>9 F: The menstrual cycle and associated myths.</td>
<td>9C: Gaseous exchange: Use of an analogy.</td>
<td>9D: Twins and traditional beliefs.</td>
</tr>
</tbody>
</table>
Lesson observations were videotaped and analysis of the videos involved identifying and describing evidence of each of the observed areas. Appendix A shows an example of an analysis of a lesson using RTOP.

Each teacher was interviewed after every lesson using a structured interview schedule to allow them to clarify and elaborate practices observed when teaching. Interviews were audio-taped. Curriculum documents, lesson plans and teachers’ journals were analysed to triangulate the data. Data from post-lesson interviews and documents were analysed using the constant comparative method (Merriam, 1998) which allowed for themes and patterns to emerge from the data.

**Research findings**

The findings are presented in four main themes that were derived from the three sources of data. Each theme represents the teaching strategies that teachers employed when incorporating learners’ socio-cultural background in some NS topics.

**Theme 1:** *Teachers provided real-life scenarios and used prompt and open-ended questions to elicit learners’ pre-instructional knowledge arising from their socio-cultural background.*

The teachers ascertained learners’ pre-instructional knowledge arising from their socio-cultural background as the basis for teaching new content. They used prompt and open-ended questions in teaching infertility and the menstrual cycle in the female reproductive system. Ascertaining learners’ pre-instructional knowledge prevented distortion of new concepts in cases where prior knowledge from their socio-cultural background conflicted with new content (Manokore et al, 2014), as learners tend to transform meaning based on previous knowledge (Campbell & Campbell, 2009).

**Example 1: Infertility in females**

For instance, one teacher, Thuli, provided a scenario of an infertile woman. Such concepts had not been dealt with before in class, so it required learners to bring knowledge built up from years of experience in their communities. The teacher inquired, “What could be the problem?” The question stimulated discussion with some learners placing blame on the husband and others on the woman. Some suggested that the woman was bewitched or cursed by ancestral spirits. The teacher withheld certain information to allow learners to explore all possible reasons for infertility. The teacher intermittently provided information, for example that the medical doctor confirmed that the woman had functional eggs and that the husband was fertile, in order to channel learners’ thinking towards certain concepts to be covered. The teacher asked, “What then could possibly be affecting the couple?” This provoked learners to explore other possible causes of infertility and even to question their earlier reasons. In this way, teachers identified and addressed conceptual difficulties likely to be experienced by learners at specific points to allow smooth acquisition of new concepts.

Class and group discussions of the above real-life scenario enabled learners to express ideas which if ignored could have created barriers to the understanding of new concepts. Some
learners’ ideas were scientifically wrong, for instance, that HIV/AIDS could have caused infertility in the woman. The teacher made reference to a local orphanage home in the community that caters for orphans born of HIV-positive women. This made the learners abandon the idea and focused on STIs as possible causes of infertility.

The teacher failed to pursue the issue of witchcraft and also failed to comment on the issue of ancestors where some learners suggested the importance of spiritual guidance for effective infertility therapy. Such arguments demonstrate how learners’ ideas are influenced by their socio-cultural beliefs and practices. During post-lesson interviews the teacher indicated that she was not aware of how to address such issues as they tend to conflict with science knowledge. This shows that learners may bring socio-cultural beliefs that are contentious and might prove to be counterproductive. For instance in an observation of another teacher, Nhlamulo, on that same section, the teacher said, “To be honest with you when it comes to things involving witchcraft, I cannot help the children much because I also don’t understand whether it really happens or not.”

On options for the woman to have a child, adoption came first from different classes. The teachers revealed that learners were quick to suggest adoption since quite a number of them were adopted. Others lived close to the orphanage where adopted children led a comfortable lifestyle under the care of people other than their parents. Adoption was a reality and a meaningful solution to infertility.

During class discussion, the teachers did not readily provide learners with information that could have made it easier for them to answer the questions at hand. Connections between a real-life scenario and scientific concepts enabled the teachers to elicit learners’ pre-instructional knowledge. Use of prompt and open-ended questions helped teachers elicit learners’ alternative conceptions that could have remained unarticulated if the teacher had not provided the scenario.

**Example 2: The menstrual cycle**

In post-lesson interviews, teachers pointed out that traditionally parents are not comfortable discussing issues of sexuality with their children. Instead, such roles of sexual education and orientation are assigned to the aunts and uncles. Because most learners are no longer in touch with their extended families due to urban migration, teachers adopted new roles as they incorporated learners’ socio-cultural background, which Irvine (2003) refers to as parental/surrogate roles. As a result, in certain instances, the teachers did not bring in scenarios for discussion, but learners raised sexuality issues of concern to get solutions or explanations to some experiences they encounter in their lives. Learners made attempts to validate what they already knew about sexuality against the scientific concepts they had learned. Teachers pointed out that in certain instances the level of ignorance and misconceptions learners display in terms of their reproductive systems was disturbing.

In one of the lessons taught by Nhlamulo, a learner asked, “What causes period pains?” Two learners’ responses are stated below,
Learner 1: There is too much dirt in your body so menstruation is a way of removing the filthy stuff from the body, the body is cleaning itself, my grandmother told me so.

Learner 2: This cleans evil spirit from your body.

The teacher asked, “How do you explain the source of the dirt”. One learner retorted, “It’s coming from some of the junk food we eat”.

The response shows that the learner could not distinguish the reproductive system from the digestive system. As a result Nhlamulo structured subsequent lessons in a way that would help learners distinguish scientific knowledge from their worldviews and to deduce any connections particularly on the issue of evil spirits causing period pains. The grandmother could have misinformed the learner as she could not discuss matters of sexuality with the child as already mentioned.

Therefore, through prompt and open-ended questions teachers identified gaps which learners’ social-cultural beliefs and practices create between what they teach and what is learnt.

**Theme 2: Teachers used argumentation and cooperative groups to promote learner interactions.**

Teachers used argumentation and cooperative groups to incorporate learners’ socio-cultural background when teaching the male reproductive structure, circumcision and the respiratory system. These inclusive participatory teaching strategies stimulated debates and discussions among learners.

**Example 1: Teaching male reproductive system and circumcision using argumentation**

The lesson on male circumcision was based on a task on circumcision and its benefits. Teachers tasked learners to discuss the question: Why is circumcision important in some cultures? Circumcision was explained from traditional, religious and medical perspectives due to learners’ diverse backgrounds. Learners failed to distinguish circumcision from the traditional practice of initiation which then formed the basis of the argumentation.

One of the teachers, Thuli, also provided a newspaper article entitled “Boys die in the mountains during initiation” for learners to discuss. Learners defended their cultural practices, despite the views in the article. Incensed by the newspaper article, remarks against those who opposed the traditional initiation were made, for example, “Ufana nabafazi” meaning, “You will be like ladies.” The teacher asked, “What do you mean?” One girl interjected, “but already they are men when they are born”.

The learners freely shared their opinions in class. For instance, cruel behaviour by the traditional people who performed circumcision was suggested as a cause of deaths during
the initiation ceremonies. The teacher allowed learners to argue for a while and only interrupted by asking questions which focused learners on important issues. An example is “Can we say they are cruel?” which stimulated intense discussion.

During these discussions, an emotional boy argued,

Ma’am, bontate ba tshwanetse go rutiua gore ba tiye ba seke ba tshwarwa go tshwana le bomme ka nako ea lebollo.

The boy stresses and defends the need for men to be trained to be tough and not to be treated like women, while in initiation schools. Some learners argued for the ban of initiation schools to prevent deaths. At this point learners showed differences between their socio-cultural practices and religious beliefs because while some learners tried to justify their traditional initiation process, others felt it was just a way of inflicting pain on youngsters since medical circumcision was readily available in the local hospitals. The class later agreed that medical doctors should train adults that administer circumcision at the initiation schools in terms of hygiene and provision of proper nutrition to the initiates.

The teacher created an environment where learners freely spoke about their cultural belief systems and practices and made use of argumentation where learners tried to justify their claims, making them tolerant of each other’s views on the practices and beliefs. During discussions a clash of science culture and the learners’ worldviews was evident and teachers acted as guides to provide focus to the discussions. The argumentation process therefore fostered cultural diversity tolerance and divergent thinking among the learners. The teachers’ patience allowed vibrant exploration of science concepts despite learners’ divergent ideas.

Teachers made use of probing questions to sustain the arguments and encouraged learners to provide reasons/evidence to support/refute any claims made. Argumentation facilitated the active participation and knowledge construction by learners. Throughout the process, teachers inculcated the tenets of the nature of science in learners particularly the empirical nature, its tentativeness, theory-laden and its subjectivity. At the same time social interaction among learners facilitated learner-centred learning.

**Example 2: Teaching respiratory system using cooperative group activities**

Teachers used cooperative groups to facilitate learner interactions as they shared information and learnt from each other’s insights before reaching consensus. Such interactions motivated learners to articulate and justify their conceptions as learners at various performance levels worked together.

Figure 2 shows Peter’s class working in cooperative groups to explore the role the circulatory system plays in the respiratory system. The group activity was meant to integrate related topics within the discipline instead of learning them in isolation.
used most to embrace diversity in science teaching through the incorporation of learners’ socio-cultural background. This was evident in the lessons observed as learners easily mixed and assisted each other so much that one could not tell that there were three different ethnic groups in the classes. These teachers allowed for inter- and intragroup sharing of information, although learners’ individual effort was also encouraged.

The teachers strongly supported the idea of cooperative groups as one teacher, Thuli, questioned, “How does it help you to be the only one knowing?” In support, Peter shared his experiences from the previous school where he taught a multiracial class. He pointed out that when the learners were tasked to work in groups, they would always settle in groups on racial lines. When forced to mix, the learners were uncomfortable and could not communicate freely due to language barriers. However, observations in Nhlamulo’s classes showed no group activities except during practical work as he felt that too much time is wasted in group discussions, particularly when learners’ socio-cultural beliefs and practices are incorporated. His main reason was due to the findings alluded to above where learners become vocal and express their preconceived ideas, in which case classroom management becomes an issue.
**Theme 3:** Teachers used authentic problems and activities which promoted the development of critical and analytical thinking skills in learners.

Social constructivism considers the nature of scientific knowledge as being socially constructed and changeable (Loyens, 2007), which calls for science teachers to foster a critical perspective on scientific culture among learners. Teachers achieved this through the use of authentic problem-solving activities as they incorporated learners’ socio-cultural background in their teaching. Such a strategy facilitated the application of content that stimulated critical and analytical thinking skills in learners. The theme is addressed under concepts on human reproduction which are: infertility in females, surrogacy and the concept of twins and healthy diets of different cultures.

**Example 1: Infertility in females**

In a lesson that followed after exploring the causes of infertility, Thuli asked learners to discuss the following:

> In some countries some women are paid to donate eggs that scientists can use in their studies, is it a good practice?

The learners’ responses touched on issues of ethics, beliefs and the scientific culture. Some learners argued that such women may end up barren as the practice may offend ancestors. One boy said, “amaeggs azopela”, meaning eggs will be depleted, to which the teacher responded by referring him to the question they had answered before, which showed calculations of the number of eggs a 30 year old woman could produce every month for 10 years. This was meant to show learners that quantity was not an issue here. Learners realised the need to gather adequate information before making well-grounded decisions. The teacher’s question, “How can scientists research on reproductive diseases if there are no egg donors?” triggered class discussions that stimulated learner thinking. Through such integrated questioning techniques Thuli actively engaged the learners, challenged them intellectually and promoted their critical thinking. The focus of instruction was on the learning process, rather than on the content.

Discussing issues based on ethics, traditional beliefs and the scientific point of view helped in challenging some of the views learners held at the beginning of the lesson. One learner pointed out that these women should not be paid as it should be an act of charity, as evidence of how much the learner was convinced about the importance of research in human reproduction. Other learners questioned how the ancestors would cause that kind of punishment in response to an earlier remark that women who donate eggs may become barren as it angers the ancestors. This shows learners critically evaluating their thinking and trying to justify their answers and decisions.

**Example 2: Surrogacy and other alternative ways of having children**

Thuli had tasked learners to go and research surrogacy and its implications in science and society. The responses given by learners were:
Learner 1: That’s when someone asks the other to carry her own child.

Learner 2: That’s when another woman falls pregnant on behalf of the other woman.

Learner 3: That’s when a woman asks a sister or niece to marry her husband so that she can bear children for her.

One learner emotionally said, “Surrogacy is a bad thing ma’am your friend sleeping with your husband!” There was a heated debate on the proper meaning of surrogacy, which then led to the exploration of how the process occurs scientifically. Two major forms of surrogacy were explored. One example was when a woman fails to have children because she is unable to receive and nourish a fertilised ovum, which then is placed in the surrogate mother’s womb. The second case was of a woman who does not have viable eggs; hence a surrogate mother is artificially inseminated by the sperm from the woman’s husband. The following are some of the learners’ views on surrogacy raised afterwards: “It is good to help each other out.” “Umm no, every woman should experience carrying their own baby.” “What if the surrogate mother refuses to part with the baby?” “Yes umtwana wa khe.” (meaning it is her baby). “She suffered for nine months.” “It is not her baby.” “Is it fair, umzimba wakhe umoshiwe?” (meaning her body structure was ruined due to pregnancy).

The above responses show learners’ interest to know more about the concept. Learners were stimulated to think critically and evaluate the logic and relevance of the practice of surrogacy against their prior knowledge and experiences. They raised and debated the medical, ethical and legal issues associated with surrogacy alongside their traditional belief systems.

To check learner understanding the teacher asked whose features the child would inherit. Some learners mentioned the biological mother, while others were convinced the child should resemble the surrogate mother since the child was born of her womb. The teacher further inquired, “Why are we referring to the other as the biological mother?” Such a question challenged learners to critically seek for information to justify their arguments. As a result, learners identified the source of the egg with reference to each case of surrogacy. The learners then debated how unfair the process was to the surrogate mother as she would bear the pains of carrying “someone else’s” child for nine months. Learners also explored the legal and ethical issues regarding surrogacy as they also raised fears that the surrogate mother could infect the baby, or the donating mother could also infect the surrogate mother in the event that either of them was HIV positive. Concepts such as ovulation, sperm production, in vitro fertilisation, diseases that should be screened before surrogacy such as HIV/AIDS and hepatitis B, hormonal effects and pregnancy were discussed in the process.

The learners were concerned about which ancestral spirits would guide and protect the child as it belonged to two families. It shows that learners valued identity, which is important in African traditional beliefs. Such discussions made learners to think and view issues from different perspectives. Learners managed to critically analyse and evaluate their initial ideas on surrogacy. This was facilitated by the teacher’s questions such as, “Why do you think that? What is your knowledge based upon?”
Example 3: Giving birth to twins

In Peter’s class the concept of twins was examined as some learners pointed out that traditionally, it was taboo to give birth to twins. Both babies were killed, as it was considered an abomination to the community. The class analysis of the practice brought in issues of lack of knowledge of how twins are formed, and failure to accept any anomaly by those enmeshed in the African tradition. Teachers accommodated traditional beliefs brought in by learners to the science class which facilitated coverage of relevant scientific concepts. Learners learnt to question their beliefs, instead of taking matters at face value.

Example 4: Healthy diets of different cultures

During lessons on healthy diets, learners raised issues surrounding food that are often controversial at home. An example was that traditionally, girls were not supposed to eat cheese, milk and eggs often and particularly during the menstruation period as it was believed that increased their fertility. Thuli asked the learners to discuss reasons why the adults forbade the girls to eat such nutritious food. She jokingly inquired, “Don’t you think your grandmothers are stingy and they do not want to share?”

The teacher did not rush to address her learners’ concerns but instead asked questions which helped learners to deepen their thought processes. The reason for many learners suggesting the idea originated from their grandmothers was that it emerged that some of them were orphans who were in the custody of grandmothers.

The teacher assisted the class to analyse the nutritional content of the forbidden food, which made learners realise that the food was rich in protein, fat and minerals and would increase growth. The teacher then managed to teach the food groups and their functions through critical analysis of cultural beliefs and experiences which learners brought to the science class. The learners concluded that this was the adult’s way of restraining children from fast growth as they would be sexually active and attract boys before the right time. In concurrence, during post-lesson interviews, teachers mentioned that in the African tradition, it is difficult for parents to engage children in matters of sexuality so they resort to other ways of communicating the message.

In a project to summarise classification of food, Nhlamulo tasked learners to identify a family in their community and interview them on their traditional meals. This was meant to establish the diets of learners’ different cultural or ethnic groups. The learners were to determine the food groups. The class then compiled tables which classified the different diets brought in by different learners. Table 3 shows an example from one class.

**Table 3. Examples of different types of diet compiled by learners**

<table>
<thead>
<tr>
<th>Carbohydrates</th>
<th>Proteins</th>
<th>Fats</th>
<th>Vitamins</th>
<th>Minerals</th>
<th>Fibres</th>
</tr>
</thead>
</table>

The teachers also involved their learners in investigations of food tests using some of the traditional food brought by learners.

**Theme 4: Teachers drew on learner experiences by using resources, examples, and language familiar to learners as useful tools to facilitate conceptual understanding.**

Incorporation of learners’ socio-cultural background in some NS topics forced teachers to create partnerships with community members and facilities such as clinics and resources that provided learners with access to knowledge and experiences that extend and complement learning experiences in a science classroom. This theme is addressed in the lessons that were observed during laboratory work to construct a model of a cell using readily available resources and sections of the syllabus on nutrition and healthy diet. Some of the information on the use of learners’ experiences and learners’ home languages was drawn from post-lesson interviews.

**Example 1: Use of readily available and familiar resources**

In an activity from the learners’ textbook which required learners to use gelatine to make models of a general structure of a cell, Thuli tasked learners to prepare models using resources that were readily available in the home and surroundings. Learners used seeds, grass, buttons, wool and needles which are all items found at home. Learners could manipulate the materials easily because of familiarity. In this way, teachers provided
opportunities for experiential learning through hands-on activities. Learners’ work in Figure 3 shows that they could make the model of the cell structure and its cell organelles.

Figure 3. Examples of models of general structure of a cell constructed by learners

Example 2: Use of learners’ home languages in science teaching

The researcher observed learners freely communicating in their home languages during group discussions in the science classrooms. However, when giving feedback to the class or answering the teacher’s questions, learners were forced to use English no matter how much
they struggled. The teachers explained some concepts in both English and the learners’ home languages. Code switching was important as one teacher, Nhlamulo asserted, “It helps me in explaining using their languages since most of the learners do not understand much English.”

In post-lesson interviews, teachers acknowledged facing challenges in explaining concepts in learners’ home languages as some scientific terms are not readily available in those languages. Examples mentioned included processes like melting and smelting which can be translated by the same word ‘ukhuncibilika’ in Zulu and Xhosa. The words “define” and “explain” can both be replaced by one word ‘chaza’ in Zulu. Under such situations, the teachers resorted to using examples in learners’ everyday experience to bring out the meaning. Below is an example one teacher mentioned to differentiate melting from smelting.

Nhlamulo: To explain melting I would ask them what happens with the ice they buy from the school tuck shop when they put it in their mouths. As for smelting, there are several people who weld around making burglar bars. I would ask them how those people use the metal rods because they always see them therefore I would tell them that those rods smelt.

This is evidence of the limitations of vernacular languages in science teaching. Another teacher lamented the language barrier in his classes.

Peter: I remember last year, despite discussing in class that the purpose of reproduction is to make sure the species does not become extinct, some learners were adamant that it’s meant to grow their surnames, meaning having more members of the family.

In the teacher’s view, learners were unresponsive to his teaching. An analysis of learners’ responses reveals that the learners encountered difficulty in using scientific terms. If the teacher had clearly explained to the learners the similarities between what the learners believed and the scientific reason the learners might have adopted a scientific way of explaining the importance of reproduction. Therefore teachers should conceptualise learners’ experiences and reasoning and then guide them to positively explain the scientific concepts.

Example 3: Teaching contraceptives using community members and resources

The teachers used the community in various ways. Learners were asked to get information from their parents or community members. For instance, teachers assigned learners a project to research methods of contraception. The teachers had to seek in writing the cooperation of nurses at a local clinic to assist learners as initially the nurses had declined to help.

Learners who approached other community members to discuss traditional methods of contraception did not get much help as the community members who were consulted assumed that the teacher wanted information for her own use without acknowledging them.
In response the teacher had to communicate with the community members to get information.

Teachers’ use of resources, examples, experiences and language familiar to learners was a useful tool to facilitate conceptual understanding. The teachers demonstrated their pedagogical content knowledge, which is essential for teachers to devise and deploy the pedagogical resources appropriate to teaching a particular topic within the constraints imposed by the teaching context.

Discussion

By incorporating learners’ socio-cultural background in the teaching of NS, teachers utilised the strengths that learners brought to the science classroom which included their experiences, beliefs and cultural practices and indigenous knowledge systems. Similarly Suh (2005) found that teacher’s knowledge about learners’ socio-cultural backgrounds and living conditions enabled identification of specific teaching strategies and resources suitable to learners’ needs and interests in science. This is supported by Lemke (2001) who posits that scientific concepts taught outside learners’ socio-cultural background may not be useful in life no matter how much learners seemed to understand them.

By providing real-life scenarios and using prompt and open-ended questions, teachers elicited learners’ pre-instructional knowledge arising from their socio-cultural background. Such approaches provoked learners to articulate their pre-instructional conceptions, which Duit (1996) found to be both the necessary building blocks and the impediments to learning. In addition, teachers could explore, challenge, revise and restructure learners’ worldviews during teaching (Duit, 1996). Furthermore, shared construction of meaning and knowledge could be achieved through social interaction (Schwandt, 1994).

Teachers’ open-ended questions promoted learners’ scientific reasoning skills (Harlen & Qualter, 2004), and also facilitated learners’ reflection on discovered or recognised ideas (Jelly, 2001). The interactions also allowed learners to reflect on the viability of their prior conceptions and then enabled them to negotiate shared meanings and reformulate new ideas (Kearney, 2004).

Teachers’ use of argumentation and cooperative groups promoted learner interactions. Unlike findings by Doidge and Lelliott (2010) where teachers and learners who were strongly influenced by their traditional and religious backgrounds, had difficulty in discussing human reproduction, in the current study incorporation of learners’ socio-cultural practices and beliefs stimulated learner-learner and teacher-learner interactions. Learners expressed their ideas freely due to the teachers’ creation of classroom communication and interactions that resemble family-like settings (Garcia, 1993). Through argumentation teachers encouraged learners to reveal their lived experiences from which they extracted valid scientific concepts (Ghebru & Ogunniyi, 2014).
Teachers also used cooperative small-group activities that related science concepts to learners’ everyday experiences and beliefs. Grossman (2004) found that inclusion of learners’ everyday experiences and beliefs can make a difference to learners’ achievement in science or development of emotional or behavioural problems. In the current study such a difference was evidenced by the learners’ harmonious sharing of viewpoints during discussions. In the same way Darling-Hammond et al. (2003) found that collaborative small-group learning activities helped learners to construct their own knowledge as they shared and debated viewpoints to form insights into new ideas in a communal spirit. Similarly, Walton et al. (2009) found that collaborative learning is significant in supporting inclusive teaching in South African classrooms.

Teachers’ provision of authentic problems that connected science with learners’ lives promoted learner transfer of knowledge by applying it in new situations (Lee, 2006). The teachers’ questions developed learners’ higher-order thinking skills, and forced them to evaluate authenticity of information before accepting it (Scriven & Paul, 2008). Such context-led teaching increased learner interest and appreciation of the relevance of learning in everyday life (Bennett, 2003). Learners’ involvement in solving authentic problems encouraged deeper reflections on the concept and enhanced critical thinking skills (Walsh & Sattes, 2005). Hence involvement of learners in argumentation helped learners grasp the connection between evidence and claim, understand the relationship between claims and warrants and promote their ability to think critically in a scientific context (Quinn, 1997). At the same time it helped to move non-scientific ideas and conceptions towards scientific ones (Hipkins et al., 2002).

Teachers drew on learner experiences by using resources, examples, and language familiar to learners as useful tools to facilitate conceptual understanding. This is in line with earlier studies by the Commonwealth for Learning 2001 cited in Ramnarain (2014) where the use of resources found in learners’ homes made learners operate within their zone of comfort, thereby overcoming some of the abstractness often associated with science learning.

Because teachers understood learners’ home languages, they could use them in science teaching, which is in line with the assertion of Nomlomo (2010) that code switching is only possible and useful when teachers are proficient in those languages. As such, learners benefitted from such a strategy particularly because language is not only used for interaction in a science class but also as a medium through which learners think and reason (Bloom & Keil, 2001).

**Implications and Conclusion**

The results of the study form a reference for teaching socio-culturally diverse and economically disadvantaged learners in meaningful ways while incorporating their socio-cultural background in certain topics. This provides information that empowers teachers who strive to meet the challenges of making science more comprehensible to socio-economically and culturally diverse learners.
Teachers incorporated learners’ socio-cultural background by employing teaching strategies which included use of various questioning techniques, use of real-life scenarios, use of argumentation and cooperative groups, project-based activities and resources drawn from learners’ experiences. These strategies acted as bridging scaffolds which served to connect new acquired scientific concepts with learners’ socio-cultural practices, experiences and beliefs.

References
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Appendix A: An example of an analysed lesson using RTOP

<table>
<thead>
<tr>
<th>DOMAIN</th>
<th>ITEM</th>
<th>DESCRIPTION OF EVENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.LESSON DESIGN AND IMPLEMENTATION</strong></td>
<td><strong>Item 1</strong>&lt;br&gt;The instructional strategies and activities respected learners’ prior knowledge and the preconceptions inherent therein.</td>
<td>The participant started by recapping on the previous work on reproduction in human beings. The current lesson was based on an activity that the learners had been asked to write as an informal assessment task in response to a newspaper article that read, “a group of boys died in the mountains during initiation process discuss what could have gone wrong.”</td>
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<td></td>
<td><strong>Item 2</strong>&lt;br&gt;The lesson was designed to engage learners as members of a learning community</td>
<td>The lesson was dominated by learners’ discussions as they interacted when giving feedback to the researched work. Questions such as, “Did you ask your parents or any adults at home?” And statements like, “Let’s see what you have”, are indicative of the teachers’ commitment to engage learners. The learners freely discussed their findings.</td>
</tr>
<tr>
<td></td>
<td><strong>Item 3</strong>&lt;br&gt;In this lesson, learner exploration preceded formal presentation.</td>
<td>It required learners to use learned content and also research on some content. The lesson is on feedback from researched work.</td>
</tr>
<tr>
<td></td>
<td><strong>Item 4</strong>&lt;br&gt;This lesson encouraged students to seek and value alternative modes of investigation or of problem solving</td>
<td>In the discussion of defining and explaining the importance of circumcision, the learners brought in the traditional, religious and medical views which showed various ways of solving real-life problems or issues.</td>
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<td></td>
<td><strong>Item 5</strong>&lt;br&gt;The focus and direction of the lesson was often determined by ideas originating with learners.</td>
<td>The teacher left learners to argue among themselves for some time and only interrupted later to ask them questions which directed their focus to important issues. For example the teacher asked, “Can we say they are cruel?” This was directed to learners’ heated arguments on traditional leaders’ role during initiation ceremonies.</td>
</tr>
<tr>
<td>II. CONTENT</td>
<td>Item 6</td>
<td>The lesson involved fundamental concepts of the subject.</td>
</tr>
<tr>
<td>Propostional Knowledge</td>
<td>Item 7</td>
<td>The lesson promoted strongly coherent conceptual understanding.</td>
</tr>
<tr>
<td>Item 8</td>
<td>The teacher had a solid grasp of the subject matter content inherent in the lesson.</td>
<td>The teacher managed to teach concepts despite the divergent ideas brought in by learners. Learners asked questions which showed a lot of misconceptions which the teacher explored systematically without dismissing learners’ ideas. An example is the way the teacher taught the use of correct scientific terms by analysing the differences between sterile and unclean razor blades.</td>
</tr>
<tr>
<td>Item 9</td>
<td>Elements of abstraction (i.e., symbolic representations, theory building) were encouraged when it was important to do so.</td>
<td>Abstraction was evident when the lesson started with a newspaper article of a real event that happened to the discussion of infection by microorganisms and sterilisation of instruments used.</td>
</tr>
<tr>
<td>Item 10</td>
<td>Connections with other content disciplines and/or real world phenomena were explored and valued.</td>
<td>When discussing the importance of circumcision, the lesson integrated social, religious, ethical and scientific issues.</td>
</tr>
<tr>
<td>CONTENT</td>
<td>Item 11</td>
<td>Learners used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.</td>
</tr>
<tr>
<td>Procedural Knowledge</td>
<td>Item 12</td>
<td></td>
</tr>
</tbody>
</table>
Learners made predictions, estimations and/or hypotheses, and devised means for testing them. | Not evident
---|---
**Item 13**  
Learners were actively engaged in thought-provoking activity that often involved the critical assessment of procedures. | The teacher asked questions which stimulated learners to reflect on their experiences at home. Learners critiqued each other’s ideas and at the end evaluated to determine the most plausible explanations.
---|---
**Item 14**  
Learners were reflective about their learning. | The teacher asked probing questions which made learners to critically think about their ideas thereby reflecting. For instance questions such, “Do you think the word unclean is the right scientific word to use?”
---|---
**Item 15**  
Intellectual rigour, constructive criticism, and the challenging of ideas were valued. | Learners questioned each other’s ideas. Some of the contributions were thought provoking for instance exploring the importance of circumcision from different angles: traditional, religiously and medically. The teacher also for the ethical.
---|---
**III. CLASSROOM CULTURE: Communicative Interaction**  
**Item 16**  
Learners were involved in the communication of their ideas to others, using a variety of means and media. | Learners gave feedback of their researched work. They were free to speak their minds particularly when it came to traditional practice of initiation.
---|---
**Item 17**  
The teacher’s questions triggered divergent modes of thinking. | Questions such as, “What other things happen during initiation other than circumcision?” “Is this a possible cause of death?” triggered divergent thinking in learners. The teacher left them to argue among themselves for some time before interrupting.
---|---
**Item 18**  
There was a high proportion of learner talk and a significant amount of it occurred between and among learners. | The following remarks by the teacher at the beginning of the lesson describes the nature of the interaction she expected in the class: “Remember I allowed to you to use any source of information available. Did you ask your parents or any adults at home? Let’s see what you have”.
---|---
<table>
<thead>
<tr>
<th>Item 19</th>
<th>Learner questions and comments often determined the focus and direction of classroom discourse.</th>
<th>Individual learners reported their answers to the class. These feedback opened discussions which at one point resulted in arguments or debates about issues.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 20</td>
<td>There was a climate of respect for what others had to say.</td>
<td>Learners took turns to air their views. Though they disagreed on viewpoints, no learner directly ridiculed another learner’s contributions.</td>
</tr>
<tr>
<td><strong>CULTURE: Learner/Teacher Relationship</strong></td>
<td><strong>Item 21</strong></td>
<td>Active participation of learners was encouraged and valued.</td>
</tr>
<tr>
<td></td>
<td><strong>Item 22</strong></td>
<td>Learners were encouraged to generate conjectures, alternative-solution strategies and ways of interpreting evidence.</td>
</tr>
<tr>
<td></td>
<td><strong>Item 23</strong></td>
<td>In general, the teacher was patient with learners.</td>
</tr>
<tr>
<td></td>
<td><strong>Item 24</strong></td>
<td>The teacher acted as a resource person, working to support and enhance learner investigations.</td>
</tr>
<tr>
<td></td>
<td><strong>Item 25</strong></td>
<td>The metaphor “teacher as listener” was very characteristic of this classroom.</td>
</tr>
</tbody>
</table>
Designing a teacher development programme for improving the content knowledge of grade 12 mathematics and science teachers

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This paper profiles a community engaged initiative that is in a form of a teacher development programme (TDP) offered by the Institute for Science and Technology Education (ISTE). The programme sought to improve grade 12 mathematics and science teachers’ content knowledge. The ISTE TDP adopts an iterative approach where feedback from participating teachers informed the planning and design of the following year’s edition. ISTE TDP is based on the teachers’ needs; conducted by facilitators who are significantly versed in the teaching and learning conditions in schools; has interactive sessions that are largely participant-centred; and takes place over 5 days of 8 hours each. The benefit of ISTE TDP is a capacitated community of teachers with more confidence and enthusiasm.

Key words: teacher development models; community engagement; teacher needs

Introduction

Prior to the inception of democracy in South Africa the education system was designed along racial lines. The black population was offered a sub-quality, under-funded and under-resourced education that was largely underpinned by the principles and philosophy of fundamental pedagogy, which prescribes control, authoritarianism and ‘top-down’ instructional approach. In particular, it was a form of education that consolidated the idea of sub-quality, subordination and inferiority. Furthermore, as mentioned by the Department of Education (2007:4), a considerable number of active teachers received their pre-service education and training (PRESET) prior to the era of democracy. It is argued that the PRESET offered to the teachers was inadequate as it was intended to perpetuate the aims and purpose of apartheid. Thus, the teachers’ content knowledge (TCK) is, arguably, inherent from the apartheid education and this renders it insufficient and irrelevant for the current school curriculum. Drawing on Shulman (1986) work on teacher knowledge, teacher content knowledge refers to the knowledge of facts, concepts, procedures and principles of either mathematics and science.

Post-apartheid era has been characterized by a number of school curriculum changes and teacher development programmes intended to reverse the legacy of apartheid education and address the educational needs of a democratic society. The changes in the curricula in South Africa have created challenges for teachers that range from inadequate content knowledge (Department of Education, 2007; Taylor, 2011) to inappropriate and ineffective instructional methods (Department of Education, 2007:4). Even though there is a multiplicity of factors that directly impact on learning, teacher effectiveness is at the crux of learner success. Hence, the link between teacher content knowledge and learner achievement is well documented (see, for example, Baumert, Kunter, Blum, Brunner, Voss, Jordan, Klusmann, Krauss, Neubrand & Tsai, 2010; Tchoshanov, 2011). In South Africa, for example, since 2010 the highest percentage pass in grade 12 learners’ results in physical science and
mathematics is 67.4% and 59.1%, respectively (Department of Basic Education, 2013: 10). It is argued that these less pleasing results can be linked to the inadequate TCK, that has been noted by the Department of Education (2007) and Taylor (2011). In addition, Bryan (2011) found that teachers in the Limpopo province, South Africa who lacked subject knowledge resorted to ‘excessive use of safe talk, supported by notes on the blackboard, frequent referral to textbooks and extensive use of repetition’ (p 136). Evidence attesting to the ineffectiveness of such an instructional approach abounds.

A tool for change will be an initiative that can empower teachers with necessary capacity to manage curricula changes and enhance effectiveness. In turn, teachers, as members of a community, have responsibility to co-operatively take joint action to find and create solutions to learning problems confronting their communities. This paper profiles a community initiative in a form of a teacher development programme (TDP) that sought to improve mathematics and science teachers’ content knowledge. It addresses the question: How has the teacher development programme offered by the Institute for Science and Technology Education (ISTE) as a community engaged initiative been designed to improve the grade 12 mathematics and science teachers’ content knowledge? ISTE is a research institute at the University of South Africa that renders community engaged oriented programmes to mathematics, science and technology teachers; conducts research; and provides post-graduate education and training in mathematics, science and technology education.

**Reflecting on some teacher development programmes**

There have been teacher development programmes in South Africa undertaken to empower teachers so that they can manage the demands and challenges posed by the curricula. The respective foci and goals of the programmes were distinct. For example, Onwu and Mogari (2004) focused on familiarising teachers with curriculum changes and improving their content knowledge and classroom practice; the programme by Mogari (2014) introduced grade 12 teachers to a particular instructional approach; the Mpumalanga Secondary Science Initiative (MSSI), was intended to improve the teaching of mathematics and science at junior secondary level in the province of Mpumalanga (Rogan et al. 2002). The Holistic Professional Development Model (HPD) was built on a university non-formal programme intended to improve teachers’ physics content knowledge and classroom practice (Kriek & Grayson, 2009) while the Data Informed Practice Improvement Project works with grades 7 – 9 mathematics teachers on understanding and engaging learner errors as a mechanism for teacher learning (Brodie, 2014). Evident in these programmes is the fact that the needs of teachers are presumed because there is no evidence of needs analysis or rather basing a programme on the needs of the participants. In other words, the planning and designing of the teacher development programme was more top-down rather than being bottom-up where there is consultation with the teachers in order to determine their needs for development.
What is also notable about the programmes is the design and approach used in each of them. For example, Onwu and Mogari (2004) adopted a systemic approach and designed their programme concentrically ranging from teachers in the centre to school district manager on the outside. The roles and responsibilities of stake-holders at each level of the spiral were clearly spelt out. The MSSI followed a cascade approach and clustered teachers according to their respective districts. Cluster leaders met periodically for professional development activities with a view to sharing their experiences with their cluster members in their school settings (Jita & Ndlalane 2005: 296). The HPD model used an engaged-participatory approach to optimise the effectiveness of the non-formal programme (Kriek & Grayson, 2009). The HPD model was designed to avail material and conceptual resources to teachers and engaging them through a participatory mode on strategies for adopting, adapting and applying the resources in a teaching context. Even though each of these teacher development programmes tends to follow an approach and use a design that is compatible with its goal(s) and purpose, it is not based on the needs of the teachers.

**ISTE Teacher Development Programme**

The ISTE TDP is a researched-based teacher-centred model of a community engaged approach that considers the needs and priorities of the community (i.e. mathematics and science teachers) and creates a space to encourage teacher participation. ISTE TDP is offered by facilitators who have been purposefully identified and then attuned to the needs of the teachers and the goals of the program. The programme is evaluated annually and the outcomes thereof serve as basis for the improvements to be effected on the subsequent one. The benefit of the envisaged development programme is a capacitated community of teachers which will hopefully teach better and effectively, and thus bring about meaningful learning.

ISTE TDP aims to empower mathematics and science teachers to be more knowledgeable about aspects of the curriculum. This is done by improving the content knowledge of the teachers. An important question is how can a community engaged initiative that is in a form of a teacher development programme be designed to enhance TCK.

**Determining the teachers’ needs for ISTE TDP**

The teachers’ needs were determined using a teacher questionnaire which was triangulated with learner questionnaire and examiner’s report. The questionnaires were developed, then scrutinized for face and content validity by established researchers and thereafter piloted. The reliability of the questionnaires was determined by checking whether there was consistency in the responses in the pilot and main studies.

**Teacher questionnaire:** The teacher questionnaire comprised 12 items of various forms (i.e. yes/no; Likert-type and open-ended questions) that elicited information on their demography, class sizes, topics considered difficult to teach, challenges they experienced in teaching the topics, and their views on possible ways to improve the teaching of the
identified topics. Mathematics, therefore, is used to illustrate how the difficult topics were identified in 2009. Table 1 shows topics teachers considered difficult to teach as well as the respective number of teachers that selected the topics.

Table 1: Mathematics topics teachers found difficult to teach

<table>
<thead>
<tr>
<th>Topic</th>
<th>No. of teachers (n = 69)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial mathematics</td>
<td>13</td>
</tr>
<tr>
<td>Linear programming</td>
<td>16</td>
</tr>
<tr>
<td>Analytical and Transformation geometry</td>
<td>12</td>
</tr>
<tr>
<td>Trigonometry</td>
<td>7</td>
</tr>
<tr>
<td>Probability</td>
<td>13</td>
</tr>
<tr>
<td>Statistics &amp; data handling</td>
<td>8</td>
</tr>
</tbody>
</table>

In terms of possible ways to improve TCK, table 2 presents the teachers views.

Table 2: Teachers’ suggestions on ways of improving the teaching of difficult topics

<table>
<thead>
<tr>
<th>Teachers’ suggestions</th>
<th>No. of teachers (n = 69)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content workshop/peer training/in-service training needed</td>
<td>40</td>
</tr>
<tr>
<td>Need equipment/apparatus</td>
<td>8</td>
</tr>
<tr>
<td>Materials/better text books needed</td>
<td>5</td>
</tr>
<tr>
<td>Reduce class size</td>
<td>9</td>
</tr>
<tr>
<td>Better teaching of learners at lower grades</td>
<td>4</td>
</tr>
<tr>
<td>Maths and Science learners to be selected based on ability</td>
<td>1</td>
</tr>
<tr>
<td>Use expert teachers for maths and science</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 2 shows 40 (58%) teachers preferred content workshop/peer training/in-service training as a way to help them improve their knowledge of the identified topics. Furthermore, they stated the topics they considered difficult to teach were not in the curriculum during their pre-service training; hence their knowledge of the topics is limited. The overwhelming choice for content workshops for the professional development of the teachers formed the foundation of the ISTE TDP.

Learner questionnaire: It teased out information on the learner demography, topics they thought were difficult to learn (see Table 3) and reasons for considering the identified topics difficult (Table 4).

Table 3: Mathematics topics learners found difficult to learn

<table>
<thead>
<tr>
<th>Topic</th>
<th>No of learners (n = 316)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial mathematics</td>
<td>39</td>
</tr>
<tr>
<td>Sequence and series</td>
<td>21</td>
</tr>
<tr>
<td>Linear programming</td>
<td>38</td>
</tr>
<tr>
<td>Trigonometry</td>
<td>103</td>
</tr>
<tr>
<td>Functions and algebra</td>
<td>59</td>
</tr>
<tr>
<td>Analytical and Transformation geometry</td>
<td>42</td>
</tr>
</tbody>
</table>
The table clearly indicates that the top four topics learners find difficult are trigonometry; functions and algebra; analytic and transformation geometry; and financial mathematics. This is not consistent with what teachers found difficult. Table 4 presents reasons learners advanced for finding the topics difficult.

Table 4: Learner reasons for difficult topics

<table>
<thead>
<tr>
<th>Reasons</th>
<th>No of learners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topics are abstract</td>
<td>15</td>
</tr>
<tr>
<td>Topics are taught in the afternoon</td>
<td>20</td>
</tr>
<tr>
<td>Not enough time is given for the teaching of these topics</td>
<td>103</td>
</tr>
<tr>
<td>Lack of appropriate skills and knowledge of such topics and subjects</td>
<td>54</td>
</tr>
<tr>
<td>My teachers are too fast in lesson delivery</td>
<td>45</td>
</tr>
<tr>
<td>Not adequate learning materials like computers systems for large classes</td>
<td>32</td>
</tr>
<tr>
<td>My teachers teach some chosen topics and leaves others to the fate of the learners</td>
<td>49</td>
</tr>
</tbody>
</table>

Notably, the majority of learners clearly indicate that not enough time is given for teaching the topics. However this was not mentioned by teachers as a possible way to improve the teaching of the difficult topics (see table 2).

Examiner’s report: After the end-of-year Grade 12 learners’ examination answer scripts have been scored, the examiner compiles a report based on the analysis of the learners’ answers. School district wide meetings of mathematics and science teachers are convened by the respective subject specialists to discuss the report. The developers of the teacher development programme attend the meetings in order to note topics that learners scored poorly in and possible reasons for poor performance in those topics.

Topic selection: The data from three sources (i.e. teacher and learner questionnaires plus examiner’s report) were thoroughly considered in order to enable the final selection of mathematics topics to be taught at ISTE TDP. It was however noted that order of preference of topics by learners and teachers was different. For example, 103 learners found trigonometry difficult to learn while 7 teachers had problems with the same topic, and the examiner also identified trigonometry as one of the topics that learners performed poorly particularly in the latter part of the question. He explained reasons for poor performance as follows:

i. Questions 8.1.3 & 81.4: Used a calculator to calculate the values of the angles $\alpha$ and $\beta$ and proceeded to find the value of the ratio ending up with the decimal. Common errors/misconceptions that occurred are: $\cos \beta = 180^{\circ} - \alpha$; $\cos \beta = \cos(-\frac{15}{17})$, in 8.1.4 after expanding they substituted with the values of the angles calculated in 8.1.3. The other common mistake in 8.1.4 is in the expansion, where they wrote as follows: $\sin (\beta - \alpha) = \sin \alpha \cos \beta - \cos \alpha \sin \beta$
ii. Question 8.2.1: Most candidates experienced problems with the co-functions, for example, wrote $\sin 2x = \sin (90^\circ - 2x)$ or $\cos 2x = \cos (90^\circ - 2x)$. Many candidates missed the bracket and $-\cos 2x = -1 - 2\sin^2 x$, division was not following the rules but cancelled in order to end up with $\tan x$, for example, 
$$\frac{1 - 1 - 2\sin^2 x - \sin x}{2\sin x \cos x} = -\frac{2\sin^2 x}{2\cos x}.$$ 

iii. Question 8.2.2: Many candidates expanded correctly and divided by $\cos x$ (forgetting that it could be zero) (Chauke, 2010)

Noting that trigonometry has always been in the curriculum and teachers were not coming across it when they had to teach it and also the fact that teachers are provided with continual support and coaching by the subject facilitators, it was decided not to include it in ISTE TDP. Instead the focus was on topics that were recently introduced in the curriculum and teachers, learners and examiner considered problematic. Thus, financial mathematics; linear programming; probability, statistics and data handling and transformation geometry were topics that were taught to teachers in ISTE TDP.

**Identification and training of facilitators and material development**

Key requirements for one to be a facilitator in ITSE TDP was to have, among others, ‘knowledge of how teachers think about content’ (Loucks-Horsley, 2010: 73), sound content knowledge, rich classroom experience and knowledge of learning difficulties and conceptual barriers usually experienced by learners. Therefore, these qualities informed the track record that was used to identify the facilitators.

Once identified the facilitators were then subjected to a one day training workshop to familiarise them with the goals and purpose of ISTE TDP; to spell out the outline and facets of the programme; to discuss with them on how to develop support materials and what support materials to develop for use in the programme; and to ascertain that they are familiar with the principles and process of adult learning. It is mentioned in Loucks-Horsley et al. (2010: 73) that to optimise teacher learning the relevance of content being taught has to be obvious and evident; the taught content has to relate to their real contexts; and teachers should be given ample time to connect new ideas to their background. Loucks-Horsley et al. emphasize that facilitators should be able to engage adult learners in activating their prior knowledge and setting goals for their own learning (p 73). Noting that teacher learning is based on the principles of andragogy while learner learning is underpinned by the principles of pedagogy. It is therefore crucially important that facilitators of teacher development programme have to be aware of the fundamental differences between teaching adults (i.e. teachers) and teaching learners.

After training, the facilitators developed support materials and handed them in to the TDP developers for vetting. This was to ascertain that the materials were in line with the goals and purpose of the programme and would indeed support teacher learning. The support materials were based on the aspects of the curriculum that were identified as problematic to
teach and learn. This contrasts the material selection process followed in school districts in the United States of America Louckes-Horsley et al (2010: 240) noted.

**Duration and sessions of ISTE TDP**

In order for a teacher development programme to be effective it has to happen over a considerable time so that it’s activities can have impact by providing opportunities for in-depth discussion of content, development of conceptions and identification of misconceptions (Garet et al, 2001). Desimone et al (2002: 82) note studies that have highlighted a relationship between the intensity and duration of teacher development programmes and the degree of teacher change. The programme ran over 5 days where each day consisted of 8 hours. For mathematics, for example, each day was dedicated to a particular aspect. Given the purpose and goal of the programme, the 5-day duration was sufficient. All sessions were largely interactive and participant-centred. For example, in a mathematics class, a facilitator would spend 5 to 8 minutes introducing and explaining a concept on the board. The teachers then individually work through a worksheet for a specified period. Thereafter, a whole class discussion led by the facilitator on possible ways to solve the given set of problems; possible misconceptions and difficulties learners may encounter learning of the concept; possible to pre-empt and anticipate misconceptions and learning difficulties; and ways to teach the concept would ensue. Whatever is mooted by any of the teachers, the facilitator would write down on the board and then encourages the class to critically analyse and delve into it. This teaching approach promotes active learning, collective participation and coherence (Desimone, et al. 2002). Garet et al (2001) indicate that such an approach makes a teacher development programme effective. The approach was also in line with the social cognitive learning theory that emphasises much of human learning occurring in a social environment (Bandura, 1996). According to the theory learning occurs by observing and interacting with others plus what is also around you. In science for example, the activities were aligned to help teachers use curriculum materials such as science equipment and technology. The use of science equipment is a curriculum requirement and during the workshop session’s provision was made for the individual teachers to share strategies. The teachers were also to share the worksheets they were to use in the classes when they returned to their schools. Furthermore they were also introduced to the use of technology to teach science. According to Dede (2000), technology can be used to reinforce student learning. Bruce and Levin (2001) and Bransford, Brown and Cocking (2000) can be used effectively as a cognitive tool for teaching and learning in the classroom. The 5 day program was developed in such a way that each activity was built on the preceding activities and was followed by more advanced work. Garet et al (2002) support the idea of having coherence and interrelatedness between the various activities, and individual activities need to form part of a coherent programme of teacher learning and development.
Feedback
At the end of ISTE TDP, the teachers completed a workshop evaluation questionnaire. The essence of the evaluation was to determine points of successes, failure (if any) and areas that need improvement for the future. The teachers evaluated the programme as follows:
Table 5 presents teachers’ views about the extent to which the set learning outcomes of ISTE TDP were met.

Table 5: Responses to Evaluation Questions on Learning Outcomes

<table>
<thead>
<tr>
<th>Options</th>
<th>No of responses</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completely well</td>
<td>26</td>
<td>49.1</td>
</tr>
<tr>
<td>Pretty well</td>
<td>24</td>
<td>45.28</td>
</tr>
<tr>
<td>Fairly well</td>
<td>3</td>
<td>5.66</td>
</tr>
<tr>
<td>Not very well</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Not at all</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>53</td>
<td>100</td>
</tr>
</tbody>
</table>

The table shows that there was no teacher who did not think the stated learning outcomes of the programme were not well achieved. Table 6, however, determines the teachers’ views about the way the content and aspects of curriculum were covered.

Table 6: Responses to Evaluation Questions on Learning Content and Curriculum Coverage

<table>
<thead>
<tr>
<th>Options</th>
<th>No of responses</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Too advanced</td>
<td>19</td>
<td>35.85</td>
</tr>
<tr>
<td>Exactly right</td>
<td>31</td>
<td>58.49</td>
</tr>
<tr>
<td>Too elementary</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No response</td>
<td>3</td>
<td>5.66</td>
</tr>
<tr>
<td>Total</td>
<td>53</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 6 shows that 94.34% of teachers were positive about the way content and aspects of curriculum were covered. Table 7 shows teachers’ views about the relevance of content.

Table 7: Responses to Evaluation Questions on the Relevance of Content Covered

<table>
<thead>
<tr>
<th>Options</th>
<th>No of responses</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>All relevant</td>
<td>49</td>
<td>92.45</td>
</tr>
<tr>
<td>Majority relevant</td>
<td>3</td>
<td>5.66</td>
</tr>
<tr>
<td>Not really relevant</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Not sure</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No response</td>
<td>1</td>
<td>1.89</td>
</tr>
<tr>
<td>Total</td>
<td>53</td>
<td>100</td>
</tr>
</tbody>
</table>
According to Table 7, slightly over 98% of teachers considered the content relevant to their teaching requirements and needs at school. It is a strong pointer to the prudence of designers in packaging the ISTE TDP in terms of materials and resources. Table 8 is about teachers’ views about the duration of ISTE TDP.

Table 8: *Duration of the teacher development programme*

<table>
<thead>
<tr>
<th>Options</th>
<th>No of responses</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Too long</td>
<td>5</td>
<td>9.43</td>
</tr>
<tr>
<td>Exactly right</td>
<td>35</td>
<td>66.04</td>
</tr>
<tr>
<td>Too short</td>
<td>12</td>
<td>22.64</td>
</tr>
<tr>
<td>No response</td>
<td>1</td>
<td>1.89</td>
</tr>
<tr>
<td>Total</td>
<td>53</td>
<td>100</td>
</tr>
</tbody>
</table>

Five teachers (about 9.43%) felt the programme was ‘too long’, 35 (about 66.04%) opined that the programme was ‘exactly right’ and 12 (about 22.64%) teachers thought it was ‘too short’. Table 9 presents how the teachers thought of the pace of facilitators.

Table 9: *Pace of Facilitators*

<table>
<thead>
<tr>
<th>Options</th>
<th>No of responses</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Too slow</td>
<td>1</td>
<td>1.89</td>
</tr>
<tr>
<td>Too fast</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Just right</td>
<td>26</td>
<td>49.06</td>
</tr>
<tr>
<td>Acceptable</td>
<td>24</td>
<td>45.28</td>
</tr>
<tr>
<td>No response</td>
<td>1</td>
<td>1.89</td>
</tr>
<tr>
<td>Total</td>
<td>53</td>
<td>100</td>
</tr>
</tbody>
</table>

The table shows that 50 (about 94.34%) teachers did not have problems with the pace of facilitators and its one teacher who the pace was slow. Table 10 presents teachers’ views about the activities of ISTE TDP.

Table 10: *ISTE TDPs Activities*

<table>
<thead>
<tr>
<th>Options</th>
<th>No of responses</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevant</td>
<td>30</td>
<td>56.6</td>
</tr>
<tr>
<td>Interesting</td>
<td>21</td>
<td>39.62</td>
</tr>
<tr>
<td>Challenging</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Unsatisfactory</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No response</td>
<td>2</td>
<td>3.77</td>
</tr>
<tr>
<td>Total</td>
<td>53</td>
<td>100</td>
</tr>
</tbody>
</table>
The table shows that 51 (96.22%) teachers are satisfied with the activities of the programme. Table 11 provides teachers’ views about group dynamics and interactions of ISTE TDP.

**Table 11: Group Dynamics and Interactions**

<table>
<thead>
<tr>
<th>Options</th>
<th>No of responses</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adequate</td>
<td>30</td>
<td>56.6</td>
</tr>
<tr>
<td>Effective</td>
<td>22</td>
<td>41.51</td>
</tr>
<tr>
<td>Average</td>
<td>1</td>
<td>1.89</td>
</tr>
<tr>
<td>Unsatisfactory</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>53</td>
<td>100</td>
</tr>
</tbody>
</table>

The table indicates that all teachers were positive with the group dynamics and interactions of the programme.

**Discussions**

It is evident from the data that ISTE TDP had a positive impact on the teachers. Probably, what made the programme to have the impact is the way it was structured and worked. ISTE TDP is circular, dynamic and functions flexibly and consists of the following interactive, iterative and incremental steps: (1) needs analyses; (2) material and intellectual resource provision; and (3) more knowledgeable community (see Figure 1).
In order to improve successfully the content knowledge of teachers, it was essential to first determine the teachers’ deficiencies and weaknesses. Hence, the innermost circle depicting needs analysis. In the next step, a teacher development programme based on the teachers’ needs was then designed to offer intellectual and material resources. The outcome of the programme was a more knowledgeable community of teachers who can teach better and effectively. The steps of programme are interlinked, interdependent and are not mutually exclusive. The design and approach of ISTE TDP is in line with a framework for designing a teacher development programme provided by Loucks-Horsely et al (2010).

The data show that the teachers’ needs and teaching and learning inadequacies were determined through teacher and learner questionnaires and by scrutinising the examiners’ reports. Determining the teachers’ needs was crucial in designing and shaping a desirable and effective teacher development programme because teacher learning happens better especially if a teacher is taught what she/he wants to learn. According to Harlow (2014) target-minded learning increases the chances for successful learning. Harlow refers to target-minded learning as ‘knowing what one seeks from a learning context’ (134). Therefore, the content of ISTE TDP was relevant and was based on what the teachers teach in their classes. In particular the programme sought to update and deepen the content knowledge of the teachers. Feedback about ISTE TDP shows that the teachers were content with what they were taught. This tends to enhance the teachers’ confidence in their ability and skills to teach better (Onwu & Mogari, 2004; Kriek & Grayson, 2009). By determining the needs of teachers at the onset helps avoid imposing on teachers what might have been irrelevant to them as well as ensures that ISTE TDP directly benefits and empowers the teachers.

Even though there have been efforts to provide teachers with the necessary knowledge and skills to manage the demands and expectations of the curricula changes (see, for example, Onwu & Mogari, 2004; Bantwini, 2009; Bryan, 2011), the current study shows that there are teachers with limited understanding of newly introduced topics in the curricula. Perhaps, the type and objectives of various teacher development programmes on offer need close scrutiny particularly that the data show that teachers need more training. The need for training is consistent with a finding by Bryan (2011). Based on this observation it is claimed that the need for teacher development programme is not always the brainchild of the authorities or education officials.

What is also evident is that what teachers consider difficult to teach, learners don’t necessarily deem it a challenge to learn and vice versa. Possibly the discrepancy, as it is posited, could be due to the fact that learners are much more obsessed with passing examinations/tests and are thus always desperate for help on those aspects of the curriculum they feel inadequate, while the teachers’ concern is more on enhancing effectiveness and becoming more competent. Moreover, there have been changes in the curricula that have
placed new demands on teachers, and as Guskey (2003) states, there is overwhelming evidence showing that teacher development initiatives are essential for making improvements and enabling teachers meet the changing educational demands. Perhaps, it is for this reason there was a sizeable number of teachers (about 58%) who made a call for more training to be organised for them.

It is evident from the data that the participants felt positive about the training methods used, facilitation process followed, activities of the ISTE TDP and group dynamics and interactions that took place during the sessions of the programmes. It may possibly be because of the fact that the facilitators used were familiar with the actual teaching and learning settings found in the participating teachers’ schools as well as the curricula teachers need to deliver. As Loucks-Horsley et al (2010: 73) point out, it is paramount that facilitators of teacher development programme know and understand the actual teaching and learning setting in schools. Anderson, Rourke, Garrison and Archer (2001: 2) indicate that such a calibre of facilitators can design and organise appropriate learning experiences, use relevant activities, facilitate beneficial participant-participant discourse, encourage co-operative and interactive learning, and scaffold learning experiences through direct institution. Harlow (2014: 120) supports, understanding what participating teachers learn and use in their teaching is important to developing appropriate instruction. Thus, it is advisable to use facilitators with profound knowledge of the participating teachers’ school settings because they can plan and design an appropriate teacher development programme that can optimise teacher learning. It is also important to note that un-interesting and irrelevant activities used in a teaching and learning setting can de-motivate participants and make them hate either the subject or facilitator; or both.

In conclusion, the study highlights key issues to consider when designing and shaping a teacher development programme. Firstly, it is important to determine the teachers’ needs and use the findings to design and shape an in-service programme for them. By so doing the programme tends to address what the teachers want to be helped with, thus rendering the programme effective. Secondly, even though there have been concerns raised about the importance of a teacher development programme being of long duration, the current study shows that the issue of duration should be informed by the goal and purpose of the programme. Thirdly, when identifying facilitators for a teacher development programme it is advisable to go for people who are considerably knowledgeable about the actual teaching and learning settings and curriculum offered. Lastly, a teacher development programme should have interlinked, dynamic and iterative steps, as this enhances relevance and effectiveness. It should however be mentioned that further data on classroom visits is required to consider ISTE TDP effective.

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Using a three-tier multiple-choice questionnaire to identify the misconceptions that Grade 10 learners from three underperforming Dinaledi Schools in Soweto hold about simple electric circuits

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Abstract

The purpose of this research study was to identify the misconceptions that Grade 10 learners from underperforming Dinaledi Schools held in the field of simple electric circuits. One hundred and thirty participants from three underperforming Dinaledi Schools in Soweto formed the sample for this study. A validated three-tier multiple-choice diagnostic questionnaire which was a combination of two questionnaires developed by Millar and Hames (2002) in the United Kingdom and Peşman and Eryilmaz (2010) in Turkey, was used to identify the misconceptions. The data was coded, captured and subjected to statistical tests in order to answer the research question. The statistical test performed included the mean score, the standard deviation (SD), the percentage of correct responses as well as the percentage of each identified misconception. The results from this study seem to support the findings of studies conducted by Peşman and Eryilmaz (2010), Taşlidere (2013), Kapartzianis and Kriek (2014) and Engelhardt and Beichner (2004). As a result, we can conclude that the identified misconceptions are not only common to learners in Asia, Europe and the United States of America, but they are also common to learners at the three underperforming Dinaledi Schools in Soweto.

Keywords: Dinaledi Schools, Three-Tier Diagnostic Questionnaire, Electric Circuits and Misconceptions

Introduction

Research data collected over more than three decades have shown that the majority of learners come to the science classroom with pre-instructional knowledge and beliefs about phenomena and concepts that will be taught (Ausubel, 1968; Nussbaum & Novak, 1976; Erickson, 1979; Brumby, 1981; Champagne & Klopfer, 1981; Driver, 1981; Smith & Anderson, 1984; Aguirre & Erickson, 1998; Duit & Treagust, 2003). A study by Pfundt and Duit (2006) revealed that these preconceptions are formed as a result of learner interactions within physical and social environments. Pfundt and Duit (2006) argue that these preconceptions affect learning as they become integrated into learners’ cognitive structures. As a result, learners experience difficulty in integrating any new information within their cognitive structures, resulting in an inappropriate understanding of new concepts. In this study, these inappropriate understandings will be referred to as misconceptions. These misconceptions have been defined by Griffiths and Preston (1992) as “any conceptual idea whose meaning deviates from the one commonly accepted by scientific consensus” (p. 611).
Substantial research has been done in first-world countries on learner misconceptions in the teaching and learning of science concepts (Driver, 1989; Driver & Bell, 1986; Mutimucuio, 1998; Tytler, 2002; Widodo, Duit & Müller, 2002). A few studies have been conducted in South Africa on misconceptions (for example, Helm, 1980; Adams, 1990; Sanders, 1993; Huddle & Pillay, 1996; Rollnick & Mahooana, 1999; Clerk & Rutherford, 2000; Ramnarain & van Niekerk, 2012); however, none of these studies has concentrated specifically on learners from underperforming Dinaledi Schools in Soweto.

Furthermore, South Africa’s performance in international benchmark tests like the Trends in International Mathematics and Science Study (TIMSS) is a major cause for concern. These studies indicate that the majority of South African learners especially from rural and township schools have not acquired the necessary science concepts and skills to perform well at science (Reddy, 2006). In light of the above, this research study concentrates on identifying the misconceptions held by Grade 10 learners from underperforming Dinaledi Schools in Soweto. Electric circuits was chosen as a topic as studies have revealed common and extensive learner misconceptions related to this topic (Kucukozer & Kocakulah, 2007; Lee & Law, 2001; Peşman & Eryılmaz, 2010). In the South African curriculum this section is a major topic that is first introduced in Grades 8 and 9 and then revisited at a higher conceptual level in Grades 10, 11 and 12. The authors selected the Dinaledi schools as they are the Department of Basic Educations specialist mathematics and physical sciences schools, resulting in them being better resourced than the normal public schools and they also have much smaller class sizes as a result of the additional mathematics and physical science teachers that are allocated to the schools. Therefore the focus and purpose of this study was to identify the misconceptions that the Grade 10 learners from the identified three underperforming Dinaledi Schools in Soweto held with regard to simple electric circuits.

Learner misconceptions in science

Prior to beginning school, learners have a wealth of experience that they have used to develop a common-sense understanding of their social and natural environment (Ausubel, 1968). Ausubel (1968) summed this idea up by stating that “the most important single factor influencing learning is what the student already knows” (p. vi). In light of this statement, we can consider learners’ concepts to be valid, invalid, naïve or sophisticated, useful or dysfunctional for the learning of science concepts (Ausubel, 1968). In defining the term “concepts”, Eggen and Kauchak (2004) suggested that the term concepts “can be considered as ideas or events that help us understand the world around us” (cited in Thompson & Logue, 2006, p. 553). In recent years, science educators have become more interested in analysing learners’ understanding of natural phenomena, both before and after formal science instruction (Brumby, 1981; Champagne & Klopf, 1981; Driver, 1981; Erickson, 1979; Nussbaum & Novak, 1976; Smith & Anderson, 1984).

There is much discussion in the literature on science education about the notions of misconceptions, alternative conceptions and naïve conceptions. Many researchers have a preference for one term over another. Sneider and Ohandi (1998) suggest that “many researchers object to the term ‘misconceptions’ because, from the student’s viewpoint, the
ideas expressed are logical. ‘Preconceptions’, ‘naïve theories’ and ‘alternative frameworks’ have been proposed as being more suitable terms to describe learners’ personal views that are at odds with modern scientific theories” (p. 66). Spada (1994) argues that the researchers who favour a Vygotskian view of situated learning would also not agree with the use of the term “misconception” as they contend that a person may possess multiple, alternate mental representations of the same phenomena.

Gentner, Brem, Ferguson, Markman, Levidow, Wolff and Forbus, (1997) are of the opinion that while the term “misconception” seems to emphasise the wrongness of a learner’s conception, and can thus be seen as critical of the holder of the conception, it should be noted that alternative terms like “naïve conceptions” and “alternative conceptions” are also value-laden. The term “naïve conception” can be viewed as implying that the holder is unsophisticated. Gentner et al. (1997) provide an example to illustrate this point. The Aristotelian notion that “motion requires a mover”, was what scientists believed for thousands of years until this idea was replaced by Newton’s laws of motion. To describe the Aristotelian concept as “naïve” could be seen as disrespectful to those who held this view in the past (Gentner et al., 1997).

Griffiths and Preston (1992) define misconceptions as “any conceptual idea whose meaning deviates from the one commonly accepted by scientific consensus” (p. 611). Smith, diSessa, and Roschelle, (1993) have gone one step further than Griffiths and Preston (1992) and listed the following criteria for a concept to be termed a misconception. Firstly, they are strongly held, stable cognitive structures; secondly, they differ from expert conceptions; thirdly, they affect in a fundamental sense how learners understand natural phenomena and scientific explanations; and lastly, they must be overcome, avoided or eliminated for learners to achieve expert understanding. For the purposes of this research study we will be using the definition of a misconception as expressed by Griffiths and Preston (1992) as we believe it best suits this research study.

There has been much work done on misconceptions that learners possess, on why they persist, on how they might be addressed and on their origins in everyday life experiences. Thus these misconceptions affect how learners perceive and interpret what they see and hear (Hammer, 1996).

**Common misconceptions on electric circuits**

After a detailed review of the literature (Fredette & Loachhead, 1980; Cohen, Eylon & Daniel, 1983; Dupin & Johsua, 1987; Shipstone, 1988; Shipstone, Rhöneck, Jung, Kärqquist, Dupin, Joshua & Licht, 1988; McDermott & Shaffer, 1992; Chambers & Andre, 1997; Borges & Gilbert, 1999; Engelhardt & Beichner, 2004; Sencar & Eryilmaz, 2004; Koltsakis & Pierratos, 2006; Peşman & Eryilmaz, 2010), Taşlidere, 2013; Kapartzianis & Kriek, 2014), the following misconceptions regarding simple electric circuits have been identified. These misconceptions have been labelled as M1 to M11 in Table 1.
<table>
<thead>
<tr>
<th>Type of Misconception</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Sink or Unipolar Misconception (M1)</td>
<td>This misconception involves the belief that in order for an electrical device to operate, only a single conducting wire needs to connect the power supply to the electrical device (Chambers &amp; Andre, 1997; Sencar &amp; Eryilmaz, 2004; Peşman &amp; Eryilmaz, 2010).</td>
</tr>
<tr>
<td>Attenuation Model (M2)</td>
<td>This misconception involves the belief that electric current travels around the circuit in one direction and that along the way the current decreases gradually due to it being consumed by resistors and other electrical devices. (Shipstone, 1988; Shipstone et al., 1988; McDermott &amp; Shaffer, 1992; Peşman &amp; Eryilmaz, 2010).</td>
</tr>
<tr>
<td>Sharing current Model (M3)</td>
<td>The current is assumed to be shared equally by electrical devices (Shipstone, 1988; Sencar &amp; Eryilmaz, 2004).</td>
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<tr>
<td>Sequential Model (M4)</td>
<td>This misconception assumes that any change taking place in a circuit is carried forward in the direction of the current, but not backwards (Dupin &amp; Joshua, 1987; Shipstone, 1988; McDermott &amp; Shaffer, 1992; Engelhardt &amp; Beichner, 2004; Sencar &amp; Eryilmaz, 2004; Peşman &amp; Eryilmaz, 2010).</td>
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<tr>
<td>Clashing Current Model (M5)</td>
<td>Learners with this misconception believe that positive and negative electricity from the power source meets at the electrical device and clashes there, causing the electrical device to work (Osborne &amp; Freyberg, 1985; Driver, Rushworth, Squires, Wood-Robinson (1994); Chambers &amp; Andre, 1997; Borges &amp; Gilbert, 1999; Koltsakis &amp; Pierratos, 2006).</td>
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<tr>
<td>Empirical Rule Model (M6)</td>
<td>The further the light bulb is from the power source (battery), the dimmer the light bulb will be. Therefore the brightness of the bulb is dependent on how close it is to the battery (Heller &amp; Finley, 1992).</td>
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<tr>
<td>The Short Circuit Misconception (M7):</td>
<td>Learners who hold this misconception believe that the conducting wire that has no devices attached to it in a circuit is irrelevant and can be ignored, and that the light bulb will glow regardless of the short circuit that is created by presence of the conducting wire (Shipstone, Jung &amp; Dupin, 1988; Engelhardt &amp; Beichner, 2004).</td>
</tr>
<tr>
<td>The Power Supply as Constant Current Source (M8):</td>
<td>This misconception involves the belief that the battery is a constant current source rather than a source of constant potential difference (Cohen, Eylon, Ganiel, 1983; Dupin &amp; Joshua, 1987; Psillos, Koumaras &amp; Tiberghien, 1988; Heller &amp; Finley, 1992 Borges &amp; Gilbert, 1999).</td>
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<tr>
<td>The Parallel Circuit Misconception (M9):</td>
<td>The more resistors that are added in parallel, the greater the total resistance. This is because learners believe that resistors act as obstacles to the flow of current; therefore adding more resistors increases the resistance in parallel (Cohen et al., 1983; McDermott &amp; Shaffer, 1992; Chambers &amp; Andre, 1997).</td>
</tr>
<tr>
<td>Local Reasoning (M10):</td>
<td>With this misconception, learners believe that changes in circuits have only local effects rather than effects on the whole circuit (Cohen, et al., 1983; Heller &amp; Finley, 1992).</td>
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<tr>
<td>Current Flow as Water Flow (M11):</td>
<td>This misconception involves the belief that electric current flows within the conducting wire just like water flows through a pipe (Sencar &amp; Eryilmaz, 2004; Peşman &amp; Eryilmaz, 2010).</td>
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</table>

Table 1. The identified misconceptions
Method

Research context

This study was conducted at three underperforming Dinaledi Schools in Soweto. The Dinaledi Schools are specialist Mathematics and Physical Sciences public schools. They were established in 2001 and there are approximately 500 schools nationally. These Dinaledi Schools each receive additional resources and support as well as an additional mathematics and physical sciences teacher from the Department of Basic Education through the Dinaledi Grant. The Dinaledi schools selected are referred to as underperforming because they had matric pass rates below 60% for two successive years. The schools are situated in fairly close proximity to each other. There is a distance of less than two kilometres between each of the schools. One hundred and thirty Grade 10 learners from these three schools formed the sample for the study. The age profile of the learners ranged from 14 to 19 years of age. Fifty-two percent of the learners were male and 48% were female and isiZulu was the mother tongue of the majority of learners.

Instrument

In this research study, the researchers chose a combination of two validated three-tier multiple-choice diagnostic questionnaires. All the questions from both questionnaires were selected. The first questionnaire was one developed in the United Kingdom by Millar and Hames (2002) and the second was developed in Turkey by Peşman and Eryılmaz (2010). The questionnaire consisted of twenty items. This resulted in a questionnaire that consisted of 20 three-tier multiple-choice test items. The first tier of each item consisted of a content question having usually two to five choices. The second tier of each item contained a set of four possible reasons for the answer given in the first tier. The reasons consisted of the designated correct answer, together with common learners’ misconceptions identified from the literature. The third tier asked the learner to identify how confident they were about their answers to the questions in the first two tiers. An example of an item from the questionnaire is displayed in Figure 1 below.

1.1 Will the light bulb in Figure 1 light up?

a) Yes, it will.
b) No, it will not.
Figure 1. Example of an item from the questionnaire

An answer was considered correct only if both the answers to questions in tier one and tier two were correct and the learner responded as being “very confident” in the third tier. Hence the maximum score for the questionnaire was 20.

Figure 1. Example of an item from the questionnaire

An answer was considered correct only if both the answer to questions in tier one and tier two were correct and the learner responded as being “very confident”. Hence the maximum score for the questionnaire was 20.

Data collection

This study was divided into two phases. Phase one involved piloting the diagnostic questionnaire, while phase two involved administering the diagnostic questionnaire to the identified 130 learners from the three Dinaledi Schools.

Phase 1: Pilot study

The pilot study for this research study was carried out with a sample of 10 learners from another Dinaledi School that was not part of the actual study. These learners, after answering the questionnaire, were interviewed to establish whether the language was clear, whether the time allocation was sufficient and whether the diagrams were clear and legible. One of the first problems exposed by the pilot study was the use of language. The pilot group found the use of language too difficult and the researcher therefore had to adjust the level of language used for the target sample. The second problem identified was the time allocation. Initially 30 minutes were allocated for the completion of the test. The pilot demonstrated that the time needed to be increased to 50 minutes. Therefore, although
the pilot study was conducted on a small scale, we were able to identify some issues in the questionnaire, which needed to be addressed before the actual study was conducted.

One of the limitations of a pilot study is contamination; however, in this study this was not an issue as the learners who participated in the pilot study did not form part of the actual study.

**Phase 2: Administering of the Questionnaire**

This part of the process involved the administering of the diagnostic questionnaire to the sample of 130 learners. The questionnaire was administered during normal teaching time. The learners were allocated 50 minutes to complete the test, but the majority of them completed the test in 45 minutes.

**Data analysis**

The first step in analysing the data was to identify the possible misconceptions. This was achieved by administering the three-tier multiple-choice questionnaire before the section on electricity was taught. Gilbert (1977) and Caleon and Subramaniam (2010) suggest that attention should be focused on those responses chosen by more than 10% of the learners, as they regard these misconceptions as serious misconceptions. The results were coded and captured in SPSS. Each learner response was assigned a numerical code before it could be entered into SPSS (e.g. male =1, female =2). Once the coding and capturing was completed, the percentage of learners who held a particular misconception was determined. The percentage of correct responses was also determined for the first tier, the first two tiers and for all three tiers.

**Validity and reliability**

The researchers distributed the questionnaires in sealed envelopes to the schools 30 minutes prior to the questionnaire being administered and all the learners wrote on the same day and at the same time. It was possible to administer the questionnaire in this manner, because the three schools were situated less than two kilometres from each other. To further ensure the validity of the research, the following measures were also taken. Firstly, learners were not informed of the date on which they would write the test, for fear that they might try to study for the test. Secondly, the test was carried out under strict exam conditions and learners were only allowed to bring a pen, pencil and calculator into the exam venue. In addressing reliability concerns, the second researcher independently scored the learner responses to the items. A high agreement in scoring ensured that reliability was established in this process.

**Findings**

In the findings, quantitative data and analysis are now presented on learner responses to items on the three-tier multiple choice questionnaire. It commences with a detailed analysis of the comparative performance for each three-tier item, a discussion of the descriptive statistics and concludes with the percentage of identified misconceptions.
Figure 2 below provides a detailed analysis of the comparative performance for each three-tier item.

**Figure 2:** Percentage of correct responses in terms of all three tiers

An answer was considered correct only if both the answer to tier 1 and tier 2 was correct and the learner responded as “very confident” in the third tier. From the result in Figure 2, it is evident that in all cases, learners had a higher percentage of correct responses for the first tier as opposed to the percentage of correct responses for the first two tiers and the first three tiers. The percentage of correct responses decreased gradually for the first two tiers. For all three tiers, there was a drastic decrease in the percentage of correct responses. For question 1, 80% of the learners got tier 1 correct, while 29% got the first two tiers correct and only 17% got all three tiers correct. The mean percentage of correct responses for the first tier was 44%, while the mean percentage correct response for the first two tiers was 23% and lastly the mean percentage correct responses for the first three tiers was 8%. Therefore we can see that there was a very sharp decline in the percentage of correct responses for tier 1 as compared to the percentage correct responses for all three tiers. The decline was possibly a result of the learners not being able to identify the correct reason for their answer in tier 1 and then not being confident in their choice of answers in tier 1 and tier 2.

Statistical tests were performed on the data and these included determining the mean score, the standard deviation and the percentage of correct responses. Table 2 represents the overall statistical data for this study. The mean score is the arithmetic average of a set of scores. It therefore is a measure of central tendency because it identifies a single score as typical or representative of all scores in a frequency distribution (Pallant, 2013). For this study the mean score was calculated to be 4.66 out of a maximum possible score of 20. The 5% trimmed mean is obtained by removing the top and bottom 5% of the population, and then recalculating the mean (Pallant, 2013). This is done to establish whether the
extreme scores had a strong influence on the mean. From Table 2 it can be seen that there is little difference between the original mean and the 5% trimmed mean. Therefore the extreme scores had no significant influence on the mean.

Table 2. Descriptive statistics

<table>
<thead>
<tr>
<th>Statistic</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>130</td>
</tr>
<tr>
<td>Mean</td>
<td>4.66</td>
</tr>
<tr>
<td>5% trimmed mean</td>
<td>4.61</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>2.49</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.00</td>
</tr>
<tr>
<td>Maximum</td>
<td>12.00</td>
</tr>
<tr>
<td>Range</td>
<td>12.00</td>
</tr>
</tbody>
</table>

From the analysis of the questionnaire responses, eleven common misconceptions were identified. The eleven misconceptions were the sink/unipolar misconception (M1), attenuation model (M2), sharing current model (M3), sequential model (M4), clashing current model (M5), empirical rule model, the short circuit (M7), the power supply as constant current source (M8), the parallel circuit (M9), local reasoning (M10) and current as water flow (M11). The results of the questionnaire analysis are represented graphically in Figure 3 below.

Figure 3. Percentage of misconceptions from the questionnaire
From Figure 3, it is evident that all the misconceptions, except for the short circuit misconception (M7) and the power supply as constant current source (M8) scored responses above 10%. Therefore all misconceptions, except short circuit misconception (M7) and power supply as constant current source (M8) were regarded as serious misconceptions. The literature on misconceptions in electric circuits has identified 11
common misconceptions as listed in Table 1. These same misconceptions have also been identified by this study. As a result, we can conclude that these misconceptions are not only common to learners in Asia, Europe and the United States of America, but are also common to learners at these three underperforming Dinaledi Schools in Soweto. The current sharing misconception (M3), achieved the most responses with 80% of the learners having this misconception. The second common misconception was M4, the sequential model misconception. The results from this study were compared to studies conducted by Engelhardt and Beichner (2004), Peşman and Eryilmaz (2010), Taşlidere (2013) and Kapartzianis and Kriek (2014). The results from the abovementioned studies seem to support the findings of this study, since the same 11 misconceptions were identified.

Discussion

The purpose of this study was to identify the misconceptions that Grade 10 learners from the three underperforming Dinaledi Schools in Soweto held with regard to simple electric circuits. This was achieved and 11 common misconceptions were identified. Eighty percent of the learners in this study displayed the current sharing misconception, while the second most common misconception was the sequential model misconception. From the overall results of the data analysis, it can also be conclude that the Grade 10 learners from the underperforming Dinaledi Schools in Soweto have the same type of misconceptions as their counterparts in other parts of the world. The results from this study cohere well with the finding of studies conducted by Engelhardt and Beichner (2004), Peşman and Eryilmaz (2010), Taşlidere (2013) and Kapartzianis and Kriek (2014). As a result, we can conclude that these misconceptions are not only common to learners in Asia, Europe and the United States of America, but they are also prevalent amongst learners at the three underperforming Dinaledi Schools in Soweto.

The percentage of correct responses for the three tiers was also compared, and the findings suggest that a high percentage of learners were able to respond correctly to the first tier of the question. However, the percentage of correct responses for the first two and all three tiers was drastically lower than correct responses for tier 1. This can be ascribed to learners not being able to advance plausible explanations for their choice, and a lack of confidence in their answer.

A possible scenario which contributes to this status is that at school there is a strong focus on quantitative problem solving where learners apply a previously learnt algorithm to “plug” values into formulæ to obtain an answer. The predominance of this “plug-and-chug” approach has meant that students are given scant opportunity to engage qualitatively with concepts in physics, and especially in electricity. The findings of this study affirm that teachers should adopt an approach where learners are supported to reason qualitatively by firstly translating a problem pictorially and verbally, before engaging algebraically with it. This qualitative approach leads learners to construct mental models, and then apply these models in solving the problem.

Based on the findings of this research study, it would be interesting to investigate whether the learners at the performing Dinaledi Schools in Soweto have the same misconceptions
as their counterparts at the underperforming Dinaledi Schools. Further research could be conducted to replicate this study in all public schools in this province and later possibly in all nine provinces.

References


Validating a questionnaire instrument for investigating the achievement goal orientation of Grade 10 Physical Sciences learners in five Soweto township schools

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Abstract

This study tested the validity of an existing Fortus and Vedder-Weiss (2014) instrument for measuring the personal-achievement goal orientations of Physical Sciences learners in Soweto township schools. The goal of the study was to develop an instrument that could be used to determine the achievement goal orientation of Grade 10 Physical Sciences learners in Soweto township schools. The constructs of the instrument, namely learners’ perceived mastery and performance goal orientations, were derived from the achievement goal theory. A questionnaire survey was conducted with five schools and 324 Physical Sciences learners using the original Fortus and Vedder-Weiss instrument. Both heuristic and theoretical reliability tests were conducted using SPSS software. The original Fortus and Vedder-Weiss instrument was found to be unreliable in the Soweto context, and thus the items had to be re-arranged. The analysis produced Cronbach’s alpha coefficients of 0.593 for personal-mastery goal orientation and 0.798 and 0.650 for the personal-performance approach and personal-performance-avoidance goal orientations respectively. The re-arranged instrument had Cronbach’s alpha coefficients of 0.74 for personal-mastery and 0.858 for personal-performance approach, and 0.832 for the personal-performance avoidance goal orientations. Therefore, this study developed a valid instrument for measuring achievement goal orientation in Soweto township schools.

Introduction

This study developed an instrument to determine the personal-achievement goal orientations of Physical Sciences learners in Soweto township schools. A learner’s achievement goal orientation refers to his or her reason for learning a subject and the reason that a learner has for leaning a subject reflects his or her type of motivation to study the subject (Ames, 1992b; Dweck & Leggett, 1988; Elliot & Murayama, 2008). Understanding learners’ achievement goal orientations is critical knowledge for both curriculum planners and implementers, since they reflect learners’ motivation, which influences school achievement (Mji & Makgato, 2006). Globally, learners’ school achievement has been used as a measure of the level of success in implementing an educational curriculum of a society and this curriculum-implementation success is directly linked to a society’s level of development (Christie, 2008; Hannum & Buchmann, 2005). In particular, high achievement in the Physical Sciences curriculum is related to the socio-economic development of South Africa (Department of Basic Education, 2011).

Since learners’ achievement goal orientation has become an important determinant of curriculum-implementation success, which in itself promotes industrial and technological
development, there has recently been increased research interest focused on learners’ achievement goal orientation. These research efforts have provided evidence on the existence of a relationship between learners’ goal orientation and their learning environment (Christie, 2008). South Africa is a suitable context for this kind of research focus, given that it has had major changes in its socio-economic environment and curriculum (Christie, 2008). South Africa could also benefit from understanding learners’ goal orientations for learning Physical Sciences, since it is a developing economy, which needs technological advancement and skilled manpower (Christie, 2008).

Recent studies on learners’ personal-achievement goal orientation in South Africa, have shown that Grade 8 Natural Sciences learners were personal-performance goal oriented (Ramnarain, 2013), but that first-year university sciences students were personal-mastery goal oriented (Ramnarain & Ramaila, 2014). These studies also show that teachers practised didactic teaching approaches, which do not allow learners to take part in knowledge development and promote the development of personal-performance goal orientation (Ames, 1992b). Thus there was need to determine the personal-achievement goal orientation of Physical Sciences learners.

Aim of study

Accordingly the aim of this study was to validate the Fortus and Vedder-Weiss instrument which was designed for determining personal goal orientation constructs in Israel. A sample of this instrument is attached in Appendix 1.

Objectives of the study

The following objectives were set:

- Conducting an exploratory factor analysis on data collected from Physical Sciences learners in Soweto;
- Conducting a Cronbach’s alpha test on the same data;
- Making relevant changes to the instrument; and
- Validating the instrument for the context of this study.

Theoretical framework

The achievement goal theory is a motivation theory, which perceives learners’ motivation to learn, to be dependent on both cognitive and affective factors (Ames, 1992). This perception of the nature of learning motivation is different from the cognitivist notion that perceives it to be a cognitive function only (Ames, 1992). The cognitivist perspective of motivation, explains it in terms of a learner’s cognitive capability (Dweck & Leggett, 1988). According to this view, a gifted learner in an area of study would be more motivated to study it, and achieve higher in it, than a learner who is less gifted in it.

However, there has been a shift of emphasis in research in educational motivation from the cognitive perception to the cognitive and affective perception (Ames, 1992). In terms of the latter perception of learning motivation, the feelings, emotions and attitudes that learning
experiences elicit from a learner contribute towards the development of his or her motivation to learn, over and above the cognitive ability of the learner (Ames, 1992). Given that feeling, emotions and attitudes are situational factors, then the learning environment becomes a very significant factor in the development of learners’ reasons for learning a subject.

The achievement goal theory consists of two constructs which represent learners’ affective position regarding the learning of a subject (Pintrich, 2000). The two constructs are personal-mastery and personal-performance goal orientations, and these affective positions towards the learning of a subject by a learner, are dependent on the learning experiences that a learner has had in studying the subject (Ames, 1992).

**Mastery goal orientation**

Mastery goal orientation refers to a reason for studying a subject for its internal value (Ames, 1992; Dweck & Leggett, 1988; Pintrich, 2003). This is because the learner has developed a positive valence for the subject (Ames, Ames, & Felker, 1977). Amongst some of the indicators of the positive valence are: the learner puts more effort into the study; perseveres in the face of challenges; has an intrinsic motivation to study (Meece, Anderman, & Anderman, 2006); takes mistakes as learning points; wants to develop new knowledge and skills (Meece, Blumenfeld, & Hoyle, 1988); develops effective studying habits; and that learning is self-referenced (Brunel, 1999; Haradkiewicz & Elliot, 1998; Heyman & Dweck, 1992). Mastery goal orientation development is referred to as an adaptive learning response, since it develops effective learning methods (Madjar, Kaplan, & Weinstock, 2011; Shim, Cho, & Wang, 2013). The development of this positive valence on a subject is dependent on the learning experiences that the learning environment offers to the learner (Ames et al., 1977). The teacher becomes a critical factor in this situation, as is it is through his or her innovation and creativity that a classroom environment conducive to learning and understanding a subject is developed (Polychroni, Hatzichristou, & Sideridis, 2012; Shim et al., 2013).

**Performance goal orientation**

Performance goal orientation is the reason for learning a subject for external goods (Ames, 1992; Meece et al., 2006; Pintrich, 2003), such as rewards and marks. A learner who is performance goal oriented has developed a negative valence for a subject and this state has the following indicators about the learner: putting less effort into learning the subject (Pintrich, 2000); developing ineffective learning strategies to learn the subject, such as rote-learning and memorisation (Elliott & Dweck, 1988); avoiding challenging work; keenness to compare own work with that of others; wanting to impress the teacher and other learners; having an external reference point of success; not liking to make mistakes; and being extrinsically motivated (Meece et al., 2006). Performance goal orientation is referred to as being a maladaptive learning response, because it causes the development of ineffective learning methods like rote and memorisation (Shim et al., 2013). This goal orientation development is also influenced by a learners’ experiences in the classroom (Belenky & Nokes-Malach, 2013; Damavandi & Shekari Kashani, 2010; Koopman, Bakx, & Beijaard, 2013).
Therefore the teacher plays a significant role in promoting the development of this goal orientation through his or her lack of innovation and creativity (Polychroni et al., 2012; Shim et al., 2013).

The achievement goal orientation theory further suggests some teacher-based classroom factors with an acronym TARGET which affect learners’ experiences during learning (Ames, 1992). In full, TARGET means task-clarity, autonomy, reward, grouping, evaluation and timing (Ames, 1992). If a teacher implements these constructs in the classroom, learners are likely to develop mastery goal orientation (Ames, 1992). Accordingly, the development of mastery goal orientation, for learning Physical Sciences, could be promoted in Black township schools in South Africa, in order to improve school achievement in those places, because it promotes adaptive learning skills development. It has been shown that mastery goal orientation is linked to high achievement in school (Covington, 2000; Damavandi & Shekari Kashani, 2010; DeCaro, DeCaro, & Rittle-Johnson, 2015; Wambugu & Changeiywo, 2008). However, there is need for research evidence on which to premise any suggestions for curriculum-implementation reforms that promoted mastery goal orientation.

Methodology

Quantitative data were collected and analysed in this cross-sectional survey. In a cross-sectional survey different individuals are observed at the same time.

Method

Achievement goal orientations are perceptions, and are, therefore, measured through self-reporting by the participants (Koskey, Karabenick, Woolley, Bonney, & Dever, 2010; Midgley et al., 1998; Scott, Hauenstein, & Coyle, ). An existing five-point Likert-scale questionnaire was used for collecting the learners’ quantitative self-reporting data. The data were statistically analysed using SPSS computer software. The software is capable of performing factor extraction and correlation tests by default (Pallant, 2007).

The interview instrument’s Likert-scale ranged from: 1, not true at all; 2, not so true; 3, somewhat true; 4, true; and 5, very true. The advantage of a five-point Likert-scale is that it is exhaustive. It provides all possible responses to a question. The questionnaire determined 17 constructs, using the following items.

<table>
<thead>
<tr>
<th>Construct</th>
<th>Number of items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student’s perception of teacher’s mastery goal emphasis</td>
<td>8</td>
</tr>
<tr>
<td>Student’s perception of teacher’s performance approach goals emphasis</td>
<td>4</td>
</tr>
<tr>
<td>Construct</td>
<td>Number of items</td>
</tr>
<tr>
<td>--------------------------------------------------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Student’s perception of teacher’s performance avoid goals emphasis</td>
<td>4</td>
</tr>
<tr>
<td>Student’s perception of school’s mastery goal emphasis</td>
<td>5</td>
</tr>
<tr>
<td>Student’s perception of school’s performance approach goals emphasis</td>
<td>5</td>
</tr>
<tr>
<td>Student’s perception of personal-mastery goal emphasis</td>
<td>7</td>
</tr>
<tr>
<td>Student’s perception of personal-performance approach goals emphasis</td>
<td>5</td>
</tr>
<tr>
<td>Student’s perception of personal-performance avoid goals emphasis</td>
<td>5</td>
</tr>
<tr>
<td>Student’s self-efficacy</td>
<td>5</td>
</tr>
<tr>
<td>Student’s perception of peers’ mastery goal emphasis</td>
<td>4</td>
</tr>
<tr>
<td>Student’s perception of peers’ performance approach goals emphasis</td>
<td>4</td>
</tr>
<tr>
<td>Student’s perception of peers’ performance avoid goals emphasis</td>
<td>4</td>
</tr>
<tr>
<td>Student’s perception of parents’ mastery emphasis</td>
<td>5</td>
</tr>
<tr>
<td>Student’s perception of parents’ performance emphasis</td>
<td>4</td>
</tr>
<tr>
<td>Behavioural and cognitive engagement</td>
<td>5</td>
</tr>
<tr>
<td>Active extra-curricular engagement</td>
<td>7</td>
</tr>
<tr>
<td>Active extra-curricular rejection</td>
<td>6</td>
</tr>
</tbody>
</table>

However, the focus of this study was on the grey-coded constructs only.

**Sampling**

Purposive convenience sampling was used to select participating schools in the study. A purposive sample is one which is selected because it presents the desired characteristics for observation, (Guarte & Barrios, 2006; Teddlie & Tashakkori, 2009; Teddlie & Tashakkori, 2011). Schools in Soweto are classified as performing and non-performing (Van der Berg, 2007). Performing schools were defined as being those with a percentage pass rate of 80%+ in the Grade 12 school exit examinations. Underperforming schools had lower pass-rates.

The District Subject Specialist for Physical Sciences for Johannesburg Central District provided the researcher with a list of five schools which were near to each other, which were also performing, and had cooperative teachers. All of the five schools became the sample for this study since they all of them met the desired characteristics.
Overall 324 learners participated in the study. This number of participants surpassed the 150 minimum required for an exploratory factor analysis test (EFA) (Pallant, 2007). An EFA test was conducted in this study to determine the reliability and validity, for the South African context, of an instrument designed for the Israeli context. Since a learning context influences perceptions (Carr, 2006), it was necessary to have an instrument that would be sensitive to the context of Black township school learners in South Africa.

**Data management**

All participating learners completed the 89 items questionnaire instrument. This quantitative data were captured and analysed by specialists at the University of Johannesburg’s Statistical and Consultancy Department (STATKON). The data were analysed using SPSS software, and confidentially stored. The involvement of specialists in the analysis of the data was to ensure reliability and validity of the results and the findings of the study (Carlson, 2010; Creswell & Garrett, 2008).

An EFA was conducted in order to determine the items which aggregated together, using a technique called the principal component analysis (PCA), (Pallant, 2007). Both first-order and second-order EFA were conducted. Although both first-order and second-order EFA tested the relationship between a construct and its items, the second-order EFA was conducted in order to test the relationship between constructs which had emerged from the first-order EFA.

The principal component analysis is suitable for the Likert-scale data (Kahn, 2006). The tests which were performed using the PCA technique are the component matrix, correlation matrix, KMO and Bartlett’s test and the total variance test. These tests were performed for both the first-order and second-order extractions.

Furthermore, a Cronbach’s alpha test was conducted to further test the reliability of the questionnaire over and above the heuristic EFA. This process is lengthy because it entails many statistical tests which augment each other. Although they may seem the same, the tests are different. The purpose was to seek confirmation of an empirical test using a theoretical test (Pallant, 2007).

**Integrity measures**

Ethical clearance was obtained by the researcher from the institution before conducting the research. Ethical issues should be observed in all research in order to safeguard the rights and freedoms of the participants (Burgess, 2005; Joy, 2007; Miller, Birch, Mauthner, & Jessop, 2012). Accordingly, gaining entry and gaining access to the participants was facilitated by the Provincial and District Offices of the Gauteng Department of Education. Parents/guardians signed the letters of consent for their children, after school Principals had allowed the researcher to distribute the consent forms to the learners. The researcher personally gave instructions on answering the questionnaires and administered them to the learners.
Pilot test results

This analysis of results is based on the literature from (Pallant, 2013) and (Pallant, 2007).

Descriptive statistics

The sample

Overall 324 Black township schools’ learners participated in the study. Their ages ranged from 14-19 years, with the mean age of 15.47, and a standard deviation of 0.937.

Out of the total 32 learners were 14 years old, 165 were 15 years old, 78 were 16 years old, 39 were 17 years old, eight were 18 years old, one was 19 years old and one learner did not provide his or her age.

Of the 324 participants 172 were female constituting 53.3% and 151 were male, constituting 46.7% of the sample and one person did not provide his or her gender.

The instrument

All items on the questionnaire were answered, but the focus of the study was on how the participants responded to the mastery goal orientation and performance goal orientation items. The frequency tables of participants’ responses to these are summarised below.

Descriptive statistics on answering the questions

<table>
<thead>
<tr>
<th>Item</th>
<th>N</th>
<th>Valid</th>
<th>Missing</th>
<th>Mean</th>
<th>Median</th>
<th>Mode</th>
<th>Std. Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>322</td>
<td>2</td>
<td></td>
<td>4.80</td>
<td>5.00</td>
<td>5</td>
<td>.547</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>23</td>
<td>324</td>
<td>0</td>
<td></td>
<td>4.64</td>
<td>5.00</td>
<td>5</td>
<td>.683</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>32</td>
<td>324</td>
<td>0</td>
<td></td>
<td>4.51</td>
<td>5.00</td>
<td>5</td>
<td>.679</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>35</td>
<td>323</td>
<td>1</td>
<td></td>
<td>4.49</td>
<td>5.00</td>
<td>5</td>
<td>.757</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>42</td>
<td>324</td>
<td>0</td>
<td></td>
<td>4.56</td>
<td>5.00</td>
<td>5</td>
<td>.668</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>69</td>
<td>320</td>
<td>4</td>
<td></td>
<td>4.41</td>
<td>5.00</td>
<td>5</td>
<td>.762</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>86</td>
<td>316</td>
<td>8</td>
<td></td>
<td>4.22</td>
<td>4.00</td>
<td>5</td>
<td>.875</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>324</td>
<td>0</td>
<td></td>
<td>3.54</td>
<td>4.00</td>
<td>4</td>
<td>1.262</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>24</td>
<td>322</td>
<td>2</td>
<td></td>
<td>2.97</td>
<td>3.00</td>
<td>4</td>
<td>1.366</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>58</td>
<td>320</td>
<td>4</td>
<td></td>
<td>3.56</td>
<td>4.00</td>
<td>4</td>
<td>1.189</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>
From the above table there were above 310 responses to each item which far exceeds the EFA minimum sample of 100. The mean scores for the personal-mastery goal orientation construct, coded light grey, are above 4, with a standard deviation of above 1.5 for all items. This means that most of the learners answered true and very true for mastery goal orientation.

The means for the performance goal orientation constructs, which are coded dark grey, are slightly above 3, with a standard deviation of above 1. This means that most of the learners answered somewhat true and true for the performance goal orientation.

**First-Order Exploratory Factor Analysis**

Factor extraction was conducted using principal component matrix process with the following stages being undertaken: the component matrix; correlation matrix; the KMO and Bartlett’s Test; and rotation. The rotation methods, which were employed, were the Varimax and the Direct Oblimin.

**Component matrix**

For the mastery and performance goal orientations, all items were positive and thus unidirectional, as shown under column 1 of the component columns. Therefore, there was no need for reverse scoring.

**Students' Mastery Goals**

**Component Matrix (Check for Reverse Scoring)**

<table>
<thead>
<tr>
<th>Component Matrixa</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Q6</td>
<td>.406</td>
</tr>
</tbody>
</table>
Extraction Method: Principal Component Analysis.

Student's Performance Approach Goals

Component Matrix (Check for Reverse Scoring)

<table>
<thead>
<tr>
<th>Component</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q7</td>
<td>.596</td>
</tr>
<tr>
<td>Q24</td>
<td>.775</td>
</tr>
<tr>
<td>Q45</td>
<td>.786</td>
</tr>
<tr>
<td>Q58</td>
<td>.805</td>
</tr>
<tr>
<td>Q75</td>
<td>.759</td>
</tr>
</tbody>
</table>

Extraction Method: Principal Component Analysis.

Students' Performance Avoid Goals

Component Matrix (Check for Reverse Scoring)

<table>
<thead>
<tr>
<th>Component</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q8</td>
<td>.560</td>
</tr>
<tr>
<td>Q26</td>
<td>.588</td>
</tr>
<tr>
<td>Q46</td>
<td>.689</td>
</tr>
<tr>
<td>Q64</td>
<td>.714</td>
</tr>
<tr>
<td>Q81</td>
<td>.672</td>
</tr>
</tbody>
</table>

Correlation matrix
The extraction scores range from 0 to 1, with 1 being the highest. The decision rule was to accept all items with correlations of 0.3 and above. The correlation matrices are displayed below.

**Correlation matrix for mastery goal orientation**

<table>
<thead>
<tr>
<th></th>
<th>Q6</th>
<th>Q23</th>
<th>Q32</th>
<th>Q35</th>
<th>Q42</th>
<th>Q69</th>
<th>Q86</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation</td>
<td>Q6</td>
<td>.121</td>
<td>.079</td>
<td>.090</td>
<td>.159</td>
<td>.168</td>
<td>.146</td>
</tr>
<tr>
<td></td>
<td>Q23</td>
<td>1.000</td>
<td>.163</td>
<td>.294</td>
<td>.099</td>
<td>.168</td>
<td>.190</td>
</tr>
<tr>
<td></td>
<td>Q32</td>
<td>.079</td>
<td>1.000</td>
<td>.258</td>
<td>.187</td>
<td>.105</td>
<td>.122</td>
</tr>
<tr>
<td></td>
<td>Q35</td>
<td>.090</td>
<td>.294</td>
<td>1.000</td>
<td>.204</td>
<td>.104</td>
<td>.303</td>
</tr>
<tr>
<td></td>
<td>Q42</td>
<td>.159</td>
<td>.099</td>
<td>.187</td>
<td>1.000</td>
<td>.200</td>
<td>.123</td>
</tr>
<tr>
<td></td>
<td>Q69</td>
<td>.168</td>
<td>.168</td>
<td>.105</td>
<td>.104</td>
<td>1.000</td>
<td>.290</td>
</tr>
<tr>
<td></td>
<td>Q86</td>
<td>.146</td>
<td>.190</td>
<td>.122</td>
<td>.303</td>
<td>.123</td>
<td>1.000</td>
</tr>
</tbody>
</table>

The correlation coefficient is less than 0.3 in most cases except for two items namely; Q35 and Q86. Therefore, most items reflect different constructs.

**Correlation Matrix for performance approach goal orientation**

<table>
<thead>
<tr>
<th></th>
<th>Q7</th>
<th>Q24</th>
<th>Q45</th>
<th>Q58</th>
<th>Q75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation</td>
<td>Q7</td>
<td>1.000</td>
<td>.304</td>
<td>.280</td>
<td>.493</td>
</tr>
<tr>
<td></td>
<td>Q24</td>
<td>.304</td>
<td>1.000</td>
<td>.584</td>
<td>.508</td>
</tr>
<tr>
<td></td>
<td>Q45</td>
<td>.280</td>
<td>.584</td>
<td>1.000</td>
<td>.471</td>
</tr>
<tr>
<td></td>
<td>Q58</td>
<td>.493</td>
<td>.508</td>
<td>.471</td>
<td>1.000</td>
</tr>
</tbody>
</table>
The correlation coefficient is more than 0.3 in most cases and therefore the items are related.

### Correlation Matrix for avoidance goal orientation

<table>
<thead>
<tr>
<th></th>
<th>Q8</th>
<th>Q26</th>
<th>Q46</th>
<th>Q64</th>
<th>Q81</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q8</td>
<td>1.000</td>
<td>.111</td>
<td>.253</td>
<td>.324</td>
<td>.214</td>
</tr>
<tr>
<td>Q26</td>
<td>.111</td>
<td>1.000</td>
<td>.322</td>
<td>.271</td>
<td>.250</td>
</tr>
<tr>
<td>Q46</td>
<td>.253</td>
<td>.322</td>
<td>1.000</td>
<td>.298</td>
<td>.316</td>
</tr>
<tr>
<td>Q64</td>
<td>.324</td>
<td>.271</td>
<td>.298</td>
<td>1.000</td>
<td>.354</td>
</tr>
<tr>
<td>Q81</td>
<td>.214</td>
<td>.250</td>
<td>.316</td>
<td>.354</td>
<td>1.000</td>
</tr>
</tbody>
</table>

The coefficient of correlation is less than 0.3 in most of the cases and the items cannot be combined.

**The KMO and Barlett’s Test: factor extraction**

The decision rule was to accept a construct if the correlation was 0.7 and above for the items.

**KMO and Bartlett's Test for mastery goal orientation items**

<table>
<thead>
<tr>
<th>Kaiser-Meyer-Olkin</th>
<th>Measure of Sampling Adequacy</th>
<th>Bartlett’s Test of Sphericity</th>
<th>Approx. Chi-Square</th>
<th>df</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>.687</td>
<td>166.464</td>
<td>21</td>
<td>.000</td>
<td></td>
</tr>
</tbody>
</table>

The KMO and Bartlett’s coefficient is less than 0.7 and the items are not strongly correlated. This weak relationship is explained further by the total variance illustration below.
Total Variance Explained: mastery goal orientation factors

The decision rule was to accept factors with eigenvalues of 1 and above. Eigenvalues indicate the number of factors which questionnaire items form and the number of factors, starting from 1 factor. In addition, a factor was only acceptable if it explained at least 50% of the items.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Initial Eigenvalues</th>
<th>Extraction Sums of Squared Loadings</th>
<th>Rotation Sums of Squared Loadings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>% of Variance</td>
<td>Cumulative %</td>
</tr>
<tr>
<td>3</td>
<td>.957</td>
<td>13.666</td>
<td>57.696</td>
</tr>
<tr>
<td>4</td>
<td>.860</td>
<td>12.287</td>
<td>69.984</td>
</tr>
<tr>
<td>5</td>
<td>.771</td>
<td>11.011</td>
<td>80.994</td>
</tr>
<tr>
<td>6</td>
<td>.763</td>
<td>10.907</td>
<td>91.901</td>
</tr>
<tr>
<td>7</td>
<td>.567</td>
<td>8.099</td>
<td>100.000</td>
</tr>
</tbody>
</table>

Extraction Method: Principal Axis Factoring.

There are two factors with cumulative variance of 44% before rotation and 26% after rotation. But they are not strong as they explain less than 50% of the items.

KMO and Bartlett's Test for the performance goal orientation factors

<table>
<thead>
<tr>
<th>Kaisser-Meyer-Olkin Measure of Sampling Adequacy.</th>
<th>.789</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Bartlett's Test of Sphericity</th>
<th>Approx. Chi-Square</th>
<th>df</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>482.566</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

The coefficient is 0.789 and thus these items are related into one factor.
Total Variance Explained for the performance approach goal emphasis

<table>
<thead>
<tr>
<th>Factor</th>
<th>Initial Eigenvalues</th>
<th>Extraction Sums of Squared Loadings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>% of Variance</td>
</tr>
<tr>
<td>1</td>
<td>2.798</td>
<td>55.955</td>
</tr>
<tr>
<td>2</td>
<td>.839</td>
<td>16.784</td>
</tr>
<tr>
<td>3</td>
<td>.552</td>
<td>11.040</td>
</tr>
<tr>
<td>4</td>
<td>.442</td>
<td>8.847</td>
</tr>
<tr>
<td>5</td>
<td>.369</td>
<td>7.373</td>
</tr>
</tbody>
</table>

Extraction Method: Principal Axis Factoring.

There is only one factor with an eigenvalue of 2.798, with a cumulative frequency of 55.955% before rotation and 45.589% after rotation. The construct is strong because it explains more than 50% of the items.

KMO and Bartlett’s Test for the performance-avoidance goal emphasis items

<table>
<thead>
<tr>
<th>Kaiser-Meyer-Olkin Measure of Sampling Adequacy.</th>
<th>.731</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bartlett’s Test of Sphericity</td>
<td></td>
</tr>
<tr>
<td>Approx. Chi-Square</td>
<td>181.768</td>
</tr>
<tr>
<td>df</td>
<td>10</td>
</tr>
<tr>
<td>Sig.</td>
<td>.000</td>
</tr>
</tbody>
</table>

The coefficient is above 0.7 and thus the items form one factor.
There is one factor with an eigenvalue of 2.097 with a cumulative frequency of variation of 41.950% before rotation and 27.867% after rotation. Therefore it is a weak factor, as it explains less than 50% of the factors.

Rotation of items: The Varimax and the Direct Oblimin rotations

The purpose of this test was to confirm the existence of factors through rotation. This process shows the factors and the items that load into them. The significant loading value of an item into a factor was set at .250.

**Rotated Factor Matrix\(^a\) : mastery goal orientation**

<table>
<thead>
<tr>
<th>Factor</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q35</td>
<td>.782</td>
<td></td>
</tr>
<tr>
<td>Q23</td>
<td>.353</td>
<td></td>
</tr>
<tr>
<td>Q32</td>
<td>.332</td>
<td></td>
</tr>
<tr>
<td>Q69</td>
<td>.665</td>
<td></td>
</tr>
<tr>
<td>Q86</td>
<td>.316 .368</td>
<td></td>
</tr>
<tr>
<td>Q6</td>
<td>.282</td>
<td></td>
</tr>
<tr>
<td>Q42</td>
<td>.273</td>
<td></td>
</tr>
</tbody>
</table>
Whereas items Q35, Q23, Q32, loaded into factor 1 which focuses on what is **valuable** to the learner, which comes from learning Physical Sciences, items Q69, Q86, Q6, and Q42 loaded into factor 2 which focuses on **objectives** for value attainment. Since item Q86 had two values, the higher loading value was selected; hence, it loaded into the second factor.

### Factor Matrix²: performance approach goal orientation

<table>
<thead>
<tr>
<th>Factor</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q58</td>
<td>.748</td>
</tr>
<tr>
<td>Q45</td>
<td>.724</td>
</tr>
<tr>
<td>Q24</td>
<td>.707</td>
</tr>
<tr>
<td>Q75</td>
<td>.682</td>
</tr>
<tr>
<td>Q7</td>
<td>.480</td>
</tr>
</tbody>
</table>

Extraction Method: Principal Axis Factoring.

All the items load into one factor for this construct.

### Factor Matrix²: Performance avoid goal orientation

<table>
<thead>
<tr>
<th>Factor</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q64</td>
<td>.615</td>
</tr>
<tr>
<td>Q46</td>
<td>.572</td>
</tr>
<tr>
<td>Q81</td>
<td>.554</td>
</tr>
</tbody>
</table>
All of the items load into one construct, that of personal-performance avoidance goal orientation.

**Second-Order Exploratory Factor Analysis: Putting emergent factors together**

A second-order EFA was done for the mastery goal orientation in order to test the validity of splitting it into two factors. All the steps of the principal component matrix were repeated for the two factors.

**Correlation matrix**

The cut-off point was 0.3.

<table>
<thead>
<tr>
<th>Correlation Matrix: mastery goal orientation</th>
<th>Mean6.1_Factor1</th>
<th>Mean6.1_Factor2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation</td>
<td>Mean6.1_Factor1</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>Mean6.1_Factor2</td>
<td>.351</td>
</tr>
</tbody>
</table>

The coefficient is above 0.3 and therefore the factors are related and so they load into one construct, but their relationship is weak.

**KMO Barlett’s test**

The cut-off point was 0.7.

<table>
<thead>
<tr>
<th>KMO and Bartlett’s Test: performance goal orientation</th>
<th>Approx. Chi-Square</th>
<th>df</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaiser-Meyer-Olkin Measure of Sampling Adequacy</td>
<td>.500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bartlett’s Test of Sphericity</td>
<td>42.226</td>
<td>1</td>
<td>.000</td>
</tr>
</tbody>
</table>
The correlation coefficient is less than .7 so the grouping of the two factors into one construct is weak.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Initial Eigenvalues</th>
<th>Extraction Sums of Squared Loadings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>% of Variance</td>
</tr>
<tr>
<td>1</td>
<td>1.351</td>
<td>67.542</td>
</tr>
<tr>
<td>2</td>
<td>.649</td>
<td>32.458</td>
</tr>
</tbody>
</table>

Extraction Method: Principal Axis Factoring.

The eigenvalue is 1.351, and so the factors load into one construct with a cumulative percentage frequency of 67.542% before rotation and 34.994% after rotation. This construct explains 67% of the factors.

**Component matrix for the mastery goal orientation factors**

The cut-off point was 0.250

<table>
<thead>
<tr>
<th>Factor Matrix: Performance-avoidance goal orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>Mean 6.1_Factor 1</td>
</tr>
<tr>
<td>Mean 6.1_Factor 2</td>
</tr>
</tbody>
</table>

Extraction Method: Principal Axis Factoring.

With a minimum acceptable loading value into one factor of .250 per factor at 0.592, the factors load into one construct.

**Cronbach’s alpha coefficient**

Cronbach’s alpha is a single test of reliability, which obtains an average value of the reliability coefficients that could be got during split two half-tests for reliability (Pallant, 2007). A construct should have both a high heuristic reliability (EFA) and a high theoretical
reliability (Cronbach’s alpha coefficient) if it is to be part of an instrument that is reliable and valid. The minimum acceptable value of Cronbach’s alpha coefficient is 0.7 (Pallant, 2007). The two mastery goal orientations which emerged from the above tests were subjected to the Cronbach’s alpha test as shown below.

**Cronbach’s alpha test for factor 1 mastery goal orientation**

<table>
<thead>
<tr>
<th>Reliability Statistics: mastery goal orientation factor 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cronbach’s Alpha</td>
</tr>
<tr>
<td>.479</td>
</tr>
</tbody>
</table>

The 0.479 value is less than the book value of 0.7.

**Cronbach’s alphas when factor 1’s items were deleted**

<table>
<thead>
<tr>
<th>Item-Total Statistics: mastery goal orientation factor 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
</tr>
<tr>
<td>Q35</td>
</tr>
<tr>
<td>Q23</td>
</tr>
<tr>
<td>Q32</td>
</tr>
</tbody>
</table>

Even if some items are deleted, the values are still low as shown in the table above.

**Cronbach’s alpha test for factor 2 mastery goal orientation**

<table>
<thead>
<tr>
<th>Reliability Statistics: mastery goal orientation factor 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cronbach’s Alpha</td>
</tr>
<tr>
<td>.467</td>
</tr>
</tbody>
</table>

The reliability coefficient of 0.467 is less than 0.7.
Cronbach’s alphas when factor 1’s items were deleted

<table>
<thead>
<tr>
<th>Item</th>
<th>Total Statistics: mastery goal orientation factor 2</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scale Mean if Item Deleted</td>
<td>Scale Variance if Item Deleted</td>
<td>Corrected Item-Total Correlation</td>
<td>Cronbach's Alpha if Item Deleted</td>
</tr>
<tr>
<td>Q69</td>
<td>13.58</td>
<td>1.912</td>
<td>.346</td>
<td>.313</td>
</tr>
<tr>
<td>Q86</td>
<td>13.77</td>
<td>1.788</td>
<td>.286</td>
<td>.385</td>
</tr>
<tr>
<td>Q6</td>
<td>13.19</td>
<td>2.526</td>
<td>.227</td>
<td>.435</td>
</tr>
<tr>
<td>Q42</td>
<td>13.43</td>
<td>2.316</td>
<td>.228</td>
<td>.432</td>
</tr>
</tbody>
</table>

Even when some items were deleted, as shown above, the reliability coefficient remained very low.

Cronbach’s alphas when factor 2’s items were deleted

<table>
<thead>
<tr>
<th>Reliability Statistics: mastery goal orientation factors 1&amp;2 combined</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cronbach's Alpha Alpha</td>
<td>N of Items</td>
</tr>
<tr>
<td>.593</td>
<td>7</td>
</tr>
</tbody>
</table>

The coefficient alpha is still lower than 0.7, even when the two factors are combined into one construct.

Cronbach’s alphas when the mastery goal orientation construct’s items were deleted

<table>
<thead>
<tr>
<th>Item-Total Statistics</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scale Mean if Item Deleted</td>
<td>Scale Variance if Item Deleted</td>
<td>Corrected Item-Total Correlation</td>
</tr>
<tr>
<td>Q35</td>
<td>27.14</td>
<td>5.397</td>
<td>.391</td>
</tr>
<tr>
<td>Q23</td>
<td>26.99</td>
<td>5.843</td>
<td>.315</td>
</tr>
<tr>
<td>Q32</td>
<td>27.12</td>
<td>6.002</td>
<td>.271</td>
</tr>
<tr>
<td>Q69</td>
<td>27.22</td>
<td>5.645</td>
<td>.314</td>
</tr>
</tbody>
</table>


Low values of coefficient alpha were again obtained with Q6 being the lowest. This item was then deleted.

**Cronbach’s alphas when the mastery goal orientation construct’s items were deleted**

<table>
<thead>
<tr>
<th>Item</th>
<th>Scale Mean if Item Deleted</th>
<th>Scale Variance if Item Deleted</th>
<th>Corrected Item-Total Correlation</th>
<th>Cronbach’s Alpha if Item Deleted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q23</td>
<td>22.20</td>
<td>5.006</td>
<td>.311</td>
<td>.540</td>
</tr>
<tr>
<td>Q32</td>
<td>22.33</td>
<td>5.126</td>
<td>.272</td>
<td>.556</td>
</tr>
<tr>
<td>Q35</td>
<td>22.35</td>
<td>4.540</td>
<td>.404</td>
<td>.498</td>
</tr>
<tr>
<td>Q42</td>
<td>22.28</td>
<td>5.175</td>
<td>.269</td>
<td>.557</td>
</tr>
<tr>
<td>Q69</td>
<td>22.43</td>
<td>4.850</td>
<td>.299</td>
<td>.545</td>
</tr>
<tr>
<td>Q86</td>
<td>22.61</td>
<td>4.359</td>
<td>.358</td>
<td>.520</td>
</tr>
</tbody>
</table>

The reliability coefficients are lower than 0.7.
Cronbach’s alpha test for factor the performance goal orientation factor

<table>
<thead>
<tr>
<th>Reliability Statistics: performance approach goal orientation 1 factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cronbach’s Alpha</td>
</tr>
<tr>
<td>.798</td>
</tr>
</tbody>
</table>

The coefficient alpha is greater than 0.7 which is the cut-off point.

<table>
<thead>
<tr>
<th>Item-Total Statistics: performance approach goal orientation 1 factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale Mean if Item Deleted</td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>Q7</td>
</tr>
<tr>
<td>Q24</td>
</tr>
<tr>
<td>Q45</td>
</tr>
<tr>
<td>Q58</td>
</tr>
<tr>
<td>Q75</td>
</tr>
</tbody>
</table>

None of the items may be deleted from the list, as all of them load higher than 0.7 alpha coefficients.

Cronbach’s alpha test for factor the performance-avoidance goal orientation factor

<table>
<thead>
<tr>
<th>Reliability Statistics performance-avoidance goal orientation 1 factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cronbach’s Alpha</td>
</tr>
<tr>
<td>.650</td>
</tr>
</tbody>
</table>

The alpha coefficient is less that the cut-off point of 0.7.
Cronbach’s alphas when the performance-avoidance goal orientation construct’s items were deleted

<table>
<thead>
<tr>
<th>Item</th>
<th>Scale Mean if Item Deleted</th>
<th>Scale Variance if Item Deleted</th>
<th>Corrected Item-Total Correlation</th>
<th>Cronbach’s Alpha if Item Deleted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q8</td>
<td>12.50</td>
<td>12.503</td>
<td>.323</td>
<td>.632</td>
</tr>
<tr>
<td>Q26</td>
<td>14.05</td>
<td>11.130</td>
<td>.357</td>
<td>.622</td>
</tr>
<tr>
<td>Q46</td>
<td>13.26</td>
<td>10.187</td>
<td>.450</td>
<td>.574</td>
</tr>
<tr>
<td>Q64</td>
<td>13.25</td>
<td>10.961</td>
<td>.467</td>
<td>.568</td>
</tr>
<tr>
<td>Q81</td>
<td>13.23</td>
<td>11.098</td>
<td>.425</td>
<td>.587</td>
</tr>
</tbody>
</table>

Deletion of any items yielded less than .70 alphas

Findings and discussion

The pilot study proved that the Vedder-Weiss and Fortus questionnaire instrument was too unreliable for use to determine the Black township schools’ Physical Sciences learners’ achievement goal orientation. Accordingly, the items of the instrument had to be re-arranged in order to cluster the items of a construct together. The reasons for re-arranging the questionnaire were theoretical, since no evidence was collected from the learners on their perception of the two formats of the questionnaire instrument. For example, Sanchez, (1992), argued that the design of the questionnaire can help or hurt the quality of data being collected. According to Brace, (2004) respondents might feel it distressing to keep shifting from one topic to another, or to be asked to return to the same subject, when they might think that they have already given their opinions about it. Therefore, distributing items on a construct throughout a questionnaire could distress respondents, resulting in them giving inconsistent responses. But the challenge was why this effect would be prevalent in Soweto township schools but not in Israel.

Furthermore, an insufficient development of critical thinking skills in learners due to the implementation of traditional teaching approaches for teaching sciences, (Ramnarain, 2013), could constrain learners’ capacity to decipher the goal orientation perceptions that were being manifested in the questionnaires. The regularities which the questionnaires reflected, might not have been evident to the learners, when the items on a construct were placed adjacent to each other. This observed fact could be explained by the social reproduction theory of Bourdieu (1977).
Bourdieu (1989)’s concept of social capital in a social space which is propounded by his theory of social reproduction, could be used to explain the differences in responses to one questionnaire instrument by Israeli and Soweto township schools learners. According to Bourdieu, (1989), all people occupy different social space or different social positions which reflect their economic, cultural, social and symbolic capital. In addition, all people employ their social capital when they act within their positions, so as to legitimate those positions, (Bourdieu, 1989). Accordingly, the Soweto township learners would respond to the questionnaire items in a manner that reflected their social capital. Metz, (2012, p. 396), has argued that the African moral values are based on harmonious relationships, where, “typical humans not only are capable of being identified with and cared for, but also can identify with others and care for them”. After the pilot study, when learners were asked to explain their responses to the questionnaire, particularly why they felt that it was important for them to display their marks to other learners, they argued that it was to offer assistance to the less knowledgeable. Therefore the purpose of displaying scores was meant to help other learners to understand, but not to seek recognition as assumed by the questionnaire. The learners expressed that it was good to help others to succeed and that it was bad to leave them alone with ignorance, which was social reproduction!

The adapted questionnaire

The re-arranged instrument had the following format.

<table>
<thead>
<tr>
<th></th>
<th>Not true at all</th>
<th>Not so true</th>
<th>Somewhat true</th>
<th>True</th>
<th>Very true</th>
</tr>
</thead>
<tbody>
<tr>
<td>It’s important to me that I improve my skills in science this year.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>An important reason why I do my work in science class is because it is important to me to improve my knowledge in science.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>It’s important to me that I thoroughly understand my science class work.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>An important reason why I do my work in science class is because I want to get better at it.</td>
<td>.4</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>I do my work in science class because I want to learn and advance as much as possible.</td>
<td>.5</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>An important reason why I do my science class work is because I like to learn new things.</td>
<td>.6</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>I like science class work that I'll learn from even if I make a lot of mistakes.</td>
<td>.7</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>One of my goals is to show others that science class work is easy for me.</td>
<td>.8</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>One of my goals is to look clever in comparison to the other students in my science class.</td>
<td>.9</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>One of my goals is to show others that I'm good at my science class work.</td>
<td>.10</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>It’s important to me that I look smart compared to others in my science class.</td>
<td>.11</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>It’s important to me that the science teacher and other students will think that I’m good at science studies.</td>
<td>.12</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>It's very important to me that I don't look stupid in science class.</td>
<td>.13</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>The reason I do my class work is so my science teacher doesn't think I know less than others.</td>
<td>.14</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
<td>Very true</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>-----------------</td>
<td>-------------</td>
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</tr>
<tr>
<td>One of my goals in science class is to avoid looking like I have trouble doing the work.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>It’s important to me that my science teacher doesn’t think that I know less than others in class.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>It’s important to me that my science teacher doesn’t think that I’m not as good as other students.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

The new reliabilities

The re-arranged instrument had higher reliability coefficients that are indicated in the table below.

Cronbach’s alpha coefficients for the re-arranged personal-achievement goal orientation instrument

<table>
<thead>
<tr>
<th></th>
<th>Cronbach’s alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal mastery</td>
<td>0.74</td>
</tr>
<tr>
<td>Personal-performance approach</td>
<td>0.858</td>
</tr>
<tr>
<td>Personal-performance avoid</td>
<td>0.832</td>
</tr>
</tbody>
</table>

Conclusion:

Basing on the EFA and Cronbach’s alpha tests, it could be concluded that this study developed a reliable instrument for measuring Physical Sciences learners’ achievement goal orientation in five Soweto township schools. According to the theoretical framework, the importance of determining learners’ achievement goal orientation is that, achievement goal orientations are linked to classroom conditions for learning, which have various impacts on the quality of learning.

References


Appendix 1

Student Questionnaire

<table>
<thead>
<tr>
<th>Student number</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree</td>
<td></td>
</tr>
<tr>
<td>Registered modules</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td></td>
</tr>
<tr>
<td>Gender (Male or Female)</td>
<td></td>
</tr>
<tr>
<td>Previous school attended</td>
<td></td>
</tr>
<tr>
<td>Grade 12 symbol in Physical Sciences</td>
<td></td>
</tr>
</tbody>
</table>

This questionnaire is not a test! There is no right or wrong answer to each question. The best answer is whatever you think or feel is true. None of your teachers and nobody in your school will know what you’ve answered on this questionnaire.

It is very important that you answer the questions seriously and mark what you truly think or feel. Your answers will help us improve the way science is taught in your and other schools.

In the questionnaire you are asked to mark which answer best fits what you think. For example, if the following sentence appears:

<table>
<thead>
<tr>
<th>I like vanilla ice cream very much.</th>
<th>Not true at all</th>
<th>Not so true</th>
<th>Somewhat true</th>
<th>True</th>
<th>Very true</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

A student that likes vanilla ice cream a lot will circle the number 5 – Very true. If you like vanilla ice cream, but it’s not your favourite ice cream, you can circle number 4 – True. If you like vanilla ice cream just a bit, you can circle number 3 – Somewhat true. If you don’t like vanilla ice cream you’ll circle number 2 – Not so true. Finally, a student that doesn’t like vanilla ice cream at all will circle the number 1 – Not true at all.
Attention! Every now and then there are sentences that state what you don’t like or don’t do. For example:

<table>
<thead>
<tr>
<th></th>
<th>Not true at all</th>
<th>Not so true</th>
<th>Somewhat true</th>
<th>True</th>
<th>Very true</th>
</tr>
</thead>
<tbody>
<tr>
<td>I don’t like vanilla ice cream at all.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

In this case a student that likes vanilla ice cream very much would circle number 1 – Not true at all, and a student that doesn’t like vanilla ice cream at all would circle number 5 – Very true.

ALL ITEMS BELOW RELATE TO YOUR EXPERIENCE

<table>
<thead>
<tr>
<th></th>
<th>Not true at all</th>
<th>Not so true</th>
<th>Somewhat true</th>
<th>True</th>
<th>Very true</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. My science teacher thought mistakes were okay as long as we were learning.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. My science teacher told us how we compared to other students.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3. My science teacher said that our goal should be to show others that we are not bad at class work.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4. In my school students were told that making mistakes is OK as long as they were learning and improving.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5. In my school it was easy to tell which students got the highest marks and which students got the lowest marks.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>6. It is important to me that I improve my skills in science this year.</td>
<td>1</td>
<td>2</td>
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<td>4</td>
<td>5</td>
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<tr>
<td>7.</td>
<td>One of my goals at school was to show others that science class work was easy for me.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
</tr>
<tr>
<td></td>
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<td>1</td>
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</tr>
<tr>
<td>8.</td>
<td>It was very important to me that I didn't look stupid in science class.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
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<td></td>
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</tr>
<tr>
<td>9.</td>
<td>I can do even the hardest work in science class if I try.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
</tr>
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</tr>
<tr>
<td>10.</td>
<td>In our school science class, really understanding the work was the main goal.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
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<td>1</td>
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</tr>
<tr>
<td>11.</td>
<td>In our science class, getting right answers was very important.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
</tr>
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<td>4</td>
</tr>
<tr>
<td>12.</td>
<td>In our science class, showing others that you are not bad at class work was really important.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
</tr>
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<td>1</td>
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</tr>
<tr>
<td>13.</td>
<td>My parents would like me to do challenging class work in science, even if I make mistakes.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
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<td>4</td>
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<tr>
<td>14.</td>
<td>My parents think getting the right answers in science class is very important.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
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</tr>
<tr>
<td>15.</td>
<td>I pay attention and attempt to follow the lesson in science class.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
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<tr>
<td>16.</td>
<td>If it were possible to choose whether to learn science or not in my school, I would choose to learn science.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
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<td>4</td>
</tr>
<tr>
<td>17.</td>
<td>I browse internet sites which deal with science, nature, animals, or environmental issues.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
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<tr>
<td>Question</td>
<td>Rating</td>
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<td>---------------------------------------------------------------------------------------------------</td>
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<tr>
<td>18. My science teacher wanted us to understand our work, not just remember it.</td>
<td>Not so true: 1, Somewhat true: 3, True: 4, Very true: 5</td>
<td></td>
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<tr>
<td>19. My science teacher told us it’s important to join in discussions and answer questions so it doesn’t look like we can’t do the work.</td>
<td>Not so true: 1, Somewhat true: 3, True: 4, Very true: 5</td>
<td></td>
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<tr>
<td>20. If I see an article in a newspaper about science, nature, animals, or environmental issues, I immediately turn to something else.</td>
<td>Not so true: 1, Somewhat true: 3, True: 4, Very true: 5</td>
<td></td>
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<tr>
<td>21. In my school students were normally told that learning science should be fun.</td>
<td>Not so true: 1, Somewhat true: 3, True: 4, Very true: 5</td>
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<tr>
<td>22. My science teacher pointed out those students who get good marks as an example to all of us.</td>
<td>Not so true: 1, Somewhat true: 3, True: 4, Very true: 5</td>
<td></td>
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</tr>
<tr>
<td>23. An important reason why I do my work in science class is because it is important to me to improve my knowledge in science.</td>
<td>Not so true: 1, Somewhat true: 3, True: 4, Very true: 5</td>
<td></td>
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<tr>
<td>24. One of my goals is to look clever in comparison to the other students in my science class.</td>
<td>Not so true: 1, Somewhat true: 3, True: 4, Very true: 5</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>25. I’m certain I can master the skills taught in science class this year.</td>
<td>Not so true: 1, Somewhat true: 3, True: 4, Very true: 5</td>
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<tr>
<td>26. The reason I did my class work was so my science teacher didn’t think I knew less than others.</td>
<td>Not so true: 1, Somewhat true: 3, True: 4, Very true: 5</td>
<td></td>
<td></td>
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<tr>
<td>27. My parents wanted me to see how my science class relates to things outside of school.</td>
<td>Not so true: 1, Somewhat true: 3, True: 4, Very true: 5</td>
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<tr>
<td>28. I participated in conversations and discussions that took place in science class.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
<td>Very true</td>
</tr>
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<td>1</td>
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<td>5</td>
</tr>
<tr>
<td>29. I build or take apart stuff related to science or technology (such as electrical appliances) on my own.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
<td>Very true</td>
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<td>5</td>
</tr>
<tr>
<td>30. My science teacher praised us for trying hard.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
<td>Very true</td>
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<td>5</td>
</tr>
<tr>
<td>31. In my school students who got good marks were used as an example to others.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
<td>Very true</td>
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<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>32. It’s important to me that I thoroughly understand my science class work.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
<td>Very true</td>
</tr>
<tr>
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<td>1</td>
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<td>5</td>
</tr>
<tr>
<td>33. If I see on the internet something related to science, nature, animals, or environmental issues, I immediately move on to something else.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
<td>Very true</td>
</tr>
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<td></td>
<td>1</td>
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<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>34. I don’t like vanilla ice cream at all.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
<td>Very true</td>
</tr>
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<td></td>
<td>1</td>
<td>2</td>
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<td>4</td>
<td>5</td>
</tr>
<tr>
<td>35. An important reason why I did my work in science class was because I want to get better at it.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
<td>Very true</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>36. I watch TV programs on science, nature, animals, or the environment.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
<td>Very true</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>37. My science teacher gave us time to really explore and understand new ideas.</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
<td>Very true</td>
</tr>
<tr>
<td></td>
<td>1</td>
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<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
<td>Very true</td>
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</tr>
<tr>
<td>38. If I receive in an email, a message, or a presentation related to science, nature, animals, or environmental issues, I ignore it.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>39. My science teacher helped us see how what we learn relates to the real world.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>40. I talk to friends, parents, or other people about science, nature, animals, or environmental issues.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>41. In my school the emphasis was on really understanding schoolwork, not just memorising it.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>42. I did my work in science class because I wanted to learn and advance as much as possible.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>43. My science teacher used lots of other interesting materials to teach, not just our textbook.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>44. In my school students heard a lot about the importance of getting high test scores.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>45. It was important to me that I looked smart compared to others in my science class.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>46. One of my goals in science class was to avoid looking like I have trouble doing the work.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>47. In our science class, learning new ideas and concepts was very important.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
<td>Very true</td>
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</tr>
<tr>
<td>48. I’m sure that I can learn and understand everything that the lecturer will teach till the year’s end.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>49. My parents want me to understand concepts in science, not just do the work.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>50. In our science class it was important to students to appear smarter than others in the class.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>51. I tried to understand the material studied in science class.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>52. In our science class, it was important not to do worse than other students.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>53. My parents would like it if I could show that I’m better in science than other students in my science class.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>54. I look in newspapers or magazines for articles related to science, nature, animals, or environmental issues.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>55. I didn’t go to any activities out of school that are related to science, nature, animals, or environmental issues.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>56. My science teacher encouraged students to find different ways to solve problems in class.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>57. In my school a real effort was made to recognize students for effort and improvement.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>58. One of my goals was to show others that I was good at my science class work.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>----------------</td>
<td>-------------</td>
<td>---------------</td>
<td>------</td>
</tr>
<tr>
<td>59. In our science class, how much you improved was really important.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>60. My parents wanted me to understand my science class work, not just memorise how to do it.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>61. I planned or performed science experiments, outside the requirements of science class.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>62. My science teacher let us know who got the highest scores on a test.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>63. In my school test marks were not talked about a lot.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>64. It was important to me that my science teacher didn’t think that I know less than others in class.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>65. In our science class, it was important to students that others thought they are good at studies.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>66. My parents would be pleased if I could show that science class work is easy for me.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>67. If I run into a TV program which deals with science, nature, animals, or environmental issues, I immediately change the channel.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>68. My science teacher told us it’s important to answer questions in class, so it didn’t look like we couldn’t do the work.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>S.No.</td>
<td>Statement</td>
<td>Not true at all</td>
<td>Not so true</td>
<td>Somewhat true</td>
<td>True</td>
</tr>
<tr>
<td>-------</td>
<td>---------------------------------------------------------------------------------------------</td>
<td>-----------------</td>
<td>-------------</td>
<td>---------------</td>
<td>------</td>
</tr>
<tr>
<td>69.</td>
<td>An important reason why I did my science class work was because I liked to learn new things.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>70.</td>
<td>I’m certain I can figure out how to do the most difficult science class work.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>71.</td>
<td>In our science class, it was very important not to look dumb.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>72.</td>
<td>In science classes, I tried to look busy, but I really did not pay attention.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>73.</td>
<td>My science teacher encouraged us to find interesting and different ways to do our assignments.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>74.</td>
<td>In my school a real effort was made to show students how the work they did in school was related to their lives outside of school.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>75.</td>
<td>It was important to me that the science teacher and other students thought that I was good at science studies.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>76.</td>
<td>In our science class, it was important to understand the work, not just memorise it.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>77.</td>
<td>It was important to my parents that I learned new and interesting things in science.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>78.</td>
<td>I only browse internet sites which don’t deal with science, nature, animals, or environmental issues.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>79.</td>
<td>My science teacher called on smart students more than on other students.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Question</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>80. My school emphasized getting high marks.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>81. It was important to me that my science teacher didn’t think that I was not as good as other students.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>82. In our science class, it was important to students to show others that studies are easy to them.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>83. My parents liked me to show others that I was good at science class work.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>84. I read books about science, nature, animals, or scientists (not including science fiction).</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>85. My science teacher used students that weren’t succeeding as examples to us all for what we shouldn’t be doing.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>86. I liked science class work even if I make a lot of mistakes.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>87. Even if the work in science was hard, I made an attempt to learn it.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>88. In our science class, it was important that you don’t make mistakes in front of everyone.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>89. In science classes I tried to learn as much as possible.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
Students’ perspectives on teacher practices in Physical Science and their implications on inquiry based instruction

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dnampota@cc.ac.mw

Abstract

This paper reports a study that was conducted as part of a larger action research project aimed at exploring teacher use of inquiry in Physical Science classrooms in Malawi. Using an open ended questionnaire, the study sought answers from 654 students studying Physical Science in Form 1, 2, 3 and 4 in three secondary schools, on the question of what they like or do not like about the way Physical Science is taught in their classrooms. Students’ responses were used to inform teacher practices. Bybee et al.’s (2006) 5Es inquiry based instructional model was used to link the teacher practices to inquiry. The findings show that explanation is the most commonly used strategy of the 5Es of inquiry based instruction, albeit highly authoritative, which in itself does not augur well with inquiry. Aspects of evaluation were noted, although not commonly used. Engagement, exploration and elaboration, which centre on student autonomy in the construction of scientific knowledge based on an elicitation of and a challenge to their prior ideas and/or extension of the same, and application of the newly constructed ideas to new situations, were less used, which is a set-back to inquiry. The implications of these findings to both pre-service and in-service teacher training, which could possibly be addressed as part of an action research project, are discussed.

Introduction

Inquiry based instruction has been at the centre of international debates in science education for decades. The understanding is that use of this instruction enhances students’ understanding of science and promotes scientific literacy among citizens. Inquiry based instruction has its roots in the cognitive development theories advocated by Piaget and Vygotsky. Piaget’s theory of cognitive development had two strands: stage-wise development and construction. While stage-wise development entailed that children’s thinking changes quantitatively as a child progresses from one stage to another, construction meant that children construct their own meanings or understandings through interaction with the social and physical environment. The construction of meanings is influenced by the students’ prior knowledge and understanding implying that teaching should involve provision of necessary experiences that engage the students both for elicitation of prior ideas and for challenging and extending them in order to enable construction of meanings. Similarly, Vygotsky (1978) distinguished between scientific and spontaneous or everyday concepts. While spontaneous concepts were said to consist of everyday and frequently used knowledge, scientific concepts were seen to consist of formalised knowledge, which was learnt from more able individuals in formal situations such as school. Vygotsky saw teaching
as involving two stages, exposition to the formal knowledge on the one hand and practice in using that knowledge to make it everyday knowledge on the other, the latter of which is described as application. In the 1990s, when there was much research on pupils’ understanding of science concepts and teaching strategies to bring about conceptual change, most of the proposed strategies adopted Vygotsyian ideas in some form and included elicitation and exploration or clarification of previous knowledge, introduction of new ideas, practice using new ideas and reflection on changes in understanding (Driver, 1989).

Several instructional models that build on the Piagetian and Vygotsyian theories of learning have been developed by researchers and educators alike, all having similar characteristics. One recent model, which was useful in the analysis of teacher practices in the study reported in this paper, is that developed by Roger Bybee and his colleagues in 2006 (Bybee, Taylor, Gardner, Van Scotter, Powell, Westbrook, & Landes,2006). Bybee et al.’s model is an integrated instructional model, popularly known as 5Es instructional model, whose value lies not only in its ability to help teachers organise coherent instruction but also helps students formulate a better understanding of scientific and technological knowledge, skills and attitudes, following the ideas of elicitation or exploration of previous knowledge, introduction of new ideas and practising and reflecting on the new ideas as earlier on argued by Driver (Driver, 1989). The 5Es represent five stages of instruction: Engagement, Exploration, Explanation, Elaboration and Evaluation. The descriptions for each of the five stages are summarised in the Table 1.

**Table 1. The 5Es instructional model**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description and strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engagement</td>
<td>This aims at exposing students’ prior conceptions and organise their thinking towards the learning outcomes. The strategies, therefore, involve eliciting thoughts and actions related to students’ prior knowledge that directly relate to the lesson objectives. The activities provided should help organise students thinking towards the learning outcomes and arouse students’ curiosity and interest.</td>
</tr>
<tr>
<td>Exploration</td>
<td>Students are enabled to use prior knowledge to generate new ideas, explore questions and possibilities and design and conduct preliminary investigation. Students are given time to explore their knowledge and skills basing on own ideas of phenomena or problem and communicate their ideas in order to build a shared understanding.</td>
</tr>
<tr>
<td>Explanation</td>
<td>Presentations of scientific concepts for student deeper understanding. Teacher gives an explanation to help develop deeper conceptual understanding and directs students’ attention to specific aspects of the engagement. Students also explain their understanding of a concept.</td>
</tr>
</tbody>
</table>
Elaboration The primary goal is to enable students transfer learning and generalise concepts. Activities that require the application and use of scientific concepts and vocabulary in new situations or problems are used. The students are engaged in discussions where they present and defend their approaches.

Evaluation Culminating activity that provides the students and teacher with an opportunity to assess their understanding of the science concepts and skills and students’ progress towards achieving educational objectives

Adapted from Bybee et al. (2006)

The model starts with students’ engagement with activities that not only help elicit their prior ideas, but also motivates and helps them in organising their thinking towards the lesson’s outcomes. The teacher then provides activities that help students explore their ideas further, by extending or challenging them, in order to construct new knowledge and both the teacher and the student explain the ideas constructed. Later the teacher provides activities or situations where the students apply the new knowledge and skills in other familiar and unfamiliar situations, including real life situations, in the elaboration phase and finally both the teacher and the students evaluate the learning that has taken place.

There have been a number of initiatives to promote use of inquiry in science classrooms in response to the dominance of teacher centred didactic teaching methods that have persisted in many countries. In the US project 2061 set the scene for inquiry science. In Japan, lesson study and lesson analysis has been used to promote reflective discussion and inquiry science processes. In the Southern Africa region, programs have been implemented with support from the Japanese International Cooperation agency and has taken such labels as Science Teacher Education Project (STEP) for Zambia and Strengthening of Mathematics and Science in Secondary Education (SMASSE) for Kenya and Malawi. Although inquiry based instruction has received so much attention in science education for decades, the evidence that this informs instructional practices of teachers in science classrooms is scanty. Instead, a number of studies have reported contrary instructional practices, largely depicting the traditional didactic teaching methods although sometimes this has been interspersed with question and answer and recipe following type activities that make the methods more interactive. In a study of science teachers in South African classrooms for example, Mokiwa and Nkopodi (2014) found that teacher centred approaches dominated. Although interaction between the teachers and students was encouraged through question and answer, these were often teacher directed and highly authoritative. Similar findings had been reported earlier by Dudu and Vhurumuku (2012) in the same country where teachers were found to use close ended inquiry, with less argumentation and students undertook investigations that often involved following instructions. Hassan and Rajab (2014), however, found a slightly better situation with science teachers in Malaysian schools where teachers used some form of inquiry although this did not include all the 5Es. Engagement and elaboration were noted in
the teacher practices although exploration, explanation and evaluation were not evident. Similarly, a study conducted in 2013 by Nampota (Nampota, 2015) revealed that the practices of the majority of the teachers in Malawi remained didactic although they claimed to use inquiry and discovery methods. For example, although half the teachers observed incorporated student activities in their lessons, only 40 percent engaged the students in such activities meaning that in most cases the students were just following teacher instructions in the activity. Similarly, although students were able to produce something to show to the class in 46 percent of the lessons, only in 19 percent of such lessons did the students produce something arising from their own investigation where they made own predictions and verified them.

The study conducted by Nampota however relied on classroom observations, just like most studies on teacher practices. Though useful in getting first hand information on teacher practices, this approach has limitations. While on the one hand teachers sometimes stage lessons once they know that they are going to be observed, on the other, the observer often distracts the classroom interaction even where attempts are made to minimise these effects. This necessitated the present study that sought to explore teacher practices from the students’ perspective. In the study reported in this paper therefore, student perspectives on teacher practices were sought. This was done as part of a larger on-going action research project being implemented in form of a partnership between Mathematics and Science educators at the University of Malawi and Mathematics and Science teachers in three secondary schools. The aim of the project is to improve the teaching and learning of Mathematics and Science in secondary schools. It is anticipated that effective teaching strategies that are grounded in constructivist and inquiry based instructional strategies will be developed and shared with the rest of the teachers in the country. Before the intervention, however, a needs assessment with the target schools, students and teachers was conducted. It is the result of this needs assessment, with regards to current teacher practices, that this paper presents.

**Research questions**

The main research question was on what are the teacher practices in Physical Science lessons in Malawi?

In order to answer this question, however, two questions were raised with the students; whether they like Physical Science lessons or not; and an explanation of what they like and do not like about the lessons.

**Methodology**

The nature of the research question necessitated use of a qualitative methodology where students would describe the teacher practices that made them like the lessons and those that made them dislike the lessons. However, in the interest of getting responses from a wide group of students, a questionnaire that used both open ended and close ended questions was used. In order not to lose much of the description of the students’ perceived practices, the students were instructed to write as extensively as they could, within the constraints of using...
a questionnaire. Despite its limitations, use of questionnaire was deemed helpful in enabling the students express their ideas freely without fearing that someone will penalise them for what they said.

The subjects of study were 654 students in all classes (Form 1-4) in three secondary schools: here named school 1, 2 and 3 respectively. The three schools were chosen because they represented different kinds of secondary schools in Malawi with School 1 being a conventional secondary school having laboratories and basic resources for practical work while Schools 2 and 3 were Community Day Schools. Although under ordinary conditions Community Day Secondary Schools do not have laboratories and equipment for science teaching, School 2 had new laboratories and equipment unlike School 3 which had no laboratories and consumables for experiments. All the targeted students, except Form 2 students at School 1 took part in the study. On the day the questionnaires were administered at School 1, Form 2 students were due to start writing their Junior Certificate examinations in the following two days and it was feared that the questionnaire might distract their focus.

The questionnaire was administered to the students while in their classes, accompanied by explanations of both how to complete it and the ethical rules of not writing their names on the papers and ensuring confidentiality with the data collected. The supervision of the administration of the questionnaire had several advantages including ensuring 100% return rate and minimising shared responses against the possible disadvantage of interfering with students’ privacy.

Data from the close ended questions were analysed using excel in order to discern frequencies. However, data on the open ended questions was first analysed qualitatively by using the 5Es according Bybee et al, as themes. On such data, frequencies were worked out by counting the number of similar responses in order to arrive at a quantifiable picture of the findings for ease of interpretation.

Study findings

In total, six hundred fifty four students, 42.7 percent of whom were female, took part in the study. The majority (74.3%) of the students were aged between 16 and 18, which was quite a mature group of students. Their responses to the three questions will be discussed according to the questions below.

a) Whether or not students like Physical Science subject and Physical Science lessons

The findings on this first question are summarised in Table 2. In general, the majority of the students (89.9 percent) like Physical Science as a subject although a slightly lesser majority (77.8 percent) enjoy the Physical Science lessons. Nearly a fifth (20 percent) of the students either do not enjoy the Physical Science lessons or are not sure if they like them or not, which could be is a sign of some discontent with the way Physical Science is taught in the classrooms or indeed other reasons.
Table 2. Students’ views about Physical science and its lessons

<table>
<thead>
<tr>
<th>Question</th>
<th>Percentage response</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>I like Physical Science</td>
<td>89.9</td>
</tr>
<tr>
<td>I enjoy Physical Science lessons</td>
<td>77.8</td>
</tr>
</tbody>
</table>

b) What students like about the way Physical Science is taught

When a specific question was raised on what they like about Physical Science lessons, a picture shown in Figure 1 emerged. Overall, teacher use of explanations, teachers giving students a chance to ask questions, teacher use of relevant and clear examples or stories, giving of good notes and use of experiments were the top five reasons. However use of class exercises was also mentioned and ranked number 6.

![Figure 1: What students like about Physical Science lessons](image-url)
Table 3 shows major agreements on why students like Physical Science lessons among the three schools that formed the sample, which might imply similarities in teacher practices, although there are also some variations. Teacher explanation is a highly ranked strategy by the students in all the three schools with its taking first position in School 1 and School 3, although it is ranked second in School 2. Although not as popular at School 1 as it is ranked fourth, the strategy of teachers giving students a chance to ask questions is highly valued by the students, occupying second priority in School 3 and third priority in School 2. Similarities among schools also exist on strategy of teacher giving good and clear notes since it is one of the top five reasons in all the three schools despite slight variations in their ranking. However students at School 3 and School 2 did not appreciate teacher use of clear examples and stories, perhaps these are not used as much in those schools, and variations also existed on teacher use of experiment, which nevertheless was mentioned as a top priority at School 2, much in contrast to the practice at School 1 which should in an ideal situation use more experiments since the school has laboratories and basic equipment. This is indicative that at School 2 there are more chances for student experiments compared to the other two schools, and students take part in those experiments. Other variations were on teacher ability to attend to slow learners, teacher practice of giving class exercises and teacher being hard working. Interestingly, the use of exercises in class was among the top five factors that students liked physical science lessons for at School 2 and School 3 although not prominent at School 1, but ranked sixth in the overall analysis.

Table 3. Top five reasons for liking the way Physical science is taught by school

<table>
<thead>
<tr>
<th>Reason</th>
<th>% of responses Overall</th>
<th>% of responses School 1</th>
<th>% of responses School 2</th>
<th>% of responses School 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher gives good/clear explanations</td>
<td>19.5 (1)</td>
<td>15.4 (1)</td>
<td>13.8 (2)</td>
<td>18.3 (1)</td>
</tr>
<tr>
<td>Teacher gives students a chance to ask questions</td>
<td>11.6 (2)</td>
<td>8.6 (4)</td>
<td>12.6 (3)</td>
<td>9.9 (2)</td>
</tr>
<tr>
<td>Teacher gives good and clear examples or stories</td>
<td>10.1 (3)</td>
<td>13.1 (2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher gives good and clear notes</td>
<td>8.1 (4)</td>
<td>6.0 (5)</td>
<td>9.2 (4)</td>
<td>6.9 (5)</td>
</tr>
<tr>
<td>Teacher gives good experiments</td>
<td>6.5 (5)</td>
<td></td>
<td>16.1 (1)</td>
<td></td>
</tr>
<tr>
<td>Teacher attends to slow learners</td>
<td></td>
<td></td>
<td></td>
<td>8.9 (3)</td>
</tr>
<tr>
<td>Teacher gives class exercises</td>
<td></td>
<td></td>
<td>6.9 (5)</td>
<td>7.4 (4)</td>
</tr>
<tr>
<td>Teacher is hardworking</td>
<td></td>
<td></td>
<td></td>
<td>8.6 (3)</td>
</tr>
</tbody>
</table>
What these findings suggest is that teacher explanations, intermixed with question and answer and giving of notes is a common strategy for teaching Physical Science lessons. However, students are also given a chance to ask questions in all schools, which the students really enjoy. However, only teachers at School 1 give clear examples and stories that could be helpful not only to illustrate the concepts but also to contextualise them to ease knowledge construction. Use experiments do not appear to be a common practice, more surprisingly at a conventional secondary school such as School 1. Its inclusion at School 2, which is rare for CDSS as most do not have equipment, is commendable. This could be explained by the presence of a science laboratory at the school, since it is one of the new CDSS. In addition however, it may be due to teacher beliefs about teaching science at the school. Similarly, use of exercises to reinforce student understanding through practice but also providing opportunities for application of the concepts learnt, is not very common, and more so for School 1.

c) What students do not like about Physical Science lessons?

The reasons why students do not like Physical Science lessons are summarized in Figure 2. A look at Figure 2 shows that the reasons why students do not like the way Physical Science is taught reinforce the teacher practices discussed in the foregoing discussion. If teacher explanations are not sufficiently clear, students do not like the lesson. And the same happens if the teacher does not give notes (or gives notes without explanation), and practicals are not done. In addition, however, students do not like Physical Science lessons due to other general factors concerning the teacher such as spending less contact time with the students by not coming to class often or coming to class and start talking about other things as opposed to focussing on lesson outcomes. Other teacher characteristics such as teaching at a slow pace and being temperamental also worked negatively to students’ linking of the Physical Science lessons.
School similarities and differences were also noted on the reasons why students do not like the way Physical Science is taught as shown in Table 4. If teacher explanations are not clear, students do not like the Physical Science lessons, at least for School 1 and School 2, where this was ranked second although it was not part of the top 5 reasons for School 3. What worried School 3 students more appeared to be less contact time as teacher either did not come to class often or spent most of the time talking about other things and not concentrating on lesson outcomes. In fact, it would appear that at the Community Day Secondary Schools (School 2 and School 3), less contact time, as opposed to teacher practices in achieving the lesson outcomes, was the major problem. While teacher absenteeism was not a problem for School 1, teacher waste of quality time to talking about other things was mentioned as a fifth priority problem. What worried School 1 students was the teacher teaching very slowly, which was ranked first, and teacher being temperamental. With use of experiments having been a top ranked reason for liking Physical Science lessons for School 2 (see Table 2), it is surprising that lack of practical is also mentioned as one of the reasons why students do not like Physical Science lessons in the same school.

Figure 1: What students do not like about Physical Science lessons
### Table 4. Top five reasons for not liking the way Physical science is taught by school

<table>
<thead>
<tr>
<th>Reason</th>
<th>% of responses Overall</th>
<th>% of responses School 1</th>
<th>% of responses School 2</th>
<th>% of responses School 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher explanations not clear/ not sufficient</td>
<td>14.8 (1)</td>
<td>12.4 (2)</td>
<td>14.8 (2)</td>
<td></td>
</tr>
<tr>
<td>Teacher does not come to class often</td>
<td>11.2 (2)</td>
<td></td>
<td>26.2 (1)</td>
<td>9.1 (4)</td>
</tr>
<tr>
<td>Teacher teaches less time, talks about other things</td>
<td>7.9 (3)</td>
<td>5.8 (5)</td>
<td>6.6 (5)</td>
<td>36.4 (1)</td>
</tr>
<tr>
<td>Teacher does not give notes</td>
<td>7.9 (4)</td>
<td></td>
<td>14 (3)</td>
<td></td>
</tr>
<tr>
<td>Practicals not done</td>
<td>6.8 (6)</td>
<td>8.2 (4)</td>
<td>13.6 (2)</td>
<td></td>
</tr>
<tr>
<td>Teacher speaks very fast</td>
<td></td>
<td></td>
<td></td>
<td>10.6 (3)</td>
</tr>
<tr>
<td>Sometimes teacher gives notes without explanation</td>
<td></td>
<td></td>
<td></td>
<td>4.5 (5)</td>
</tr>
<tr>
<td>Teacher does not give notes</td>
<td></td>
<td></td>
<td></td>
<td>4.5 (5)</td>
</tr>
<tr>
<td>Teacher teaches very slowly</td>
<td>7.4 (5)</td>
<td>14.1 (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher is short tempered</td>
<td></td>
<td></td>
<td>9.6 (3)</td>
<td></td>
</tr>
<tr>
<td>Teacher speaks with low voice</td>
<td></td>
<td></td>
<td>6.2 (4)</td>
<td></td>
</tr>
</tbody>
</table>

The picture emerging from the findings is that teacher explanation and giving notes is what is preferred by the students in the learning of Physical Science, although for the CDSS issues of teacher attendance in the classrooms and sticking to the objectives of the lesson is something that needs to be addressed with the teachers.

**Teacher practices and inquiry based instruction**

In an attempt to appraise the teacher practices as implied by the student perspectives of what they like and do not like about Physical Science lessons, Bybee et al.’s 5Es instructional model was useful as shown in Table 5. From the analysis of what students like and do not like about Physical science lessons, one gets the impression that Explanation is the most dominant of the 5Es in the teacher practices in the target schools in Malawi and this could be so in other schools as well as there were no differences between the two different kinds of schools used in this study. It would appear that teachers spend most of the time explaining scientific concepts during the lessons, which students like very much, and if this is not done, then the students dislike the lesson. There is evidence from the findings that the teacher extends the explanations through use of examples or stories especially for School 1 and giving of notes for all schools. If notes are given without teacher explanations, then students do not like the lesson, further emphasising use of teacher explanations as a common strategy.
Table 5. The Es commonly used in Physical Science classrooms

<table>
<thead>
<tr>
<th>Reason/teacher practice</th>
<th>Bybee et al.’s 5Es</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher gives good/clear explanations</td>
<td>Explanation</td>
</tr>
<tr>
<td>Teacher gives students a chance to ask questions</td>
<td>Evaluation</td>
</tr>
<tr>
<td>Teacher gives good and clear examples or stories</td>
<td>Explanation</td>
</tr>
<tr>
<td>Teacher gives good and clear notes</td>
<td>Explanation</td>
</tr>
<tr>
<td>Teacher gives good experiments</td>
<td>Exploration</td>
</tr>
<tr>
<td>Teacher gives class exercises</td>
<td>Elaboration</td>
</tr>
</tbody>
</table>

There is evidence that teachers give a chance for students to ask questions and where this is done students like the lessons. Where students are given a chance to ask questions, they are given an opportunity to think about their learning, the knowledge gaps that they may have, and therefore evaluate their learning. And depending on the nature of the experiment done, there is potential for the teachers to embed Exploration in the lessons. However, this is only possible if the experimentation is not a recipe following kind of experimentation, which is rare in Malawi, as often experiments are conducted to verify theory (Nampota, 2008). Where the teacher gives some exercises, then elements of elaboration are evident although this depends on the nature of the exercises given. While recipe type exercises enhance students understanding from the teacher explanations, exploratory exercises that involve application of the science concepts to other situations could be categorised as elaboration. With recipe type exercise being common in the schools, implementation of real elaboration is questionable.

The analysis shows that explanation is the dominant E in the teacher practices in Physical Science lessons although elements of evaluation were also noted with debatable inclusion of elements of exploration and elaboration. However, opportunities for student engagement, especially where it relates to eliciting students’ prior knowledge and using it to enable students construct new meanings, appear not to be used at all.

Summary and conclusions

In summary, teacher explanations appears to be the dominant teaching strategy used by teachers in Physical Science classrooms in the three schools in Malawi and perhaps other schools as well. The dominance of teacher explanation means that a lot that happens in science classrooms is rote learning, as students have to listen and take down notes. Students own construction of knowledge as advocated by cognitive theorists such as Jean Piaget seem far fetched as often students’ ability to use their prior knowledge and engage with new knowledge and experiences to construct own meanings and use them to solve otherwise insoluble problems as espoused in the three Es of Engagement, Exploration and Elaboration are limited. This may need redress so that students engage with the content they are learning if the teaching and learning situation is going to be meaningful to the
students. This may have to be emphasised in the teacher capacity building as part of the action research programme to improve the teaching and learning of Physical Science. Attempts will be made to help teachers arrange activities for students’ Engagement, Exploration, Elaboration and Evaluation for the various topics during the action research project and these will be shared with pre-service Physical Science teachers.

Acknowledgements
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References


Abstract

A cohort consisting of 23 science teachers and science educators (henceforth, participants) were exposed to an ubuntu-based dialogical argumentation instructional model (DAIM) for a period of two years. The aim was to: (1) enhance their awareness about the educational and cultural value of indigenous knowledge (IK); and (2) equip them with instructional skills to implement an indigenized science curriculum in a multicultural science classroom context using DAIM. This paper presents a brief account of the participants’ experiences with DAIM. An analysis of the data derived from video-audio-recordings and interviews shows that DAIM increased their awareness about the educational and cultural value of IK; improved their argumentation skills and enhanced their self-image. The implications of the findings are highlighted in the paper.

A current challenge facing science teachers worldwide has been the emergence of multicultural classrooms. Talking about the same phenomenon Lee & Buxton (2010) claim that as a result of recent rapid increase of immigrant students US schools “are characterized by rich ethnic, cultural, linguistic, and religious diversity” (p. ix). They further claim that US schools are more diversified today than they have ever been since the 1900s and that if the present trend continues then the students of colour would equal or exceed the percentage of White students within a decade or two. For similar reasons the same phenomenon is has become evident in Great Britain, Canada, Germany, France and other western countries. The emergence of multicultural classrooms in South Africa is largely due to the demise of the apartheid system of government. Whatever the case in other countries multicultural classrooms pose great challenges for teachers and non-mainstream second language students in that the latter are greatly disadvantaged from participating actively in classroom discourses. Besides this are the perpetual conflicts between the students’ home-based funds of indigenous knowledge and school science. To mitigate this unsavoury situation calls have been made to on teachers to integrate students’ IK with school science (e.g. Aikenhead & Elliot, 2010; Cajete, 1999; Garrouste, 1999; Lee & Buxton, 2010; Nichol & Robinson, 2000; Ogunniyi, 2007a & b; Snively & Corsiglia, 2001).

Several reasons for the incorporation of IK into school science in South Africa and other countries include among others: the assumed loss of wisdom resident in IK due to the effect of colonization; the emergence of diverse environmental problems associated with scientific and industrial activities e.g. global warming, environmental pollution, erosion of the ozone layer, greenhouse effect, flooding, drought and, desertification; and the failure of western science to solve diverse social problems such as poverty, hunger, diseases and pests. Another reason frequently mentioned in the extant literature has been the poor performance
of students in international science assessments (e.g. Aikenhead & Elliot, 2010; Bang & Marin, 2015; Cajete, 1999; Department of Basic Education (DBE), 2011; Department of Education (DOE), 2002; Garrouste, 1999; Govender, 2007; Hewson & Ogunniyi, 2011; Ogunniyi, 2011; Reddy, 2007; Snively & Corsiglia, 2001). In light of these and similar problems new science curricula have been implanted and science education journals, books and conference proceedings have begun to give an increasing attention to the issue of making school science to all students regardless of their socioeconomic backgrounds (e.g. Bang & Marin, 2015; JRST, 2015).

The irony of course is that while the rest of the world is eager to incorporate IK into science curriculum many influential people in South Africa (including policy makers; officials) have begun to call for the “back-to-the basics” instead of calling for a “forward-looking-curriculum” which makes school science culturally relevant to all students. However, this playing the ostrich with the new curriculum, so to speak, would again lead us into a back tract where school science is seen by students as a collocation of informational items to be memorized for examination purposes.

The extant literature has shown unequivocally that IK has been used and abused in various ways. Pharmaceutical companies have carried out recruited scientists and pharmacologists to study the diverse medicinal uses of several indigenous plants for financial purposes. The saga surrounding the patency of the rooibos tea (produced from a plant native to South Africa) by an international food company has been going on the courts for several decades. Indigenous knowledges developed by diverse indigenous peoples have been stolen and commoditized by various international commercial companies leaving the real owners impoverished, devalued, cheated and marginalized. In fact IK has been used by the by advanced economies to oppress the indigenous peoples worldwide (e.g. Aikenhead & Elliot, 2010; Cajete, 1999; Govender, 2011; Hoppers, 2002; Ogunniyi, 2004, 2007a, 2011).

In view of the above scenario researchers science educators have developed instructional strategies aimed at making science more relevant especially to second language indigenous students. Some of the approaches used include: the adoption of indigenous methods of solving practical problems in the science lessons; the invitation of IK experts into the science classroom; and the use of cultural symbols, myths, metaphors, storytelling, drama, songs, poems, proverbs, art and music in the science classroom (Aikenhead, 2006; Aikenhead & Elliot, 2010; Cajete, 1999; 2010; Garrouste, 1999; Gonzalez, Moll & Amanti, 2005; Govender, 2007; Lee & Buxton, 2010). In addition to these approaches some studies in recent years have explored the potential argumentation instruction for discussing controversial socioscientific issues (e.g. Erduran, Simon & Osborne, 2004; Hewson & Ogunniyi, 2011; Moyo and Kizito, 2014; Naidoo & Vithal, 2014; Ogunniyi, 2007a & b).

**Argumentation as a dialectical and instructional tool**

Since the past decade, a plethora of studies have pointed out the effectiveness of argumentation instruction in fostering classroom discourses; the most popular being the Toulmin’s (2003) argumentation pattern (TAP) (e.g. Erduran, Simon & Osborne, 2004;
Simon & Johnson, 2008). TAP is grounded in the Aristotelian deductive-inductive logic. The study adopted a modified version of TAP developed by Simon & Johnson (2008) which consists of various levels of arguments such as: Level 1- non-oppositional arguments or arguments with simple claims versus counter-claims; Level 2- arguments with claims supported with grounds (data, warrants and backings) but with no rebuttals; Level 3- arguments with claims supported with grounds and only occasional weak rebuttals; Level 4- arguments with claims supported with grounds and at least one strong rebuttal; and Level 5- arguments with claims supported with grounds and with more than one strong rebuttal.

One difficulty however, is that TAP is only suitable for analysing logical arguments rather than the non-logical arguments that tend to emerge when discussing value-laden arguments relating to students’ indigenous beliefs and cultural practices (e.g. Cajete, 1999; Garrouste, 1999; Gonzalez, Moll & Amanti, 2005; Oggunniyi, 2007a & b). To cater for the latter and to ameliorate the sense of alienation that indigenous students feel in science classroom the study adopted complementary theory to TAP known as the contiguity argumentation theory (CAT) (Ogunniyi, 2004, 2007a). CAT is grounded in the ubuntu worldview-a worldview that drives the African way of life (Nthuli, 2002). CAT is premised on the assumption that ideas are always in a dynamic state of flux depending on the nature of the contextual arousal at a given point in time. CAT recognizes five dynamic cognitive states or worldview that could emerge in an argumentative discourse. They are: dominant-the most prevailing or accepted argument or worldview in a given context; suppressed-the worldview that is subdued by the dominant one; assimilated- a worldview that is subsumed by a dominant one; emergent-a worldview arising from a new experience; and equipollent-a worldview consisting of two or more co-existing worldviews exerting equal cognitive force on a person’s overall worldview.

While TAP is suitable for analysing deductive-inductive arguments CAT is suitable for analysing both logical and the non-logical metaphysical arguments that frequently occurs in the science classroom when discussing controversial socioscientific issues e.g. the integration of science and IK. For the same reason, TAP and CAT are construed in the study as complementary units of analysis for the data.

The dialogical argumentation instructional model (DAIM) adopted in the study draws on both TAP and CAT. DAIM exemplifies three stages of conflict resolution in an ubuntu-driven indigenous community and to some extent in a scientific community of practice such as: the individual or self-conversational stage (intra-argumentation) or what Szasz (1987) calls inner dialogue or self-conversation; to the small group (family) stage (inter-argumentation); and finally at the whole or community stage (trans-argumentation) e.g. in form of seminars, meetings or conferences (Ogunniyi, 2007a, 2011). More details on this will be presented later.

What is ubuntu?

Ubuntu is a central African worldview theory which construes people’s knowledge, perceptions, and behavioural patterns in accordance with certain societal norms. Ubuntu, an
Nguni word is called different names in different African indigenous communities e.g. botho in Sotho is central to the African way of life (Venter, 2004). Ubuntu or being fully human is an African concept with universal application. The term ubuntu has recently gained prominence in Africa because of people’s increased awareness of the need to re-discover and authenticate their Africaness, humanness and their sense of self that have been badly battered during the 300 years of colonization. Although ubuntu emphasizes communality rather than individualism prevalent in most western societies, it is equally cognizant of the important role that individuals play in that community. The African term umuntu or man in a generic sense construes a person as a tripartite being (with body, soul and spirit) which finds expression in a communal rather an individualistic milieu. In other words, to be a person depends on other persons (Beets & le Grange, 2005). Ubuntu is about the interconnectedness, interdependence, reciprocity, synchronicity and inseparability of a person from his/her community. It is more about “us” not “me”. Your joy or pain is mine as mine is yours. In such a setting any claim to a particular idea is therefore unwarranted. It is about shared values and mutual responsibility and mutual respect.

Ubuntu as the core of the African worldview is mobilized in resolving both the individual and social conflict. It is the motivating force behind diverse communal activities such as planting, harvesting, hunting, organization of a festival, building a house or a school, or constructing a bridge or a road etc. However, as a plethora studies have shown the non-mainstream indigenous students tend to find a disconnection between the way they do things at home e.g. in terms of cooperation, seeking the welfare of others, putting the interest of others before one’s self-interest are completely deemphasized in the science classroom. Thus, their sense of fulfilment in interdependence, interrelatedness and togetherness is replace with competitiveness and individual attainment (e.g. Aikenhead & Elliot, 2010; Cajete, 1999; Garrouette, 1999; Hewson & Oggunniyi, 2011; Nichol & Robinson, 2000; Ogunioni, 2004, 2007a). It is in light of this that the study explored how the philosophy of ubuntu, particularly its emphasis on collectivity, togetherness and communal consensus could be explicated or demonstrated practically in a classroom situation.

**Purpose of the study**

The study attempted to determine the effects of DAIM in enhancing the participants’ awareness about the cultural and educational value of an indigenized science-IK curriculum in the classroom context. In pursuance of this aim answers were sought to the following questions:

- What views of the new inclusive science-IK curriculum did the participants hold before and after being exposed to DAIM?

- What specific aspects of DAIM influenced the participants’ changing views about the educational and cultural value of a science-IK curriculum?

**Method**
**Dialogical argumentation instructional model (DAIM)**

DAIM was used as a platform for exposing the participants to the nature of argumentation and the way it is used to resolve conflicts and controversies within the scientific and indigenous African communities. Next they participated in debates on various controversial issues at the time of the study to familiarize them with the nature of argumentation discourses within the scientific and indigenous communities of practice. More details about this have been published elsewhere (e.g. Ogunniyi, 2004, 2007a & b).

After familiarizing the participants with the nature of argumentation within the scientific and indigenous communities they were exposed three-hour a week to a series of lectures and seminars on the nature of science (NOS) and IKS (NOIKS) as espoused by some renowned scientists, philosophers, historians and sociologists of science and indigenous experts (e.g. Habermas, 1999; Hempel, 1966; Hoppers, 2002; Hountondji, 1997; Mbiti, 1996; Kuhn, 1970; Popper, 2001; Ziman, 2000) for a period of three months. For the next 20 months they participated in various hands-on activities aimed at facilitating their awareness about the scientific and indigenous methods of solving problems, resolving conflicts or doing things generally. For example, they were asked to determine the scientific processes involved in three indigenous methods gari processing. Gari is a staple food derived from the root tuber cassava Manihot esculenta that is eaten in many tropical and sub-tropical countries in Africa, the West Indies and Asia.

During the hands-on DAIM-based workshops the participants were randomly distributed to five groups. Each group with a leader was assigned a number of time-based cognitive tasks which they tackled first as individuals (intra-argumentation stage), then in small groups (inter-argumentation stage) and finally in the whole group (trans-argumentation stage) in line with CAT sketched earlier. It is apposite to mention that as much as possible DAIM as deployed in the study attempted to capture the way that scientists and indigenous people attempt to resolve conflicts or to solve problems at the individual, group or community level. Usually a problem that cannot be resolved at the individual level is taken to the family. If this fails it is then carried to the community level. However, in line with the ubuntu way of life the focus of the paper is on how conflicts or problems are resolved at the group or community level to reach communal consensus or social cohesion.

In order to ensure maximum participation the roles played by members of each group (including the leaders) were rotary. This provided the necessary opportunity for each participant to have a personal experience of what took place in the activities instead of some dominating the others. For the same reason no group was permanent. Each section had different group formations and leaders (Ogunniyi, 2007a & b). At each stage of DAIM the research facilitator moved from group to group playing the devil’s advocate by asking thought-provoking questions as well as sorting out incipient problems (Erduran et al, 2004). He was also responsible in leading the whole group to reach consensus on the tasks and in determining the kinds of argumentation mobilized in the classroom discourses.
It is apposite to mention that in deploying DAIM we adhered strictly to the ubuntu core values of humanness-caring, cooperation, respect, sharing and commitment to achieving communal consensus (Venter, 2004) as well as Habermas’ criteria for a fair argument: (i) no person who could make a relevant contribution may be excluded; (ii) all participants have equal opportunities to make contributions; (iii) participants are truthful in what they say; and (iv) the contributions made are freed from any form of external coercion (Habermas, 1999). The instructions on the tasks to be performed (including the questions) at each stage were provided in the worksheets given to each participant.

**Reflective Diaries Questionnaire (RDQ)**

The initial draft of RDQ consisting of 12 open-ended items was given to a panel of 20 science teachers and science educators for critical comments concerning their suitability for the purpose. Based on their critical comments and suggestions it was reduced to only seven items. To establish the validity and reliability of RDQ an experienced science teacher and an experienced science educator were asked to independently rate the items of RDQ in terms of their clarity based on a five-point scale (1 = poor; 2 = fair; 3 = good; 4 = very good; 5 = excellent). Their rating yielded an inter-rater reliability of 0.97 using the Spearman Rank Difference Formula. The Cronbach alpha reliability for internal consistency coefficient (ICC) between a pair of independent science teachers (STs) stood at 95.6% while another pair of independent science educators stood at 66.7%. This indicates a very high agreement between the two science teachers compared to the science educators (SEs). Nevertheless, both ratings are higher than the normally accepted range of between 40 and 59%. The differences between the two pairs may be due to the differences in the contexts they focused upon. For instance, while the STs might be focusing on authentic classroom contexts the SEs might be focusing on vicarious classroom contexts. However, for lack of space only the participants’ responses to two of the seven open-ended questions of the RDQ are reported in this paper. For the same reason the data based on the interview and classroom observation are not included in the paper.

**Result and Discussion**

An analysis of Table 1 reveals significant differences between the narratives of the STs and SEs on themes 1, 2, 3, 5 and 9 dealing with the issue of integrating science and IK in the classroom (see Q1). However, their narratives to themes 4, 6, 7, 8, 10 and 11 are comparable.
Despite the differences in their dispositions towards the new inclusive science-IK curriculum both groups agreed that the ubuntu-driven DAIM which stressed collaborative consensus:

- Enhanced their awareness of the feasibility of the new inclusive curriculum in a classroom situation.

- Facilitated their awareness about the educational and cultural value of argumentation instruction in resolving conflicts and in reaching collective consensus.

- Showed them that despite the differences between the scientific and indigenous ways of knowing and doing things they do share some commonalities in the methods used for resolving conflicts, solving problem or doing things generally.

- Increased their awareness that IK would not water down their knowledge of school science but rather enrich their instructional practices as well as make what they teach relevant students’ life worlds.

These findings differ considerably from the earlier findings in the area (e.g. Hewson & Ogunniyi, 2008; Ogunniyi, 2004, 2007a & b, 20011a & b; 2013a, b & c; Ogunniyi & Hewson, 2008).
Table 1b: Themes on which the science teachers and science educators agreed or disagreed

Themes with significant differences   Themes that are comparable for both groups

1  I was ignorant about IK before joining SIKSP  4  I thought implementing IK in a class context was not feasible
2  I regarded IK as witchcraft or superstition.  6  DAIM has increased my awareness of the education and cultural value of IK
3  Had knowledge of IK before joining SIKSP, but was not seen to be relevant to school science  7  DAIM has increased my awareness of the value of argumentation instruction
5  Science alone shaped my worldview before participating in SIKSP  8  I am now an enthusiast of implementing a science-IK curriculum.
9  Assessment and inadequate training hindered teachers from implementing the new science-IK curriculum  10  Before joining SIKSP I thought that IK would water down school science.

11  SIKSP has shown me that integrating science with IK will not water down school science, but rather enrich my ability to make school science culturally relevant to the students’ life.

In question 2a the participants were asked to state in what specific ways DAIM and related activities (e.g. seminars, lectures and hands-on workshops) influenced their views about IK and the science-IK curriculum. Items 3 and 7 show significant differences between the STs and SEs (p = 0.038 and 0.032 respectively) relative to the following themes:

3:  My exposure specifically to lectures and seminars on NOS, NOIKS and DAIM helped me to be able to integrate science and IK in the classroom context.
7:  DAIM helped me to change the way I look at everything around me; it makes me to be more critical and not just take things for granted.

Table 2: Specific ways in which DAIM influenced the participants’ views about the Science-IK curriculum

<table>
<thead>
<tr>
<th>Themes</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>M_rank_ST</td>
<td>5.25</td>
<td>5.25</td>
<td>6.25</td>
<td>6.13</td>
<td>5.63</td>
<td>5.75</td>
<td>6.25</td>
<td>5.75</td>
<td>6.00</td>
</tr>
<tr>
<td>M_rank_SE</td>
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<td>3.75</td>
<td>2.75</td>
<td>2.88</td>
<td>3.38</td>
<td>3.25</td>
<td>2.75</td>
<td>3.25</td>
<td>3.00</td>
</tr>
<tr>
<td>Sum_ST</td>
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<td>21.00</td>
<td>25.00</td>
<td>24.50</td>
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<td>25.00</td>
<td>23.00</td>
<td>24.00</td>
</tr>
<tr>
<td>Sum_SE</td>
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<td>15.00</td>
<td>11.00</td>
<td>11.50</td>
<td>13.50</td>
<td>13.00</td>
<td>11.00</td>
<td>13.00</td>
<td>12.00</td>
</tr>
</tbody>
</table>
The STs had a higher mean rank values for the above themes than the SEs. Although the views of STs and SEs differ significantly relative to the new curriculum, they agreed to a large extent that the DAIM enhanced their views about the educational and cultural values of the new curriculum. Likewise, both groups agreed that before their exposure to DAIM science alone dominated their worldview. However, after being exposed to DAIM they became enthusiasts of implementing the new science-IK curriculum. Similar findings have been found in studies where teachers have been exposed to classroom discourses on controversial socioscientific issues (e.g. Cajete, 1999; 2010; Garrouste, 1999; Gonzalez, Moll & Amanti, 2005; Govender, 2007; Lee & Buxton, 2010; Ogunniyi, 2007a).

Table 3: Participants’ stances regarding the new curriculum over time

<table>
<thead>
<tr>
<th>Q.2b</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<td>5.50</td>
<td>6.00</td>
<td>4.75</td>
<td>5.88</td>
</tr>
<tr>
<td>M_rank_SE</td>
<td>5.38</td>
<td>4.63</td>
<td>3.50</td>
<td>2.63</td>
<td>3.25</td>
<td>3.50</td>
<td>3.00</td>
<td>4.25</td>
<td>3.13</td>
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<td>4.000</td>
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<td>Sig.(2 tail)</td>
<td>0.304</td>
<td>0.992</td>
<td>0.215</td>
<td>0.027*</td>
<td>0.122</td>
<td>0.127</td>
<td>0.046</td>
<td>0.765</td>
<td>0.110</td>
</tr>
</tbody>
</table>

In question 2b the participants were asked to indicate if they once opposed the new inclusive science curriculum and whether or not their encounter with DAIM had changed such a view. Most STs indicated that for various reasons e.g. poor preparation of the teachers by the curriculum developers, lack of instructional materials, the top-down approach used by the curriculum planners, etc. they were opposed to the new curriculum. Although several SEs indicated that they were not opposed to the new science curriculum they agreed with the STs that the curriculum was poorly implemented. They indicated as in earlier studies (Ogunniyi, 2004, 2007a & b, 2011a &b; Ogunniyi & Hewson, 2008) that they were not adequately consulted by the curriculum planners and so did not have adequate time to prepare the teachers for the new curriculum. Themes 4 and 7 below show significant differences between the STs and SEs relative to the impact of DAIM on their changing perceptions of the new curriculum:
I have changed my view of the new curriculum because of my experience in the SIKSP/DAIM.

I was not favourably disposed to the new curriculum because IK in the LO.3 is not assessed in the examinations. Although themes 4 and 7 in Table 3 show significant differences between the way the STs and the SEs perceived the new curriculum as a result of being exposed to DAIM (p = 0.027 and 0.046 respectively) there are themes on which they expressed comparable views. Also, while Tables 1-3 show the themes on which the STs and SEs differ or expressed similar views they do not show the nature of the actual perceptual changes. In terms of TAP their level of arguments ranged between level 1 i.e. non-oppositional arguments or arguments with simple claims versus counter-claims at the initial stages and level 4 i.e. arguments with claims supported with grounds and at least one strong rebuttal.

An examination of Tables 1-3 above suggests that while the STs and SEs do not agree on all items their differences might not be unrelated to the nature or focus of their instructional practices. For instance, while the teachers at the coalface may be concerned about actual classroom context the SEs are probably more concerned with the vicarious experiences that the teachers may encounter in the course of their practice. Whatever the case the considerable impact of DAIM on both groups cannot be ignored considering their responses on themes 4, 6, 7, 8, 10 and 11 (Table 1b). The issue here is not just their enhanced awareness about the value of a science-IK curriculum but DAIM that facilitated that awareness.

Using CAT as a unit of analysis it is easy to track the nature or direction of conceptual shifts among the participants as a result of their encounter with an ubuntu-driven DAIM. The shaded letters reflect the pattern of perceptual shifts among a few selected participants using CAT categories as the units of analysis: DSw- a dominant scientific worldview; SIKw- a suppressed IK worldview; DIKw- a dominant IK worldview; SSw-, a suppressed scientific worldview; Asw- an assimilated worldview; Ew- an emergent worldview; and EQw- an equipollent worldview.

Idowu: A male high school physical science teacher with 20 years’ experience in the Chemical Engineering industry and with 12 years of teaching experience said, “When I started, I felt that IKS and science where two different knowledges (DSw/SIKw) and that it was almost impossible to combine the two (DSw)… After attending the workshops and seminars, I came to understand (Ew) that …many people are still using it [IKS] nowadays EQw)… and hence is just knowledge which is authentic to a particular people’s experiences and by no means inferior to present day technologies…”(EQw)

Lola: A 49 year-old female grade 3 teacher with 30 years of teaching experience said:

“Before the workshops I thought that Western Science is dominant (DSw) over IKS… (SIKw). In my view IKS was all about witchcraft…(SIKw). After attending the workshops I realized that IKS is not something new to me, perhaps the terminology…(Ew) These workshops are so valuable to me because it made me realize once again how precious IKS is (Ew).
Estralita: A 45 year-old female science educator with 25 years of teaching experience said, “Being involved with SIKSP (DAIM) has been an inspirational journey (Ew). The fact that the group is heterogeneous (students and lectures with different perspectives and knowledge about teaching IKS) has provided a very rich environment for sharing knowledge and feelings about IKS (Ew).

Diamond: A 47 year-old male science/math educator with 22 years teaching experience said: “Before being part of the IKS group I was a bit skeptical about the role which IKS can play in our everyday life...(DSw). Having attended the workshops and seminars I have grown to understand (Ew) that knowledge from both IKS and modern science are all the same (EQw)...(and) can actually co-exist (EQw).

Rob: A 45 year-old life science teacher with over 20 years of teaching experience said, “As we’re arguing we’re getting more sense.” (Ew)

Similar perceptual shifts to the ones above occurred among the other participants most probably as a result of their exposure to DAIM. Table 4 below is an example of the types of CAT categories mobilized by the participants in the process of changing from one worldview to another. The most noticeable CAT categories mobilized by the STs relative to the scientific worldview, in a descending order, are: dominant; equipollent; emergent; and assimilated. In terms of IK the categories in the same order are: emergent; suppressed; equipollent; and dominant.

Table 4: CAT categories mobilized by the participants in response to question 2a

<table>
<thead>
<tr>
<th>CAT cognitive categories</th>
<th>ST</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science IK Science IK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant- a dominant worldview</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Suppressed- a worldview dominated by a dominant worldview</td>
<td>-</td>
<td>16</td>
</tr>
<tr>
<td>Assimilated- a worldview that capitulates to, or is subsumed by a dominant worldview</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Emergent- emergent-a worldview that arises from a new experience or insight.</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Equipollent- the equipollent- two or more co-existing but distinctly different worldviews exerting comparable cognitive force on a person’s worldview.</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

ST =Science teachers (n =12); SE =Science educators (n =11)

The data presented in Tables 1-4 suggest that DAIM has been effective in enhancing the participants’ awareness of the educational and cultural value of the new curriculum as well as their self-image and social identity. For example Idowu claimed that IK is as authentic
and a valid way of knowing as science. Lola asserted that DAIM workshops are so valuable to her because they made her to become aware of the value of IK. Diamond claimed that the DAIM-based workshops and seminars made him realize that science and IK can co-exist. The participants’ perceptive shifts from a predominantly scientific worldview to an emergent or equipollent worldview have certainly buttressed their awareness of IK and consequently their self-image.

**Conclusion**

The findings show that DAIM was effective for: (1) engendering the participants’ sense of collectiveness and responsibility in finding ways to resolve conflicts or solve a problem; (2) facilitating their awareness about the potential argumentation instruction in classroom discourse; (3) enhancing their understanding of the nature of science (NOS) and IK (NOIKS); (4) fostering their positive views about the new indigenized curriculum; (5) facilitating their emergent understanding about NOS and NOIKS; and (6) for increasing their awareness of IK as a legitimate way of knowing and interpreting experience as science (Kean, 2008; Ogunniyi & Hewson, 2008). This finding certainly holds promise for studies concerned with resolving conflicting views that tend to emerge between the students’ home-based knowledge and what is presented to them in a science lesson.

It is apposite to state that the ubuntu core values (e.g. humanness, togetherness, relatedness, cooperative learning, respect for the views of others (while not ignoring the individual) emphasized by DAIM have been amply demonstrated in the study. These cultural values are important in science teaching not only in South Africa but other countries facing the challenges of multicultural classrooms.


Investigating the impact of Dialogical Argumentation Instructional Model on Grade 3 learners’ conceptions of the causes and effect of water pollution

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Abstract

This study investigated the cognitive shifts of learners’ conceptual knowledge of the causes and effects of water pollution after being exposed to a Dialogical Argumentation Based Instructional Model. The Contiguity Argumentation Theory and Toulmin’s Argumentation Pattern were used as a framework to capture and interrogate learners’ arguments with argumentation frames developed to categorize the learners’ argument responses. Analytical approaches were used to assess learners’ argumentation skills along four stages namely intra-argumentation, inter-argumentation, whole class discussion and trans-argumentation. The study employed both quantitative and qualitative methods. Data were collected from grade 3 learners in a primary school in Cape Town, Western Cape Province in the form of a pre-post questionnaire, focus group interviews and classroom observation. The major findings of this study indicated that even though Dialogical Argumentation Instructional intervention model has its challenges; it can assist learners to develop acceptable argumentative skills. The findings also revealed that with more argumentation activities their views gradually got changed to the extent that they began to support their claims with valid evidence. They challenged each other’s arguments as well as required them to give valid reasons for their claims. The findings also revealed that the learners had prior knowledge on the causes and effect of water pollution. The only difference between the two groups was that, the experimental group (E group) was exposed to a Dialogical Argumentation Teaching Model (DAIM) and the comparison group (C group) to a traditional teaching approach.

Keywords: Dialogical Argumentation, Environmental education, water pollution, Indigenous Knowledge Systems, Contiguity Argumentation Theory, Toulmin’s Argumentation Pattern, conceptions, foundation phase learners

Introduction

The common purpose of science education and environmental education is to educate learners to be responsible citizens (Volk, 1984). Environmental awareness has been built into the new South African curriculum for all grades to promote environmental environmental consciousness and sustainability issues (Revised National Curriculum Statement, 2002). Schools play an important role in the development of children’s positive attitudes towards the environment, therefore it is essential that they need to be exposed to environmental literacy from a young age, in order to help them develop an appropriate understanding and perception about preserving the environment (Chu et al. 2007).
Environmental education should not only be limited to formal education, but should sustain a lifelong activity. To address environmental concerns and problems learners can apply their scientific knowledge and skills and become increasingly aware of these problems which will enable them to analyze these and find possible solutions (Arms, 1994).

As a result of the apartheid legacy, not enough emphasis is being put on environmental education in schools situated in the poverty stricken communities in South Africa. Factors believed to be contributing to this problem is unemployment resulting in poverty, overcrowded classrooms, overloading of the curriculum, poor assessment, enormous administration duties of teachers, lack of resources, environmental illiteracy, as well as the fact that many educators were not fully equipped to teach the curriculum effectively.

The study sought to find out the impact that a dialogical argumentation instructional model had on grade three learners' understanding of how water pollution affect human welfare. It is expected that the findings of this study will contribute to studies focussing on the enhancement of grade three learners' understanding of and awareness about causes of river pollution. It also seeks to determine the alternative conceptions that the learners hold on water pollution. To motivate teachers to use various teaching strategies, such as argumentation and inquiry-based approaches to increase learners' understanding and awareness of the causes of river pollution in the area.

Contiguity Argumentation Theory (CAT) (1997) and Toulmin’s Argumentation Pattern (1958) provided a framework to view the impact that DAIM has on the understanding about river pollution. Transformational theory conceptualizes and defines learning as a process of critical reflection and interpretation of a person’s experiences in order to guide future action. These theories assisted me to interpret the cognitive changes learners have made after they have been exposed to DAIM.

**Background**

According to Schreuder (1995) the majority of the environmental problems in South Africa are related to the educational crisis caused by the previous apartheid policies of the South African government. With the adoption of South Africa’s final constitution, human rights and social responsibilities have been linked to environmental issues. The 1995 White Paper on Education saw the need for environmental education processes that involved an active approach to learning. (Department of Education 2001b:3-7).

The new South African science curriculum statement has called on science teachers to integrate school science with Indigenous Knowledge Systems (IKS). The call for the integration of science in IKS can be ascribe to systems that reflect the wisdom and values that Southern Africans have acquired over centuries. In response to the call to integrate science and IK this study focused on how DAIM could enhance grade three learners' understanding of water and water pollution as well as how science and IK could be integrated to accomplish this objective.
The quality of a stream or river is often a good indication of the way of life within a community through which it flows. It is an indicator of the socio-economic conditions and environmental awareness and attitude of its users. Although the Department of Water and Forestry claims that South Africa’s drinking water is safe, it has pointed out that lack of capacity and slack maintenance have caused health risks and pollution in some ways. Water quality of rivers and streams may differ depending on the geology, morphology, vegetation and land use in the catchments area. Industries, agriculture and urban settlements produce nutrients and toxic substances such as organic and inorganic pollutants and other chemicals including heavy metals.

1.3 Motivation for the study

Most of my teaching years have been spent in the Foundation Phase. Several studies done on argumentation had been with High school learners (e.g. Eskin, 2008; Kelly et al. 1998; Maloney & Simon, 2006) of which, only a few of these studies had been done in South Africa. I was therefore inspired when I came across studies done among primary school learners (e.g. Keogh, Naylor & Downing, 2003; Samarapungavan et al. 2007). The findings of these studies convinced me that even young children from the age 4-9 are capable of arguing in a scientific context. Argumentation instruction has been found to enhance learners’ understanding of various concepts in science and to overcome their misconceptions in science.

Purpose of the study

The aim of the study was to determine the effect of a dialogical argumentation instructional model on grade three learners’ understanding of how water and water pollution affect human welfare. More specifically the study attempted to determine:

(1) The effectiveness of a Dialogical Argumentation Instructional Model (DAIM) in enhancing grade three learners understanding of, and awareness about some of the causes of water pollution.

(2) The effectiveness of DAIM in enhancing grade three learners’ understanding of the scientific and Indigenous methods of keeping water safe for human consumption.

Research question

In pursuance of the aims of the study, answers were sought to the following questions

1. What conceptions of the causes and effects of water pollution do grade three learners hold?

2. How effective is an argumentation-based instruction in enhancing the learners’ understanding of water pollution?

Literature review

Argumentation

Arguments play a vital role in scientific discourses. Arguments are not limited to science. It is frequently used among indigenous communities to relate one experience with another. Arguments are presented in various versions in the oral histories and myths of indigenous
people. It normally follows whenever people try to convince one another about the topic in question (Ogunniyi, 2008).

Arguments are normally not being encouraged in the South African classrooms as well as in the textbooks. This can be due to the instructional strategies used by teachers. Teaching science in an argumentation approach has been suggested in studies done by Ogunniyi (2004, 2006, and 2007), Ogunniyi and Hewson (2008) and Osborne et al (2004). Various studies have reported the value that dialogical argumentation have as a leading instructional approach to develop teachers’ and learners’ scientific knowledge in science education as it increases their awareness about scientific inquiry (Ogunniyi, 2004). Irrespective of the knowledge we possess, arguing with people might create an opportunity for one to learn. But whatever relative.

The manner in which children learn on how to engage in a debate and use evidence in science is important for future decision making, especially in the context of socio-scientific issues (Maloney and Simon, 2006: 1817). Learners love socio-scientific topics and when such topics are introduced into the classroom debates cannot be prevented. If learners are exposed to argumentation, they will be able to reason scientifically. Khun (1991) agrees that argumentation is obtained through on-going hands on activities which are appropriate. It seems that arguments and debates tend to deepen their scientific knowledge on the topic in question.

**Water pollution**

Children are seen as an essential linkage for environmental communication in society and going "green" is a synopsis of becoming more aware of environmental problems that challenge the human race (Mohapatra and Bhadauria, 2009). Environmental Education is a vital element of a child's education in order for him or her to develop sufficient environmental awareness and to adopt a positive attitude. Although many studies have been done to reconstruct alternative conceptions held by learners of water pollution, not many have targeted the primary school level.

Starvidou and Marinopoulos (2001) found that that the learners between the ages of 11 and 12 years old, knew very little about the causes and sources of water and air pollution and its harmful effects on humans in a questionnaire. As pointed out by Stavridou and Marinopoulos (2001) the majority of the learners involved in their study regarded the phenomenon of water pollution as a local event without seeing the global picture.

A study done by Mohapatra and Bhandauria’s (2009) reported on grade 10 learners’ alternative conceptions of water pollution. Their findings indicated that learners do not see the relationship between sewage, pesticides and soil erosions and water pollution. Yurttas and Sulun (2010) study aimed at determining the nature of the conceptions that grade eight learners held about the most common environmental problems in Turkey and the rest of the world. Their results reflected that air pollution was seen as the most serious problem followed by water pollution.
Generally, children who enter school do not have any formal instruction on scientific topics. The concepts and perceptions that they hold about the natural world is mainly based on their experiences and observations. It is very important for teachers to be aware of the learners' prior knowledge of science concepts, as it can inform the teachers to plan their instructions as well as the teaching materials (American Association for the Advancement of Science [AAAS], 1990).

Shodh, Samiksha, aur Mulyanka (2009) have done a study amongst grade six and seven Indian learners on environmental pollution. Their findings reported that the learners in the study have a sound understanding of air pollution. Only 93% learners partially knew about water pollution. Most of the grade seven learners partially understood that diseases are caused by polluted water. The majority of the learners have some understanding on how to control water and soil pollution. Yet, some of them held the misconception that solid waste should be dumped underground to prevent the upper soil from being polluted. This means that they were not aware that the underground pollutants could still contaminate underground water.

**Theoretical framework**

This study is underpinned by Toulmin’s (1958) Argumentation pattern (TAP) and Ogunniyi’s (1997) Contiguity Argumentation Theory (CAT). TAP is concerned with scientific arguments based on the inductive-deductive method of argument while CAT is based on the cognitive shifts that tend to occur when a person holding an indigenous knowledge or belief encounters science and makes sense of the two systems of thought.

The two frameworks seem to provide an overview of how science educators can use and assess the nature and quality of scientific argument in particular; and emphasize the linkage between each framework (Sampson & Clark 2008).

**Toulmin’s Argumentation Pattern (PAT)**

Numerous studies have shown the significance of dialogic argumentation as a valuable instrument for teachers’ and learners’ conceptual understanding as well as making them aware of the tentative and material-discursive nature of science construction (Ogunniyi & Hewson, 2008). Toulmin’s (1958) Argumentation Pattern (TAP) has been used by several researchers to improve educators’ and learners’ understanding of the Nature of Science (e.g. Kelly & Bazerman, 2003; Kelly & Takao, 2002; Osborne et al, 2004; Erduran et al, 2004; Jimenez-Aleixandre et al, 2000).  

**TAP consists of such elements as:**

1. **Claim**—The statement that is asserted or declared as the truth of a subject matter e.g. the liquid in the glass is water. However, we would not be certain of how truthful this statement is until we have carried a scientific test. In other words, we need more data. show the learners how to argue effectively. The tasks given were to assess the quality of argumentation of the learners before, during and after the instructional intervention model.
For each task the learners’ were to come up with evidence to support their claims and also to come up with evidence to rebut or counter other learners’ claims. To facilitate and scaffold learner argumentation open ended questions were used to elicit justification of a claim. The quantitative data were collected through the use of pre and post tests in order to get their initial and later views on the causes and effect of water pollution. This was done in order to determine the possible impact of use of dialogical argumentation and indigenous knowledge.

Focus group interviews and discussions were conducted with the learners. This was done to look for further clarification of ideas the learners would have raised in their earlier responses.

Sample
The sample consisted of 38 grade three learners from a primary school in Cape Town. The learners who participated in the study were diverse in nature. The medium of instruction at the school is both English and Afrikaans. Only the two English grade three classes were chosen to participate in the study. The learners that participated in the study were heterogeneous. The ages of the learners varied from 7-9 years old. I used the DAIM for the experimental group and the other grade three teacher (Control group) used the normal OBE structured teaching. This study used both quantitative and qualitative approach. Using both methods gave me the opportunity to assemble a thorough holistic data set at the research being done.

The research
This study is based on a quasi-experimental research design. Two groups of learners were involved in the study. The two groups involved are intact rather than randomized groups. One class in the school served as the true experimental group (E), and another class served as the true control group (C). The control (C) teacher however used Outcomes Based Education (OBE) instruction approach whereas the experimental (E) teacher used Ogunniy’s (2008) Dialogical Argumentation Method based on Toulmin’s (1958) Argumentation Pattern (TAP). Learners in the E group were exposed to the same instructional model for ten weeks. The E group had 20 learners and C group 18 learners. The experimental group (E) will undergo a pre-test and a post test. The control (C) group will experience the pre-test, normal OBE structured teaching and a post test. The groups were all similar with respect to their chronological age, gender and achievement. The research design adopted for this study is as follows:

O1 X O2 (E)
O3 O4 (C)

Figure 1: Quasi-experimental control group design
Instruments
Three different instruments were used to collect data. An Argumentation-Based Questionnaire (ABQ) followed by an interview and a structured classroom observation involving field notes were the major data sources. These instruments were used to assess the participants' ability in engaging in dialogical argumentation and to provide evidence in resolving their arguments.

The Water Pollution Questionnaire went through a validation process to attain a high level of reliability. Validity checks involved average pair-wise ratings of items from 1-5 (1 being strongly disagree and 5, strongly agree). All items ranked under 3 were eliminated to ensure that the discrepancies were not visible in the WPQ. Using the Spearman Rank Difference Correlation Formula, the final version obtained 0.98 using Kuder-Richardson 21 formula.

A focus group interview were then carried out with eight learners (four boys and four girls) from the main study to triangulate the data from the questionnaire as well as to get a deeper understanding of learners' concepts of water pollution. The interviews were conducted at the beginning of the study and at the end of the study to determine whether or not learners held alternative ideas after the study.

The classroom observations were done during the lesson while learners were in discussions. A series of activities were developed which the learners first had to do individually followed by group discussions to reach a common agreement. The group discussions were tape-recorded and video-recorded and transcribed. Analysis of the transcripts used well established frameworks from Toulmin (1958), which were adapted by Eduran, Simon & Osborne (2004).

Teaching Strategies
The activities done during the studies were based on a pedagogical schema of earlier work done by (Erduran, Simon & Osborne, 2004; Ogunniyi, 2007 a and b) that developed from a sequence of workshops that has been piloted. The first phase of the pedagogical schema is based on an individual task which required learners to come to grips with the given problem in making claims and providing grounds for it. The second phase results in dialogical argumentation in small groups, where individual members share their science/IKS phenomena by making claims and providing grounds. During the third phase learners presented their group's results to the rest of the class indicating their claims, counterclaims, grounds and even a rebuttal if any. The fourth phase gives the rest of the class the opportunity to question the group who is presenting, and to add more ideas which the group presenters might have overlooked. The fifth stage is a focus group interview where questions are raised to determine their conceptual understanding of both science and IKS. This model allowed learners to actively participate in the activities, and not to be scared when making mistakes.

Results and discussion
The data obtained in this study were analyzed both quantitatively and qualitatively. The quantitative data derived from the Water Pollution Questionnaire (WPQ) was used to determine the nature of the impact of the Dialogical Argumentation Instructional Model on
the experimental (E) and the Control (C) group using mean scores, standard deviation and t-test. The means scores are indicative of the nature of the improvement brought about by DAIM. The performance of the E group was compared with the C group on the WPQ. The qualitative aspects paid close attention to the units of analysis in terms of Toulmin's (1958) Argumentation Pattern (TAP) for example, claims, grounds and rebuttals) and the Contiguity Argumentation Theory (CAT) framework (Ogunniyi, 1997, 2007 a&b) for example dominant, suppressed, assimilated, emergent and equipollent categories. These categories served as the units of analysis for interpreting the findings.

**Pre-test Post test**

Table 1 describes the average performance of the two groups in the sample on the WPQ pre-test. The pre-test percentage mean scores of the E group was 40.90 % and the C group was 41.33 %. The standard deviations for both groups were also similar at the pre-test stage. A t-test was employed to test whether or not the difference in the mean scores of the two groups was statistically significant. The calculated t value of the entire pre-test (t=0.0179; p< 0.05) with 36 degrees of freedom) implies that the difference is not statistically significant. Therefore it can be concluded that the two groups of learners were very much comparable at the pre-test stage. At the pre-test stage the distribution of errors for both groups were similar as well. At the post-test, the average performance of the two groups on the Water Pollution Questionnaire (WPQ) had changed considerably. A mean of 71.75 % was obtained by the E group compared to 50.1% by the C group. The E group showed a greater improvement in their understanding of the concepts of water pollution than was the case for the C group learners. A t-test was employed to find out whether or not the difference between the mean scores of the two groups was statistically significant.

A highly significant difference between the pre-and post-test percentage mean scores of E (t=18.643; p<0.05) versus that of the C group (t=18.64; p>0.05). When the post-test mean scores of the two groups were compared the E group achieved much better results than the C group (t=8.49; p<0.05). It is obvious that those learners exposed to DAIM has benefitted from the intervention, compared to those who were exposed to the traditional instruction. The null hypothesis can be rejected which expected to show no significance difference between the pre-post test mean scores in both groups on the hand and the post-test of E and C group. For this difference to have occurred by chance was only 5% (Ogunniyi, 1992).

**Table 1: Performance of the experimental and the control group on the WPQ**

<table>
<thead>
<tr>
<th>Experimental Group</th>
<th>Control Group</th>
<th>E group versus C group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>Post test</td>
<td>Pre-test</td>
</tr>
<tr>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>40.9</td>
<td>4.73</td>
<td>71.75</td>
</tr>
<tr>
<td>t-value=18.643</td>
<td></td>
<td>t-value=8.4938</td>
</tr>
<tr>
<td>t-value=9.888</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Learners’ conception on water pollution

The transcript below indicates how the first group constructed different views on water pollution and reached a common agreement in the end. They made well grounded arguments through dialogical argumentation by reasoning with each other and by providing evidence to support their claims. They reflected on their own thoughts and that of others which resulted in a much clearer understanding on the causes and effects of water pollution.

Table 2: Group 1 learners co-constructing an argument on container A

<table>
<thead>
<tr>
<th>Learner</th>
<th>Claim</th>
<th>Grounds</th>
<th>Counter Claim</th>
<th>Grounds</th>
<th>Rebuttal</th>
<th>(AL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>Container A is clean water...</td>
<td>There is no dirt in it.</td>
<td></td>
<td></td>
<td></td>
<td>L3</td>
</tr>
<tr>
<td>L3</td>
<td>L1 said water but ... I th..think it can perhaps be rainwater or tap water</td>
<td>It has no smell. It is a liquid. It takes up the shape of the container</td>
<td></td>
<td></td>
<td></td>
<td>L3</td>
</tr>
<tr>
<td>L5</td>
<td>I also agree it is tap or rain water. The water is crystal clear and transparent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>L4</td>
</tr>
<tr>
<td>L3</td>
<td>It can also be cooldrink.</td>
<td>It smells like lemonade. It is also transparent</td>
<td></td>
<td></td>
<td></td>
<td>L5</td>
</tr>
</tbody>
</table>

Table two is the co-constructing arguments of Group one learners. Their arguments appeared to be well focused and they used evidence to justify their claims or counter claims. L3’s counterclaim that there was cool drink in the bottle and not water, because of its smell. This was followed by a direct rebuttal where L6 agreed with L3 that lemonade is transparent but disagreed with him due to the fact that the container smells like lemonade and therefore it is not lemonade in the container, but water. Also, the lemonade has a gas in it, and not water.
In the following transcript the third group engaged in an experiment on how to clean polluted water for drinking. After reading a short story in a dialogical form the learners completed the worksheet individually and thereafter had to reach consensus in the group. The content of Table 3 below was extracted from their dialogical argumentation session.

<table>
<thead>
<tr>
<th>Learner</th>
<th>Claim</th>
<th>Grounds</th>
<th>Counter claim</th>
<th>Grounds</th>
<th>Rebuttal (AL)</th>
</tr>
</thead>
</table>

In the table above L3 claims that a teaspoon of Jik needs to be added to the boiling water to kill the germs. Hence, the possibility of the indigenous and scientific influence the learners displayed equipollent world views. In the same vein, it can also be regarded as the emergent in that it was most probably learnt at school, thought the same view was probably inherent within the IK worldview that in this particular instance has been suppressed.

The analysis of the transcripts indicates that grade 3 learners are able to construct arguments through collaborative interactions which are also stated by Keogh, Downing and Naylor (2003). The substantial improvement of the E group learners can be directly accredited to the quality of the new learning environment of dialogical argumentation through the small group collaborative learning; co-constructing arguments based on the phenomena under study; intra- and inter-group discussion leading to coherent arguments; development of leadership qualities as learners take up leadership roles; opportunities to reach consensus and harmonization of ideas during whole class discussion. The children were task orientated and listened attentively to the claims made by their fellow learners before responding. This resulted in the learners’ co-constructing arguments of a high quality.

In this study, DAIM gave learners the opportunity to inquire as scientists and independent learners (Hall and Sampson, 2009). Learners were able to interpret the data they got from an investigation. Through collaboration, they reached a common agreement on the different topics presented in this study. Not only did it develop their scientific knowledge, but it also improved their communication skills (Duschl and Osborne, 2002).

**Integrating IKS with science concepts**

The excerpt below shows a clear example of the cognitive shifts learners made between the scientific and IK world views. The discussion shifted from science to indigenous beliefs and practices. In some instances their scientific views were dominant while in others IK was dominant. However, in some cases the scientific or IK worldview seems to emerge. The concept of ancestors is emergent to L1 and L4. For L2 the role of women rather than men to collect the water is emergent within the CAT categories. The cognitive shift between the scientific and IK beliefs is referred to an amalgamated worldview (Ogunniyi and Ogawa, 2008).

**Integrating IKS with science concepts above.**

The following excerpt represents the responses of learners to the question: ‘Why were rivers not so polluted in the past?’
L3: I used to live with my grandma in the Eastern Cape before coming to live in Cape Town with my father. She lived in a rural area. Early the morning my grandma and I had to go fetch water by the river. The river is very far. It is the woman’s duty to go fetch water where I use to live.

L2: Why can’t the men fetch the water?
L4: It is not their duty to do it. That is how we do things in the rural areas.
L3: What is a rural area?
L4: It’s like living on a farm. The schools, houses and rivers are very far from you. When we go fetch water then I must not run in the river, because my grandmother says the ancestors will get angry because I will disturb the animals in the water and also pollute it.
L4: Who are the ancestors?
L3: It is our forefathers. Your grandfather’s father’s and so on…

L1: Oh, now I know. The ancestors are like the gods of Ghana. They want people to look after the water and not waste it. They must also look after the environment.
L4: My grandmother says that the ancestors respect water because it is powerful and we must listen when the ancestors speak to us or something bad will happen.
L1: That is why there must be no houses near the rivers so that people can’t pollute the river which will cause people to get sick.
L2: My dad told me that in the olden days they travelled with a horse and cart to places. This did not pollute the air and acid rain did not lower the oxygen level of the water causing animals in the rivers to die.

Integrating science with IKS was justified in the excerpt above. Both IK and scientific world views of the learners were dominant. There were also valid grounds in putting together the two distinct worldviews through dialogue so long as it was not compromised by the integrity of either science or IKS (Ogunniyi, 2007). Learners understood why the rivers were not polluted in the past compare to today. The fact that some cultures feared the gods, caused the people to live in harmony with the environment. Therefore the people were only allowed to go down to the river to collect water. Under no circumstances were they allowed to live or play near the river.

It is very important for teachers to be sensitive to the learners' beliefs so that they do not offend the learners’ sensibilities. Teachers must make learners aware not to ridicule the beliefs of their classmates. It became obvious to me that argumentation is a powerful tool for knowledge building and for changing the views of people. The above excerpt is an illustration of the potential of arguments in knowledge building and shifts of worldviews (Ogunniyi, 2007 a & b).

**Conclusion**
Current classroom practices give little opportunity for young people to develop their ability to construct arguments. Not only do learners need to develop an awareness of the nature and structure of arguments, but their performance is additionally enhanced if they are able to monitor their involvement in group activities. The major barrier to developing young
people’s skills of argument in science is the lack of opportunity offered for such activities within current pedagogical practices. If students are to be given greater opportunities to develop these skills, then this will require a radical change in the way science lessons are structured and conducted.

Opportunities must be created for learners to engage in these matters, otherwise learners will continue to compartmentalize their knowledge. Therefore, it is of utmost importance for science educators to develop effective teaching strategies to enhance learners’ conceptual understanding for successful learning to take place. If this is to change, then it seems fundamental that any intervention should focus not only on ways of enhancing the argument skills of young learners, but also to improving teachers’ knowledge, awareness, and competence in managing learner participation in discussion and argument.

Dialogical Argumentation Instructional Model enables teachers and learners to co-construct arguments in understanding the content knowledge on socio-scientific issues. This study has proven that foundation phase (Grade R-3) learners are capable of participating in dialogical argumentation. Engaging learners in reflective thinking on socio-scientific issues, teachers can challenge learners’ moral and ethical beliefs through explicit instruction on NOS and Indigenous knowledge and in what respects the two knowledge corpuses are compatible or otherwise. Sadler and Donnelly (2006) claim that upholding scientific literacy where social scientific issues is vital, strategies for enhancing students' reasoning and argumentation skills in SSI in collaboration with IKS must be agreed upon. Further studies needs to be done before any generalization can be made in this regard.

do not offend the learners' sensibilities. Teachers must make learners aware not to ridicule the beliefs of their classmates. It became obvious to me that argumentation is a powerful tool for knowledge building and for changing the views of people. The above excerpt is an illustration of the potential of arguments in knowledge building and shifts of worldviews (Ogunniyi, 2007 a & b).

Reference


Ogunniyi, M. B. (2006a). Using a practical arguments-discursive science education course to enhance teachers’ ability to implement a science-indigenous knowledge


Yurttas, G.D., Sulun, Y. (2010) What are the most important environmental problems according to the second grade primary school students?
Students’ perceptions of the Physics Laboratory Classroom Environment at the University of Johannesburg

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Abstract

This research describes the students’ perceptions of the Physics laboratory learning environment at the University of Johannesburg. In achieving this, a 35 item questionnaire in 5 dimensional scales called the Science Laboratory Environment Inventory (SLEI) has been used for this purpose. The research focussed on 5 dimensional scales: Student Cohesiveness, Open-Endedness, Integration, Rule Clarity and Material Environment. The SLEI instrument consisted of 2 questionnaires. One elicited students’ perceptions of the learning environment they experienced while the other elicited views on their preferred environment. Learners were requested to respond to the questionnaire to indicate their preference to each of the items on both forms of the questionnaire, on a 5 point Likert-scale type of evaluation from Always Never to Very Often. Results were evaluated statistically by finding the means, variances and standard deviations. A cohort of 100 learners participated in this survey. Results reveal that the preferred option of the questionnaire was found to be more favourable than the actual perceptions in 5 scales of SLEI assessment. The learners’ perception of the laboratory environment was found to be less favourable in respect of Student Cohesiveness, Integration and Open-endedness but more favourable in respect of Materials and Equipment and Rule Clarity on the SLEI dimensional scale of description. These findings give us more insight into dynamics of the laboratory learning environment in the eyes of the learner.

Key words: Student Cohesiveness, Integration, Rule Clarity, Open-Endedness and Materials and Environment

Introduction

Laboratory activities have played a distinctive and crucial role in the science curriculum (Hofstein et al., 2001; Hofstein & Lunetta, 1982; Lunetta, 1998) and it goes without saying that many benefits accrue from such activities. In particular, the laboratory learning environment has been extensively studied over the past 30 years, with the purposes of determining the relationship between teaching strategies employed and psychosocial interactions during the process of laboratory instruction (Hofstein et al., 2001, Reiss et al, 2012 & Dillon, 2010). In order to measure effectiveness of the learning environment, cognisance must be made of instructional strategies used to achieve the desired result. Educational practitioners have suggested that information gathered from students’ perception pertaining to the laboratory is vital for curriculum developers and those involved in the technical set-up of the laboratory. The impact of this is an enhancement in teaching and learning and a positive feedback from learners.

A typical science laboratory can be described as one where students interact physically and intellectually with the instructional material through hands-on experience following a prescribed experimental procedure (Hofstein et al., 2001). Some critics (Fraser et al., 1993;
Giddings and Hofstein, 1980; Hofstein and Lunetta, 1982; Lunetta et al., 1981) have argued the justification of the high cost of resourcing such elaborate laboratories in terms of equipment, materials and staffing instead of an alternative cost effective way of pursuing teaching in a non-laboratory setting. Unfortunately, such assertions have to be verified through a comprehensive research undertaking with the premise that it has no impact on teaching and learning. In this respect, Fraser et al. (1993) has developed an instrument in the form of 2 questionnaires to assess students’ perceptions of the laboratory learning environment. He called the instrument, the Science Laboratory Environment Inventory (SLEI). The SLEI consists of 2 forms, one to elicit students’ perceptions about the actual laboratory and the second to elicit the preferred (expected) laboratory choices of practice. To validate the reliability of the instrument, Fraser et al. (1993) did a comparative study on the students’ perspective of the laboratory environment in 6 selected countries; namely, UK, Nigeria, Australia, Israel, Canada and the USA. The results showed variations in the students’ perspective of the laboratory environment, particularly in 3 subject areas of the study; namely, biology, chemistry and physics. This means that the SLEI instrument was sensitive to the subject being offered and the nature of the environment to conduct experiments. Research conducted in Israel by Hofstein et al. (1996), for the subjects chemistry and biology, revealed significant variations on 2 aspects of the SLEI questionnaire; namely, integration and open-ness. In this respect, integration refers to how the laboratory activities are integrated with regular theory classes and open-ness refers to an open-ended or divergent approach to experimental investigation. On the other hand, research undertaken by Fisher, Harrison, Henderson and Hofstein (1999), found differences in students’ perceptions in both the actual and preferred forms for students engaged in practicals for the subjects: physics, chemistry and biology, respectively. Most students viewed their science laboratories favourably but had a low perception of the open-ness dimensional scale, as was reported by Giddings and Waldrip (1996). Clustered research in 3 area domains, such as humanities, science-oriented and science-independent streams for Korean learners revealed a high level of student cohesiveness in laboratory sessions (Lee and Fraser, 2001). They also indicated that their laboratory work was well integrated with their theory lessons in class. Further, their laboratory sessions were well coordinated with clear rules to follow. On the downside, their study also revealed that students responded less favourably to open-ness and the lack of materials to conduct the prescribed experiments. In the case of Taiwanese students, they indicated that the laboratory sessions were less integrated with the theory work in class, students displayed less cohesiveness and the laboratory rules were less informal in nature (Tsai, 2002).

The aim of this investigation was to determine students’ perception of their actual and preferred laboratory environments at the University of Johannesburg where they followed an expository style of practical investigation. This provides a useful evaluation of the institutional approach to and provisions of practical work.

The nature of the Physics Laboratory System at the University of Johannesburg

On the 7th floor of the John Orr Building of the University of Johannesburg, we have 7 laboratories that are allocated for Physics practicals. Each of these laboratories are fully
equipped and functional to offer some 350 fundamental physics practicals to both secondary high school and tertiary students. These laboratories were built over a period of 20 years. Each of these laboratories are fully loaded with equipment to address specific theme areas, such as:

Laboratory 1: Temperature, Heat and thermodynamics.
Laboratory 2: Basics, Statics, simple Machines, Elasticity, Static and dynamic fluids.
Laboratory 3: Physical Optics and Illumination.
Laboratory 4: Geometrical optics.
Laboratory 6: Electrostatics, AC and DC circuits and Electricity.
Laboratory 7: Radioactivity.

In each laboratory station, the variables are adjusted so that it yields a unique result but still verifies the scientific principle in the end. The purpose of doing this is not to allow students to copy their friend’s work.

In the light of what is said above, it is necessary to test the efficiency of the laboratory system. Whilst we think the system is ideal, it is the perceptions of the learners that matter most and guides us to continually modify these systems, hence the use of the SLEI questionnaire in this scenario.

**Method and Procedure**

The following methods and procedures were adapted for this study:

The participants that formed part of this survey consisted of a heterogeneous group of 100 students from mixed quintiles and secondary school backgrounds. These students were registered for qualification programmes in Engineering and Health Sciences at the University of Johannesburg.

**Instrument used for this survey**

An extant questionnaire, originally designed by Fraser et al. (1993), was used as an instrument to assess students’ perception of the science laboratory classroom learning environment. This instrument is called Science Laboratory Environment Inventory (SLEI). Prior to the commencement of this research, permission was sought from the authors concerned, such as Professor Fraser and his colleagues. Further, permission was also sought from the Head of Laboratories, Mr Jan Oelofse as well as the staff from the University of Johannesburg to administer this questionnaire.

**3. Dimensional description of the SLEI instrument**
This version of SLEI is comprised of two 35 item questionnaires incorporated into one and labelled Appendix A and B, respectively. Appendix A consists of items that invoke the learners’ perception of a practice that actually takes place in the laboratory environment, while Appendix B is of a preferred practice (expected or ideal) in the laboratory classroom. Question from these appendices will focus on the following practices in the laboratory in respect to appendix A and B, respectively:

- How often does each practice actually takes place, and
- How often you would prefer each practice to take place.

Within the questionnaire, each of the 35 items is further sub-divided into 7 scales for further differentiation into sub-scales such as (Fraser et al., 1993): Student Cohesiveness, Open-Endedness, Integration, Rule Clarity and Material Environment. Each of the items in the inventory required responses from the learner based on the Likert-type of assessment, which comprised of 5 alternate responses: Almost Never, Seldom, Sometimes, Often and Very Often. The anonymous data was then analysed using statistical procedures whereby the following were determined: means, averages, variances and standard deviations. There is no differentiation in the type of questions in both appendices except that one appendix is labelled Actual Form and the other Preferred Form, therefore only Appendix A is shown for discussion purposes.

The dimensions of human environments in terms of Moos’s taxonomy (1978) can be classified into 3 categories: Relationship dimension, Personal dimension and System Maintenance and Change. These categories will then be aligned to each of the 5 dimensions of SLEI scale such as: Student Cohesiveness, Open-Endedness, Integration, Rule Clarity and Material Environments, as shown in table 1 below.

Table 1: Dimensional description of Moos’s categorization of the human environment to that of the SLEI system (Fraser et al., 1993)

<table>
<thead>
<tr>
<th>Scale name</th>
<th>Moos category (1978)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Student Cohesiveness</td>
<td>Relationship dimension</td>
<td>It is how students get to know each other, work together, and help each other in a supportive and cooperative way.</td>
</tr>
<tr>
<td>2. Open-Endedness</td>
<td>Personal dimension</td>
<td>It is the nature of the laboratory activity and whether it allows for a divergent/independent approach to experimentation.</td>
</tr>
<tr>
<td>3. Integration</td>
<td>Personal dimension</td>
<td>It relates to how well laboratory activities are aligned or integrated to their classroom activities.</td>
</tr>
<tr>
<td>4. Rule Clarity</td>
<td>System Maintenance and Change</td>
<td>It relates to how learners’ behaviour conform to the guidelines set out in the laboratory.</td>
</tr>
<tr>
<td>5. Material Environment</td>
<td>System Maintenance and Change</td>
<td>It relates to the adequacy of laboratory equipment for the</td>
</tr>
</tbody>
</table>

450
Appendix A: Science Laboratory Environment Inventory (SLEI)

Actual Form

Directions: The following items in the questionnaire describe what actually your laboratory is like. You are required to tick how often each of the following practices actually takes place, like the one given in the table below.

<table>
<thead>
<tr>
<th>1. Practice actually takes place:</th>
<th>2. Practice actually takes place:</th>
<th>3. Practice actually takes place:</th>
<th>4. Practice actually takes place:</th>
<th>5. Practice actually takes place:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almost Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

Questionnaire Questions:

1. Students in this laboratory classroom get along well as a group of students.
2. There is an opportunity for students to pursue their own science interests in this laboratory classroom.
3. What we do in our regular science class is unrelated to our laboratory work.
4. Our laboratory class has clear rules to guide student activities.
5. The laboratory is crowded when we are doing experiments.
6. Students have little chance to get to know each other in this laboratory class.
7. In this laboratory class, we are required to design our own experiment to solve a given problem.
8. The laboratory work is unrelated to the topics we are studying in our science classroom.
9. This laboratory class is rather informal and few rules are imposed.
10. The equipment and materials that students need for laboratory activities are readily available.
11. Members of this laboratory class help one another.
12. In our laboratory sessions, different students collect different data for the same problem.
13. Our regular science class work is integrated with laboratory activities.
14. Students are required to follow certain rules in the laboratory.
15. Students are ashamed of the appearance of this laboratory.

16. Students in this laboratory class get to know each other well.

17. Students are allowed to go beyond the regular laboratory exercise and do some experimenting of their own.

18. We use the theory from our regular science class sessions during laboratory activities.

19. There is recognized way of doing things safely in this laboratory.

20. Laboratory equipment is in poor working order.

21. Students are able to depend on each other for help during laboratory classes.

22. In our laboratory sessions, different students do different experiments.

23. The topics covered in regular science class work are quite different from topics dealt with in laboratory sessions.

24. There are few fixed rules for students to follow in laboratory sessions.

25. The laboratory is hot and stuffy.

26. It takes a long time to get to know everybody by his/her first name in this laboratory class.

27. In our laboratory sessions, the teacher/instructor decides the best way to carry out the laboratory experiments.

28. What we do in the laboratory sessions helps us to understand the theory covered in regular science classes.

29. The teacher/instructor outlines safety precautions before laboratory sessions commence.

30. The laboratory is an attractive place in which to work.

31. Students work cooperatively in laboratory sessions.

32. Students decide the best way to proceed during laboratory experiments.

33. Laboratory work and regular science class work are unrelated.

34. This laboratory class is run under clearer rules than other classes.

35. The laboratory has enough room for individual or group work.

You are now required to provide answers to the same questions but with different instructions, as indicated below.

Appendix B: Science Laboratory Environment Inventory (SLEI)
Preferred Form

Directions: The following items in the questionnaire describe what you prefer (or expect) to take place in the laboratory. You are required to tick how often you prefer (or expect) each of the following practices to take place in the laboratory, like the one given in the table below.

<table>
<thead>
<tr>
<th>Practice you prefer to take place:</th>
<th>Practice you prefer to take place:</th>
<th>Practice you prefer to take place:</th>
<th>Practice you prefer to take place:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almost Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Very Often</td>
</tr>
</tbody>
</table>

Questionnaire data

After administering the SLEI questionnaire, separate results were obtained for the actual and preferred versions of the survey about the students’ perceptions of the laboratory classroom environment for teaching and learning. Items in the questionnaire were disaggregated into 5 dimensional scales, such as: Student Cohesiveness, Open-Endedness, Integration, Rule Clarity and Material Environment. Analysis of the learner’s choices is shown in tables 2 to 6, respectively. In some cases, items may overlap with different subscales (these items are not taken into consideration for statistical evaluation). Note the abbreviation of the distractors in the tables 2 to 6, are assigned as follows for both practices: Almost Never (AN), Seldom (SE), Sometimes (SO), Often (OF) and Very Often (VO). Learner responses were recorded from 1 to 5 (1 = almost never, 2 = seldom, 3 = sometimes, 4 = often, 5 = very often). There were thirteen negatively (item numbers: 3, 5, 6, 8, 9, 15, 20, 23, 24, 25, 26, 27 and 33) worded items, and recorded in the reverse direction (from 5 to 1). The rest of the items were positively worded (1, 2, 4, 7, 10, 11, 12, 13, 14, 16, 17, 18, 19, 21, 22, 28, 29, 30, 31, 32, 34 and 35).

Table 2 show students’ responses in relation to statements concerning Student Cohesiveness.

**Table 2:** Analysis of the actual and preferred choices of items relating to the dimension: Student Cohesiveness

<table>
<thead>
<tr>
<th>Item number</th>
<th>Actual Practice (mean value)</th>
<th>Preferred Practice (mean value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AN</td>
<td>SE</td>
</tr>
<tr>
<td>1</td>
<td>0.02</td>
<td>0.08</td>
</tr>
<tr>
<td>6</td>
<td>1.75</td>
<td>1.12</td>
</tr>
<tr>
<td>11</td>
<td>0.11</td>
<td>0.40</td>
</tr>
<tr>
<td>16</td>
<td>0.08</td>
<td>0.16</td>
</tr>
<tr>
<td>21</td>
<td>0.14</td>
<td>0.44</td>
</tr>
<tr>
<td>26</td>
<td>2.05</td>
<td>0.88</td>
</tr>
<tr>
<td>31</td>
<td>0.10</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Overlapping items

<table>
<thead>
<tr>
<th>Item number</th>
<th>Actual Practice (mean value)</th>
<th>Preferred Practice (mean value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AN</td>
<td>SE</td>
</tr>
<tr>
<td>19</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
These results are similar to those of international studies, such as those undertaken by Hofstein et al. (2001). There appears to be a reasonable level of students’ cohesiveness in the laboratory sessions, except in the cases where learners are unable to help and provide meaningful suggestions to problems. This stems from the fact that each cubicle station has a unique set-up with variable parameters, therefore learners are unable to plagiarise results from their peers. In this respect, learners would have idealistically preferred uniformity of results (mean of 1.90) instead of differentiated laboratory results (mean of 0.40). Due to the compartmentalised set-up of the laboratory, learners do not get to know each other or socialise as is expected in laboratory sessions. Knowing each other by their actual name (mean score of 2.05 for “always never”) as opposed to their preferred choice (mean score of 1.80 for “always never”), could means that they know each other very well and this dimensional aspect is of no consequence to them. In spite of these comments, they never the less appear to enjoy working cooperatively and get along well as a group in the laboratory sessions.

Table 3 shows students’ responses in relation to statements concerning Open-Endedness.

**Table 3**: Analysis of the actual and preferred choices of items relating to the dimension: Open-Endedness

<table>
<thead>
<tr>
<th>Item number</th>
<th>Actual Practice (mean value)</th>
<th>Preferred Practice (mean value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AN</td>
<td>SE</td>
</tr>
<tr>
<td>2</td>
<td>0.23</td>
<td>0.30</td>
</tr>
<tr>
<td>7</td>
<td>0.60</td>
<td>0.18</td>
</tr>
<tr>
<td>12</td>
<td>0.14</td>
<td>0.08</td>
</tr>
<tr>
<td>17</td>
<td>0.50</td>
<td>0.36</td>
</tr>
<tr>
<td>22</td>
<td>0.68</td>
<td>0.10</td>
</tr>
<tr>
<td>32</td>
<td>0.17</td>
<td>0.64</td>
</tr>
<tr>
<td>Overlapping items</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

454
Students have demonstrated a low level of Openness in the laboratory environment, as reflected in both forms. On the issue of different students collect different data for the same problem seems to be strongly emphasized in both forms. Unfortunately due to the very nature of the laboratory set-up, students are not required to design their own experiment to solve an experimental problem. In respect of data collection, the way they collect data by following a prescribed procedure to verify a known principle is not met with any reservations. Despite the fact they show a low level of openness, they do not show any willingness to follow an open-ended or divergent approach to experimentation. The mean score in both the actual and preferred forms for this dimensional aspect is 0.65 and 0.50, respectively. A relatively large number of students have indicated that all students are doing the same experiment in different formats (mean score of 0.35 for “very often”), but would rather prefer different students do different experiments in the same class instead (mean score of 0.70 for “very often”).

Table 4 shows students’ responses in relation to statements concerning Integration.

**Table 4**: Analysis of the actual and preferred choices of items relating to the dimension: Integration

<table>
<thead>
<tr>
<th>Item number</th>
<th>Actual Practice (mean score)</th>
<th>Preferred Practice (mean score)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AN</td>
<td>SE</td>
</tr>
<tr>
<td>3</td>
<td>1.75</td>
<td>0.76</td>
</tr>
<tr>
<td>8</td>
<td>1.45</td>
<td>0.84</td>
</tr>
<tr>
<td>13</td>
<td>0.20</td>
<td>0.28</td>
</tr>
<tr>
<td>18</td>
<td>0.24</td>
<td>0.36</td>
</tr>
<tr>
<td>23</td>
<td>1.40</td>
<td>0.68</td>
</tr>
<tr>
<td>28</td>
<td>0.16</td>
<td>0.18</td>
</tr>
<tr>
<td>33</td>
<td>0.80</td>
<td>0.64</td>
</tr>
</tbody>
</table>

Overlapping items

<table>
<thead>
<tr>
<th></th>
<th>AN</th>
<th>SE</th>
<th>SO</th>
<th>OF</th>
<th>VO</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.03</td>
<td>0.12</td>
<td>0.42</td>
<td>0.64</td>
<td>3.05</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.65</td>
</tr>
</tbody>
</table>

Research findings from Hofstein, Nahum and Shore (2001), resonates with the perceptions of these learners, that although the science laboratory provides a unique learning environment, it differs from the environment that exists in the classroom. Due to the robust nature of the laboratory usage among 3000 learners per semester in each of our 7 dedicated laboratories, alignment of classroom topics may be difficult to attain. From the learners’ responses to this dimensional scale, it appears that Integration has probably the lowest total mean score, implying that laboratory activities were partially integrated with non-laboratory activities. These sentiments are reflected in the learners’ responses to Questions 3 and 8 (and probably Questions 23 and 33 as well), respectively of the questionnaire in both the actual and preferred forms. Idealistically learners would prefer compliance of laboratory work with classroom activities. Perhaps, not surprisingly, the most positive comment from learners is
their response to Question 28, where they indicate that laboratory sessions helps them to understand the theory covered in the classroom (mean score of 1.45 for “very often”). Whilst this may be their preference, laboratory practices have the tendency of reinforcing concepts learnt in the classroom at any stage in their learning progression.

Table 4 shows students’ responses in relation to statements concerning Rule Clarity.

Table 5: Analysis of the actual and preferred choices of items relating to the dimension: Rule Clarity

<table>
<thead>
<tr>
<th>Item number</th>
<th>Actual Practice (mean score)</th>
<th>Preferred Practice (mean score)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AN</td>
<td>SE</td>
</tr>
<tr>
<td>4</td>
<td>0.03</td>
<td>0.10</td>
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<tr>
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<tr>
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</table>

On the aspect of Rule Clarity, every laboratory has a well tabulated chart that clearly indicates what is expected of them throughout the laboratory session. Non-compliance of these rules has serious consequences. Learners are expected to behave in an appropriate manner. Learners response to the question: “This laboratory class is rather informal and few rules are imposed”, where they a mean score of 2.60 (“very often” on the actual form) for this aspect is a testament to this assertion. According to Wong and Fraser (2008), a laboratory that has clear rules to follow has a positive effect on their attitudes. Learners have indicated that they would prefer this to be in place always, a mean score of 2.30 for “very often” is attributed to this question in the preferred form. Safety is of primordial importance in our laboratories and every effort is in place to counter any eventualities, especially in our radiation laboratory. Learners feel safe to work in these laboratories, and these are reflected in both the actual and preferred forms. Although these rules are clearly stated in charts and discussed at the beginning of the year, they would prefer that the rules be reinforced at the start of each practical session (mean score of 0.29 for “very often” in the actual form). Learners have responded favourably to the question: “This laboratory class is run under clearer rules than other classes” in both the actual (mean score of 1.80 for “very often”) and preferred forms (mean score of 1.95 for “very often”).

Table 6 shows students’ responses in relation to statements concerning Material Environment.

Table 6: Analysis of the actual and preferred choices of items relating to the dimension: Material Environment
The physical setting of our laboratories is characterized by fully equipped cubicle stations, surrounded by chairs that allow students to work independently. The unique layout does not allow for much distraction and an attractive place to do experimental work. For this dimensional aspect, students have strongly indicated that the laboratories have adequate equipment and materials (and readily available) for experimentation (mean score of 3.05 for “very often”). Each of the 7 laboratories have 24 cubicle positions (stations) which allows only 24 students to work in any one laboratory at a time. These laboratories have enough space even for learners to work in groups. Their response to Question 5 which refers to overcrowdedness of a laboratory, they clearly indicate that this aspect is inconsequential in both the actual (mean score of 2.25 for “almost never”) and preferred (mean score of 2.85 for “almost never”) form. They take great pride in working in our laboratories and are not ashamed of it. In this respect, mean scores of 2.85 and 2.65 for “almost never” are, respectively awarded for both forms in the questionnaire. All laboratory equipment are in excellent working order (they are routinely checked on a daily basis) and students have commented positively on this aspect. On a very positive note, students have indicated that the laboratories are well ventilated (a high mean score of 3.20 on the actual form for “almost never”) and not hot and stuffy.

In Table 7, the sum of Means Scores ranged from 15.41 to 26.60 on the Actual form, and from 15.90 to 27.17 on the preferred form. Correspondingly the mean scores ranged from 2.56 to 3.80 and 2.65 to 3.88, respectively.

<table>
<thead>
<tr>
<th>Item number</th>
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<th>Preferred Practice (mean score)</th>
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</thead>
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<tr>
<td>6</td>
<td>1.25</td>
<td>0.60</td>
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</table>

Table 7: Sum of Mean Score, Means, Variance and Standard Deviations for the actual and preferred forms of SLEI
A graphical representation of the Mean Scores as a function of Dimensional Scale (in the form of bar graphs) reveals differences between the Actual and Preferred forms. It is clear that the preferred choices by learners are slightly higher than the actual choices in most scales of the laboratory environment evaluations. This is also in keeping with international trends in the evaluation of SLEI performance (Santiboon et al., 2012). Comparatively, the mean scores for Open-Endedness is lower than that of the other dimensional scales. A graph like this will provide lecturers with a wealth of information when planning a yearly curriculum, taking into consideration the perceived learning needs and support needed by the learners. Unfortunately, attaining a perfect match (or congruence) between the actual and preferred mean scores in each of the 5 dimensional scales may be hard to achieve due to the unique nature of our laboratory set-up. Suffice to say that this research has provided us with a clearer picture of the dynamics of the laboratory learning environment. Learners have a very high expectation of what they want to see or have in the laboratory.

![Graph showing mean scores as a function of dimensional scale](image)

**Figure1**: Mean Scores as a function of Dimension Scale (1 = Student Cohesiveness, 2 = Open-Endedness, 3 = Integration, 4 = Rule Clarity and 5 = Material Environment). The true mean values for both curves are highlighted under the curve and not as represented on the y-axis.

**Discussions**
This study was useful because it gave us an opportunity to use a valid and reliable instrument to evaluate the type of learning that is taking place in each of our 7 dedicated laboratories for physics. As stated by Fraser et al. (1993), the SLEI instrument is valid for use at the university level. In general, learners have commented favourably on many aspects of the laboratory learning environment. However, what is strikingly evident from their responses is that an open-ended (or divergent) approach to practicals is not emphasised in our laboratories. There could be many mitigating factors for such responses; on the one hand our laboratory set-up is unique for its practical offering, and on the other hand it depends on nature of the experimental approach to be followed for that investigation. Our approach differs from that followed by many the traditional universities, in that students follow an expository style of data collection from specific work stations to verify a known scientific principle. However, it must be mentioned that students in this scenario initially meet with their lecturers to discuss the experimental procedures to be followed for a particular experiment before embarking on their experimental work.

It was found that, through research undertaken by Hofstein, Cohen, & Lazarowitz (1996), that the SLEI instrument is sensitive to the different types of instructional modes and curricula employed in the laboratory environment. This research was found to differ from many internationally conducted studies, namely for 2 reasons; firstly their research was conducted among secondary students, and secondly by the very nature (enquiry, discovery, problem-based or expository) of their experimental approach, allowed for varied responses.

Students have a strong negative perception about the non-alignment of laboratory work with their theory classes. This situation has created a major challenge for us in terms of availability of the laboratories and integrating laboratory work with the theory sections covered in class. In spite of this impediment, students are offered a wide array of practicals covering on average roughly 30 practicals per semester, which eventually in the end covers the required curricula.

On a more positive note, the study revealed a high level of student satisfaction for aspects such as Rule Clarity and Material Environment. Learners feel safe in the laboratory if there are clear guidelines about safety and procedures to follow in cases of emergency. Further, clear rules would warrant justifiable behaviour from the learners in the laboratory at all times. The highest mean score was awarded for the Material Environment, implying that the laboratories were fully equipped and functional to conduct any experiment as prescribed in the manual book. This is contradictory to international studies for which consistently lower scores were obtained for this dimensional scale (Giddings and Waldrip 1996, Wong and Waldrip, 1996). It could be that teachers or lecturers are not convinced about the value of laboratory activities, hence the lack of urgency in adequately equipping the laboratories for experimental investigations (Santiboon et al., 2012).

**Conclusion**

Results of this study indicated that all 5 SLEI subscales on the preferred form were higher than the actual form on laboratory expectations. In particular, there is a cause for concern on the 3 dimensional aspects, namely, Student Cohesiveness, Open-Endedness and
Integration of the SLEI subscales of evaluation. The mean scores on the aspect of Rule Clarity and Material Environment were moderate (on the actual form) as indicated in the responses by learners. In this respect, the learners have indicated that the laboratory rules were relatively clear and that formal behaviour was appropriately enforced. In terms of Materials and Equipment, we are fortunate enough to have the state of the art laboratories in Southern Africa, as was endorsed by South African Engineering Council of South Africa during the accreditation process. However, what is good and technologically sound may appeal to science practitioners but whether they meet the needs of our current cohort of learners is another matter. Suffice to say that learners should appreciate the magnitude of the efforts we have put in place to ensure fundamental principles in physics were addressed, and which was presumably missing from the secondary schooling sector.

References


Investigating teachers’ use of manipulatives to teach grade 3 equivalent fractions

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Abstract

The purpose of this study was to explore how teachers teach equivalent fractions using manipulatives and the pedagogical content knowledge (PCK) required to do so effectively. The study used a qualitative approach, where the data collected was analysed descriptively. Five grade three teachers were sampled purposively and involved in the study. A “clinical” model of observation was used to generate the data. This model involved pre-observation conference where the lesson to be observed was first discussed with the teacher, that was followed by the actual observation and finally a post observation conference where the observed lesson was discussed. The lessons were recorded through a video for reflective deliberations. They were required to teach the lessons on equivalent fractions in grade 3 predominantly using manipulatives as launch pads for conceptual understanding and what they regarded as their PCK. Further individual interviews were also conducted to establish the teachers’ understanding of their learners’ epistemological access to the concepts they teach. The findings were that while teachers embraced the use of manipulatives, they still require good professional development programmes that address the use of manipulatives effectively. It also emerged that teachers’ PCK in relation to the use of manipulatives and effective teaching skills required undivided attention. Teachers were often hesitant in explaining concepts especially the essence of equivalent fractions using manipulatives. The study also found that teachers depended on commercially developed manipulatives and had difficulties developing their own.

Key words: manipulatives, equivalent fractions, pedagogical content knowledge, professional development

Introduction

South African Annual National Assessment (ANA) tests have for the past three years (2011, 2012 and 2013) revealed that learners in grade 3 mathematics perform poorly (Department of Basic Education, 2013). This has been more prominent in provinces like Limpopo and Eastern Cape (Department of Basic Education, 2013) where there are a myriad problems relating to poor teaching and learning. More specifically, poor performance has been identified in areas such as the learning of fractions. Studies such as Themane (2015) found that learners struggle with the recall and application of basic concepts in the use of manipulatives in the teaching of fractions, which leads to lack of complete understanding of mathematics. That is, when learners fail to grasp basic concepts such as fractions they run the risk of having gaps in understanding mathematics which will end up in low performance in mathematics.

Grade 3 learners struggle with addition and subtraction, simplifying and equivalent fractions. But, in particular, they struggle with the concept and application of equivalent fractions (Borseth, 2010). This study focused on teachers’ pedagogical content knowledge on using manipulatives while teaching equivalent fraction concepts in grade 3 classes.
Research (Borseth, 2010) has established that teaching mathematics through the use of workbooks, drills and memorisation has proven to be ineffective. It has also been shown that children are unable to think and or stay on a task when they learn in an abstract manner. Instead the worksheets need to be augmented with an environment that offers manipulative tools. Unfortunately some teachers are not aware of this fact. They seem to lack the PCK on the use of manipulatives (Luneta, 2011; Themane, 2015). This poor PCK leads to learners’ lack of motivation to study mathematics (Arnon, Cottrill, Dubinsky, Oktaç, Fuentes, Trigueros, M., & Weller, 2014) and subsequently to low learner achievement. Undoubtedly this problem needs differentiated ways of addressing it if learner performance is to be turned around. Such differentiated instructional strategies may include among others incorporating manipulatives into classrooms to help learners retain concepts in the learning of equivalent fractions. The purpose of this study was therefore to explore how teachers teach equivalent fractions using manipulatives and the PCK required to do so effectively.

Manipulatives are physical objects, such as cubes or tiles that are used in the educational settings across, such as elementary school cultures to generate children’s learning and in particular to enhance the understanding of concepts like problem solving, communicating, reasoning, connections and estimation (Manches, & O’malley, 2012). They can be used to introduce, practice or remediate math concepts (Boggan, Harper & Whitmire, 2008). Research indicates that most valuable learning occurs and increase when manipulatives are used.

Since the early 1900s, manipulatives have been used at the elementary school level to help learners grasp mathematical concepts without fear. For example, in the United States of America (USA) different states nationwide including California, North Carolina, Texas and Tennessee, have mandated the use of manipulatives for teaching mathematics (Borseth, 2010). Also, the National Council of Teachers of Mathematics (NCTM) together with stakeholders in different states including Maria Montessori have recommended the use of manipulatives in teaching and learning mathematical concepts at all grade levels (Boggan et al, 2008). At the same time the NCTM (2000) recommends the use of manipulatives in all districts nationwide across all the grades in developing concrete understanding of abstract concepts.

In a meta-analysis study on the efficacy of teaching mathematics with concrete manipulatives, Carbonneau, Marley and Selig (2013) found that the use of manipulatives to teach mathematics is often prescribed as an efficacious teaching strategy. Manipulatives have also been found useful at other levels of study other than grade 3. In a study by Golfshani (2013) on the implementation of manipulatives into mathematics instruction for grade 9 learners, found that if teachers had a positive mind on the use of manipulatives it would have enhanced the understanding of mathematics. He also found that the use of manipulatives in the teaching of mathematics had a positive effect on student learning, in particular to struggling students. Satsangi and Bouck (2014) found the use of virtual manipulatives an effective tool to acquire, maintain, and generalise the concepts of area and perimeter.
However, despite this evidence it appears that teachers are not aware of the manipulatives tools available to them and how to use them in their classrooms. Therefore, incorporating manipulatives into mathematics lessons helps students grasp concepts with greater ease, making teaching more effective and more fun (Moch, 2002; Moyer, 2001). Manipulatives are extremely useful to young children when teachers use them properly and correctly. Manipulatives are also very excellent to those who are anxious to learn mathematics and also to reduce children’s anxiety to learn mathematics with confidence (Chang, 2008; Drews & Hansen, 2007). Studies have also shown that students using manipulatives in addressing math concepts are more likely to achieve more than those who do not use them (Moyer, 2001; Moch, 2002; Chang, 2008). The results of numerous studies show that mathematics achievement is increased by the long term use of concrete manipulatives, and that students’ attitude towards mathematics is improved when they have instruction using manipulatives.

However, despite their value, most teachers do not seem to use them (Boggan, Harper & Whitmire, 2010). And where they are used, they are not used correctly (D'Angelo, & Iliev, 2012). There are many explanations why their use is so negligible. Among some of these reasons is the question of lack of funds to purchase them, especially in schools that are poorly resources such as those in rural areas. Themane (2015) found that most teachers cited lack of money to buy these useful resources to enhance learning. In South Africa few studies have been documented on the PCK of teachers in the use of manipulatives to teach grade 3 equivalent fractions. However, such studies have not been conducted in Limpopo Province. Such information is extremely important if teachers are to improve their classroom practice with regard to teaching equivalent fractions better. Therefore, the purpose of this study was to explore how teachers teach equivalent fractions using manipulatives and the PCK required to do so effectively. More specifically, the study sought to address the following questions: (a) How do teachers teach equivalent fractions using manipulatives and (b) What is the PCK required to do so effectively?

**A theoretical framework for the study**

The study was grounded on Jean Piaget’s theory (1976) of cognitive development, which focuses on four stages of development. These stages show how children grow in their understanding of the world around them. The four stages are: (a) sensory-motor, (b) pre-operational, (c) concrete operational, and (d) formal operational. Each of the four stages builds upon the previous stage, which makes them not to be interchanged. But, it is possible that each child may go through each stage at a different rate. At the sensory-motor stage, which occurs between birth and two years old, children understandings are based only on perceptions and objects that they can touch and experience with. On the pre-operational stage, this is between two years and seven years old, children can now think logically. Concrete operational, which is between seven and eleven years old, children are able to perform operations mentally, which previously needed to be performed physically, and they begin to develop a rule-based system of thought. It is at this stage that they develop concepts of reversibility, which enables them to think forward and backward. The last stage is the formal stage, which is between seven and sixteen. At this stage the children are able to think in an abstract manner, and are able to think in multiple ways when solving a problem.
We adapted this theory to understand the PCK of teachers in the use of manipulatives in the teaching of equivalent fractions. The main pedagogical themes that emerge from this theory is that learning is both procedural and conceptual. In particular that teaching is developmental, moving from the concrete to the abstract. Procedural knowledge is knowledge of the rules and procedures to be followed in solving a problem. That is, learning follows a deductive approach. On the other hand, conceptual understanding is an understanding of how mathematical procedures work. In this study we postulated that since the grade 3 children are at the pre-operational stage, the use of manipulatives could help teachers to make learners understand the concepts before applying procedural laws. Manipulatives could help the understanding of mathematical concepts clearly before a procedure is introduced (van de Walle, 2007).

We hypothesised that many teachers, especially in our target group start equivalent fractions lessons by introducing learners to the algorithm before developing the conceptual idea behind it. Moyer (2001) cites that conceptual understanding is able to provide answers for the “why” questions behind the procedures.

Moreover, manipulatives provide children an opportunity to participate in their own learning rather than being passive learners. For children to truly understand a thing they need to experience it themselves. Manipulatives provide such a platform. Therefore teachers’ PCK on the use of manipulatives to teach equivalent fractions is important to develop.

Research Methodology

Research design
The study opted a qualitative research approach, situated within an interpretivist paradigm to gain an in-sider view of the PCK of teachers in the use of manipulatives to teach equivalent fractions (Creswell, 2010; Denzin & Lincoln, 2008). Within the qualitative approach, we adopted a case study design. The design allowed us to unearth the underlying reasons why and how the teachers taught fractions the way they did. It provided us with the analytical framework that illuminated the teachers’ knowledge of teaching equivalent fractions. It thus enabled us to gain a holistic picture of the phenomenon (Yin, 2009).

Sampling
A purposive sampling strategy was used to recruit five participants for the study (Creswell, 2010; McMillan & Schumacher, 2010; Yin, 2009). The features of interest were that, the teachers needed to be teaching mathematics in grade 3 at the time. Two, that the teachers should have had at least five years of teaching experience at the time of the study. Three, only teachers who taught in the Foundation Phase particularly grade 3 were selected as participants in the study. Four only teachers whose language of teaching and learning in their schools was Sepedi as mother tongue.

Study sites
The study was conducted in two primary schools of Mankweng circuit in the Capricorn District of Limpopo Province in South Africa. Mankweng circuit is situated 30 km east of
the city of Polokwane (the former Pietersburg). Mankweng circuit consists of 20 primary schools from which only 2 were selected for the study.

The profile of teachers who participated in the study was as follows: All the teachers were female. Two of the five held diplomas: Primary Teachers’ Diploma, which qualified them to teach in the Foundation Phase. The other two held degrees and honours degrees, and the last one held a Senior Phase Teacher’s diploma. Teacher 1 was age 46 and had 26 years of experience, teacher 2 was age 53 and had 31 years of experience. Teacher 3 was age 37 with 14 years of experience. Teacher 4 was age 57 with 30 years of experience and teacher 5 was age 45 with 25 years of experience.

**Data collection**

**Interviews**

An individual interview schedule was constructed through consultations with experienced teachers in the Foundation Phase, and two lecturers who taught mathematics education at a university. To ensure its validity, the instrument was piloted with two teachers, after which it was improved before usage. The interview was made up of eight questions which covered the teachers’ knowledge of fractions, knowledge on how they taught fractions, the use of learner support materials and the learning environments. The interview questions were as follows: (a) which classroom materials do you use or prefer in the teaching of grade 3 equivalent fractions and why? (b) How do you make the learning of equivalent fractions exciting and interesting for grade 3 learners? (c) How do you ensure that grade 3 learners understand the concept fractions and their operations before the application of the rules and guidelines thereof? (d) How do you help and support learners who are slow in understanding equivalent fractions? (e) Which aspects of the equivalent fractions do you find most challenging to teach? (f) Since learners have different learning styles, how do you differentiate your lesson to accommodate their different styles? (g) How do you regard your knowledge of teaching fractions? (h) How do you challenge your learners who already know about equivalent fractions to learn further? How do you improvise with manipulatives where they are not readily available?

The interview schedule was translated from English to Sepedi and back to English and then conducted in Sepedi. The interview schedule was piloted with the two teachers who were teaching grade 3 at that time. This enabled me to see where the instrument had shortcomings. We then improved on those areas that were ambiguous before embarking on the actual data collection process.

We visited the two primary schools chosen for the study, and met the principals to ask for permission and arranged for appointments. We then met the participants. We introduced ourselves and the purpose of study, and also explained why the study was conducted. The participants also introduced themselves to us, and we briefed them about their rights pertaining to the research, for example, that they had the right to withdraw from the process if they felt somehow uncomfortable. We also explained in details how the interviews and observations were to be conducted.
We then made appointments for interviews and observations, because the teachers had to check their programs, timetables and test schedules first to prepare themselves for the classroom observations as well as interviews. They gave us the dates which they have honoured. We had to conduct interviews after school to avoid class interruptions because learners would make noise during the interviews and disturb other teachers when teaching.

The teachers were provided with information on what would be expected from them during the interviews. They were also ensured that information which they would give would be kept confidential and that it would not be used for any other purpose than the one stated in the consent forms. We were guided by the principles of anonymity, confidentiality and privacy throughout the study (Berg 2011), we used pseudonyms to identify them as teacher 1, 2, 3 and 4.

During the data collection process, the teachers were allowed freedom to express themselves about their classroom experiences in teaching mathematics to grade 3 learners, and in particular with the teaching of equivalent fractions. We found the interview sessions most informative.

**Observations**

The second method we used was observation. Observation is a method of data collection where the researcher is present in the field and is active to learn about the activities of the people under the study in their natural setting (Freeman & Hall, 2012). There are mainly two types of observations, the non-participant type and the participant type. A non-participant observer plays only a bystander role, where there is little interference with the phenomenon under observation. On the other hand a participant observer becomes an active member of the group under study, embracing their skills and customs, which will enable him or her to gain a complete understanding of the phenomenon (Le Compte & Schensul, 1999). For the present study, we adopted the participant–observer stance because it enabled us to feel how things were organised, prioritised, and how teachers related to learners in the classrooms, in the two schools. The approach also helped us to become acquainted with their cultural nuances; which assisted us a great deal in easing tensions and making the research process easier and better. Of the five teachers, only four were available for observations. Permission to video-record the lessons was given by the respective principals and the teachers themselves. The process was clearly explained to them as to what the data were to be used for, and they gave us permission to proceed. A total of four lessons were observed where an observation schedule was used.

As it was the case with interviews, in this instance, the participants were provided with consent forms. Consent forms are measures according to which participants are to decide whether they want to participate in a study or not. Therefore informed consent forms were explained to the participants and they understood what was needed to them and were made to feel free to continue with the process (Creswell, 2010; Creswell, 2007) with the teachers. This assurance helped us to build trust. We ensured that we were honest to them at all times, for example, we never disclosed anything about their private life. In this way we promoted a growing relationship of mutual trust (Thompson & Rudolph, 2000).
A “clinical” model of observation was used to generate the data. This model involved pre-observation conference where the lesson to be observed was first discussed with the teacher in what was called a pre-observation conference, that was followed by the actual observation and finally a post observation conference where the observed lesson was discussed. The lessons were video recorded for reflective deliberations. The teachers were required to teach the lessons on equivalent fractions in grade 3 predominantly using manipulatives as launch pads for conceptual understanding and what they regarded as their PCK.

Data analysis
Both interview and observation data were analysed and interpreted according to what Argris, Putman, & Smith, 1985) call “the ladder of inference”. The ladder of inference follows a three-rung ladder of inference. The first step represents in their raw form, that data as observed in their unambiguous representation of events. The second step represents interpretations of data in the common cultural domain, in this case the PCK in the teaching of equivalent fractions. The third step represents the researcher’s interpretation which contains a number of assumptions, which are not shared by everyone else. This process yielded themes and patterns that helped to make sense of the data.

Results
From the interviews and observations, seven themes emerged. These included: (a) competence to teach equivalent fractions, (b) the use of context in the teaching learning situation, (c) pace of the lesson, (d) individual attention on leaners, (e) time spent on an individual task, (f) difficult sections, and (h) class time management.

Competence to teach equivalent fractions
The competence of teachers to teach equivalent fractions was measured by what Darling-Hammond and Ball (1998) refer to as the ability to apply both the procedural and conceptual knowledge in the teaching of content. In this instance, our interviews and observation data revealed that teachers were not competent to use manipulatives to foster, first the understanding of concepts before embarking on the procedures or rules to teaching these concepts. However, there was an attempt by teachers 1 and 2 to make use of the cutting of papers, the cutting of an orange and bread to illustrate the concept of equivalent fractions. This was useful to learners as they seemed to be more engaged than with the other two teachers whose children sat still and listened. The latter teachers were often hesitant to explain concepts especially on the essence of equivalent fractions using manipulatives.

The use of context in the teaching and learning situation
The five teachers embraced the use of manipulatives in the context of the social setting of learners. We found the use of the sharing of fruits and sweets by one teacher quite interesting. However, she still requires good professional development programmes that address the use of manipulatives effectively. It also emerged that the teachers’ PCK in relation to the use of manipulatives and effective teaching skills required attention. The use of home-made manipulatives; which were developed by the teachers was not emphasized as compared to the commercially acquired ones. But, on the whole the four teachers did their best to use manipulatives that were not foreign to learners. In response to an interview
question on the use of context to teach equivalent fractions through manipulatives, teacher 1 had this to say:

Learners come from home to school with the knowledge of sharing, which was emulated from parents, guardians and siblings; they know how to share sweets, bananas, apples, oranges, and whatever is at their disposal, among their siblings and friends and neighbours. Teachers are to support and help improve the learners’ prior knowledge by formal education.

This quote underlines the teacher’s knowledge of the importance of context in the teaching of equivalent fractions.

**Pace of the lesson**
The teachers regulated the pace of their lessons to accommodate different learners. We observed that in the four cases learners were given enough time to engage in learning activities such as the cutting and naming of paper sheets to demonstrate their understanding of the equivalent fractions. However, teacher five whose class was overcrowded struggled to complete what she wanted to teach as she spent most of her time trying to manage the class; which was noisy.

**Attention to individual learners**
Teacher 1 paid individual attention to her learners as her class size was relatively small, 36 learners. The learners were arranged in 4 groups of 9 each. This gave her an ample opportunity to attend to each of the four groups adequately. On the other hand, teacher 3, whose class was 72, struggled to pay individual attention to her learners. Unlike teacher 1, her use of manipulatives was not as effective as would be if her class was small.

**Time spent on a task**
Teachers 1 and 2 managed to maintain discipline in their classes. This allowed them to spend sufficient time to teach equivalent fractions through manipulatives. For example, teacher 1’s learners spent sufficient time cutting A4 paper sheets into different shapes of fractions. This allowed her class to practice the tasks over and over again. With the other teachers where there was overcrowding there was very little teaching taking place as learners were engaged in fighting, making noise and move in and out of the classroom.

**Difficult sections**
From both our interviews with the teachers and our observation of lessons, we noticed that teachers were not confident enough to use manipulatives to teach equivalent fractions. The knowledge levels of their mathematics content was not at the appropriate level. This affected their approach to the teaching of fractions for understanding the concepts. When we asked teacher 4 what she does when she finds a section difficult to handle. She indicated that she would skip the section, and not ask it in the examination.

**Time management**
Related to the issue of time spent on a task discussed above, was the issue of time management in their classrooms. The teachers revealed that they were concerned with the
completion of pace-setters, which often puts pressure to teach for the workbook. This usually made them to be off balance with their time management. As a result they were forced to rattle through certain sections, and subsequently had no sufficient time to create space for the use of manipulatives and other concrete examples in their teaching.

**Discussion**

The purpose of this study was to explore how teachers teach equivalent fractions using manipulatives and their PCK required to do so effectively. The study used a qualitative approach, where the data collected was analysed descriptively. The overall findings show that while teachers embraced the use of manipulatives, they still required good professional development programmes that address the use of manipulatives effectively. It also emerged that teachers’ PCK in relation to the use of manipulatives and effective teaching skills required attention. Teachers were often hesitant in explaining concepts especially the essence of equivalent fractions using manipulatives. The study also found that teachers hanged on commercially developed manipulatives and had difficulties developing their own.

Our findings are consistent with other findings elsewhere. Carbonneau, Marley and Selig’s (2013) literature review of 55 studies revealed that manipulatives improved retention of concepts, problem solving, transfer and justification moderately, but that teachers were unable to use them effectively. The same findings are alluded to by Lamon (2012) in his book: *Teaching fractions and ratios for understanding: Essential content knowledge and instructional strategies for teachers*, who found that teachers needed help on how to teach mathematics for understanding through manipulatives. Mendiburo, Hasselbring and Biswas (2014) researched about the use of computer aided technology to teach mathematics. They found that although manipulatives improved student learning, teachers had difficulties in using them. An, Kulm, and Wu (2004) compared PCK of teachers on the teaching of middle school mathematics between the United States of America (US) and China. They found that in the US mathematics was taught through a variety of activities, including manipulatives, whereas in China traditional methods were used. The researchers concluded both approaches had value depending on the context in which they were used. But that teachers often struggled to use manipulatives in their classrooms.

In Africa, similar findings have stressed the need for teachers to be trained in the use of differentiated teaching strategies that seek to engage learners rather than teacher-led approaches which ignore the active involvement of learners. For example, Akyeampong, Lussier, Pryor and Westbrook (2013) in their article that draws from a teacher preparation for the early primary grades in six African countries Ghana, Kenya, Mali, Senegal, Tanzania and Uganda stressed the need to use alternative approaches that include the use of manipulatives. This need was prompted by the fact that in these countries teachers seem to struggle with the use of learner-centred approaches, such in the use of concrete examples and manipulatives in their classrooms.

There is no doubt that teachers’ PCK in relation to use of manipulatives and effective teaching skills require attention. Teachers seem often hesitant in explaining concepts especially the essence of equivalent fractions using manipulatives. These findings have
several implications for the preparation of teachers by teacher education institutions. One such implication is the need to incorporate PCK on the use of concrete examples and manipulatives into their programmes among other things. So far much focus in teacher education has been on the subject matter content knowledge, but in the past few years emphasis at universities seem to shift towards the need to improve the pedagogy of such a content, though much still need to be done to change the mind-set of most professors into this direction. In South Africa, the new teacher policy on the Minimum Requirements for Teacher Education Qualifications (MRTEQ) lays strong emphasis on teaching practice; which takes cognisance of the situational knowledge of the teacher, including the use of manipulatives (Department of Education, 2011).

Again, these findings allude to the fact that a number of instructional strategies, which take into cognisance the cognitive development of children, as postulated by Jean Piaget’s theory (1976) improve learner achievement. In this study teachers point out and demonstrated the need for individual attention to learners, the need to use context-bound and concrete examples and manipulatives to mediate the teaching of mathematics improves learner achievement. This view is supported by Moyer-Packenham, Baker, Westenskow, Anderson, Shumway, and Jordan (2014) who in their study to determine variables that predict learner achievement, found that fewer demographic predictors of learner performance such as the learner socio-economic status, language of instruction and gender exist during fraction instruction when virtual manipulatives were used. When teachers used virtual manipulatives, there was an equalizing effect on achievement in third and fourth grade classrooms. In addition, Shin and Bryant (2015) synthesised seventeen intervention studies that focussed on instruction to improve the fraction skills and found that interventions that consisted of instructional components such as concrete and visual representations; explicit, systematic instruction; range and sequence of examples; heuristic strategies; and use of real-world problems led to improved performance on measures with fraction concepts and skills. There is therefore enough evidence to push for more integration of teaching practice that emphasises the use of manipulatives, and other concrete examples in the teaching of mathematics.

The study also found that teachers depended on commercially developed manipulatives and had difficulties developing their own. Part of the problem could be the lack of confidence in the ability to construct their own work. With most schools lacking basic resources such as textbooks and other learner-support materials, it may not be feasible to rely on commercially developed manipulatives. Teachers need to be taught and encouraged to develop their own manipulatives. In Singapore, Hofer (2015) reports his self-study where he introduced the concept of a bar model as a manipulative tool to teach mathematics. He found that pictorial representations needed to be supported by concrete experiences using manipulatives and scaffolding with questioning for children to benefit. In South Africa, the work of Zulu (2013) is a typical example of the value of using indigenous knowledge systems (IKS) to teach mathematics. His work epitomises the need for teachers to be creative in using local materials to develop mathematics concepts. Up to now mathematics has been couched in European languages, and culture and thus making it inaccessible to most African children who are not conversant with English. This problem can be overcome by empowering
teachers to demystify the pedagogy of mathematics. There is definitely a need for teacher education programmes to empower teachers by training them on the skills of making their own manipulatives. The ability to improvise will go a long way in solving problems of resources in poor rural schools.

Finally, our findings may be useful to policy makers who are responsible for the continuing teacher development programmes to consider the creation and the use of manipulatives in the teaching of mathematics.

References


Enduring educational inequalities: The state of physical sciences laboratories and scientific inquiry opportunities for learners in some of the schools in post-apartheid South Africa

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Abstract

Despite prolonged efforts to enforce and implement measures to reverse the effects of decades of apartheid education, inequalities continue to characterise the educational landscape in post-apartheid South Africa. One of the ways in which the educational inequalities phenomenon rears its ugly head is the limited access to science laboratory facilities for certain South African learners. This study describes the state of physical sciences learners’ access to laboratory work in seven South African schools from different contextual settings. This is a qualitative research in the form of a phenomenological study. Data were generated by means of semi-structured interviews with physical sciences teachers, observations of laboratory activities and focus group interviews with learners. Findings reveal that unequal access to laboratory facilities and scientific inquiry opportunities continue to persist in post-apartheid South Africa. The laboratory facility access patterns reflect the inequalities created by the era of apartheid. Given the crucial role played by laboratory instruction in science education, the issues pertaining to equal access to education and redress are still of critical significance in South Africa two decades after independence.

Introduction and background

Amidst affirmations by scholarship and science curricula that laboratory work is an integral part of science education (Kirschner & Meester, 1988; Lunetta et al., 2007; Hofstein & Mamlok-Naaman, 2007; Hofstein & Lunetta, 2004), it is quite relevant to ask what the learners lose if they are deprived of laboratory work experiences. Laboratory work is one of the forms of practical work in science, among other forms such as investigations and fieldwork (Science Community Representing Education [SCORE], 2008). During practical work, learners learn science through hands-on activities. McLelland (2006) posits that science is a methodological approach to studying the natural world. According to the Department of Education (2011), the study of the natural world in physical sciences is the investigation of physical and chemical phenomena. The observation of natural phenomena is important when studying science (Blosser, 1990). To this end, learners should be afforded opportunities to handle and manipulate concrete materials in authentic environments. The National Research Council (2006) posits that laboratory work experiences also include working with data drawn from the material world. The school laboratory is a way of turning a classroom into an authentic learning environment. Lunetta et al. (2007) points out curricula developers initially intended the laboratory to be a place for conducting inquiry activities. This is very significant against a backdrop in which most national science curricula, including that of South Africa, are inquiry-oriented (Barrow, 2006; Department of
Laboratory work is one significant avenue through which inquiry can be incorporated and advanced in science teaching and learning.

Christie et al. (2007) in addition to Kibirige and Hodi (2013) affirm that many schools do not have science laboratories in post-apartheid South Africa. Most of these schools are in the contexts where previously disadvantaged groups of people resided during the apartheid era (Christie et al., 2007). This is despite efforts by the post-apartheid government to put measures in place to ensure equal access to education for all. These measures were initiated at independence in 1994 by doing away with policies and laws that segregated learners along racial lines. Selod and Zenou (2003) estimate that the ratio of resource allocation for White, Indian, Coloured and Black education was 4:3:2:1. Different departments ran these different education systems (Gaigher et al., 2014). After independence, Curriculum 2005 (C2005) was one of the policies used by the education department to ensure equal access to education for learners from all races (Ocampo, 2004). The recently implemented Curriculum Assessment Policy Statement (CAPS) prescribes practical work activities to ensure equal treatment throughout the country (Kibirige et al., 2014). It is against this backdrop that this study investigated access to laboratory work and scientific inquiry opportunities for learners in seven schools from different contexts.

Conceptual frameworks

The study uses two conceptual frameworks. First, laboratory instruction is used to explain the role of laboratory work in physical sciences. Laboratory work is widely believed to be a central feature of science education (Hofstein & Lunetta, 2004; Wilkinson & Ward, 1997; Hofstein & Mamlok-Naaman, 2007). Second, the study uses sociocultural perspectives to explain how the endurance of educational inequalities, despite concerted and prolonged efforts to reverse the effects of the apartheid legacy, affects the development of learner skills in laboratory work.

Laboratory instruction

Laboratory instruction in schools has been in use since the 19th century (Blosser, 1990). Teachers believe laboratory instruction has immense educational benefits for learners that outweigh the high costs of building and running the science laboratories (Reid & Shah, 2007). Teachers use laboratory instruction to achieve a wide range of educational goals (Wilkinson & Ward, 1997). Blosser (1990) grouped the educational goals into five categories. The first category refers to the development of skills such as manipulation, inquiry, investigation, organisation and communication. The second category refers to the development of concepts such as hypotheses and theoretical models. The third category refers to the development of cognitive abilities such as critical thinking, problem solving, application, analysis and synthesis. Goals in the fourth category include facilitating learners to understand the nature of science and acknowledging the existence of a multiplicity of scientific methods and interrelationships between science and other disciplines such as technology. The fifth category refers to the development of positive attitudes towards science such as curiosity, interest, precision, collaboration and responsibility. The above-
mentioned goals in science education justify claims that laboratory work is central to science instruction.

**Sociocultural perspectives**

The perspectives are grounded in Vygotsky’s sociocultural theory. Three of the theory’s tenets were used for this study. The first tenet suggests that mental functioning should be understood in the context of its origins and the trajectory of its development (Warschauer, 1997; John-Steiner & Mahn, 1996). The implication for this study is that the development of learners’ knowledge and skills in laboratory work should be understood taking into account how they developed. Learning is influenced by the social, cultural and historic contexts in which it happens (Warschauer, 1997). Laboratory instruction cannot be disconnected from the context in which it is conducted. This is related to the second tenet, which suggests that individuals are shaped by the instruments and tools that they use in their development (John-Steiner & Mahn, 1996). Accordingly, the tools and instruments include laboratory facilities in science instruction. John-Steiner and Mahn (1996) propound that the hand or the mind alone cannot achieve much in the absence of tools and instruments. In this study, it is implied that the nature of laboratory instruction and the available facilities will shape the development of learners’ knowledge and skills in laboratory work. The development of laboratory skills and knowledge is jeopardised in school contexts where laboratory facilities and resources are scarce. The third tenet suggests that learning occurs at two levels, socially and individually (Warschauer, 1997). Learning is facilitated through social interactions before it occurs in the minds of learners (*ibid*.). Similarly, laboratory work involves learner-learner and teacher-learner social interactions in the teaching and learning process. Therefore, the internalisation of laboratory work skills by learners is influenced by the social, historical, material and cultural conditions of the school contexts (John-Steiner & Mahn, 1996). Accordingly, it is an assumption in this study that the conditions of laboratory facilities in the schools influence the quality of laboratory instruction and consequently the development of learners’ skills and knowledge.

**Literature review**

One of the topical issues in science education scholarship and orientations of science curricula is the need to move away from traditional methods of teaching and learning that rely heavily on expository styles of instruction (Kirschner, 1992; Tamir & Lunetta, 1981; Barrow, 2006). There are calls to embrace inquiry-based science instructional methods informed by constructivist learning theories (Kirschner *et al*., 2006). Notwithstanding this debate, laboratory work has been affirmed by scholarship as playing a central role in both traditional and inquiry-based methods of science instruction (Hofstein & Lunetta, 2004; Hofstein & Mamlok-Naaman, 2007). In traditional methods of instruction, laboratory work has been central in demonstrating the importance of evidence for explaining scientific concepts by engaging learners in practical activities to confirm and verify stated scientific facts (Lunetta *et al*., 2007; Chueng, 2007). ‘Cookbook’ or ‘recipe’ laboratory work styles are dominant because learners are provided with instruction sheets to the end of verifying and confirming scientific facts (Burke & Greenbowe, 2006; McDonnell *et al*., 2007; Cheung, 2007). By engaging in the verification laboratory activities, learners develop
manipulative skills as they handle materials and equipment (Kirschner & Meester, 1988). Inquiry-based laboratory work however, is widely believed to avail more learning opportunities for learners and is in line with curriculum orientations (Barrow, 2006). Both the traditional and inquiry-based science laboratory instructional practices seem to concur that science is a practical subject. On the one hand, science may be regarded as the study of the physical and natural world, while on the other hand it may also be regarded as a methodology to study nature (McLelland, 2006). The methods of studying nature include laboratory work activities. Besaude-Vincent and Simon (2012) posit that the reading of texts in science education should motivate learners to do practical work, which constitutes the various ways of observing and studying nature.

In spite of the benefits of laboratory work mentioned in preceding discussions, the construction, management and maintenance of science laboratories is very costly (Reid & Shah, 2007). If laboratory work is not practised with clear educational goals then at times its usefulness may be outweighed by the costs involved (Kirschner & Meester, 1988; Hart et al., 2000). There are scholars that bemoan the failure of laboratory instruction in some contexts to match the expectations spelled out by the purported benefits (Kirschner & Meester, 1988; Hart et al., 2000). However, other scholars view the criticism as unjustified because they claim that all factors standing in the way of successful implementation of laboratory work have not been studied or taken into account (Hofstein & Lunetta, 1984). Some schools cannot afford to have science laboratories because of the high construction, management and maintenance costs. Christie et al. (2007) affirm that many schools in South Africa teach science without laboratory facilities. They continue by saying that due to the apartheid legacy the formerly disadvantaged schools remain resource-strapped in post-apartheid South Africa. This means that many learners never get to experience laboratory work meaningfully.

It is widely believed that education is one of the tools used to shape and improve the socio-economic status of societies and individuals (DuPlooy et al., 2014). Education enhances the earning opportunities and potentials of individuals (Ocampo, 2004). Governments worldwide extensively invest resources towards education. These efforts may only be for the development of literacy and numeracy skills so that citizens can be functional members of society able to contribute and benefit meaningfully in the socio-economic activities. It is through education programmes that the work force to drive the economy is developed. It is even more relevant in developing countries such as South Africa where skills in the fields of science, engineering and technology are still categorised as scarce (Department of Higher Education and Training, 2014). The passing of laws and policies like the Bantu Education Act in 1952 was informed by racist agendas that recognised the potential of education to improve the lives of people. Therefore, the less educated had limited opportunities and earning potentials in the world of work (Ocampo, 2004). It was a well-orchestrated ploy by the apartheid regime to put other groups of people in society well ahead in terms of potential and opportunities. The careful machinations shaped a society of classes divided along racial lines as a result of differentially allocating resources for education (Selod & Zenou, 2003). More resources were allocated to white education, followed by Indian education, coloured education and finally black education received the least resources (Ocampo, 2004; Selod &
Accordingly, the socio-economic status of the black and coloured communities was placed on the bottom rung of the class ladder in society. These communities were relegated to a low earning working class (Branson et al., 2012).

The abolishment of education policies informed by racist agendas after independence resulted in the emergence of new school contextual settings (Christie et al., 2007). Former White, Indian and Coloured schools became multicultural schools as a result of the integration of the races (Viljoen, 1998). However, most of the Black schools retained the same enrolment of learners from African origins (Christie et al., 2007). Private schools also emerged out of the process (Selod & Zenou, 2003). Some of the private schools charge exorbitant fees and therefore access is restricted (ibid.). The former White schools also charge fees while most schools in the formerly disadvantaged communities are no-fee schools (Ocampo, 2004). For the purposes of redress, the government allocates more funds to schools in previously disadvantaged, poor communities. However, the funds are not enough to make an impact in the short term (Ocampo, 2004). Notwithstanding every child having access to education, some inequalities in terms of access to quality education still exist. Christie et al. (2007) point out that the former disadvantaged schools continue to be resource-strapped in post-apartheid South Africa and some of them teach science without laboratories. The implications are that schools with no laboratory facilities cannot practise laboratory instruction meaningfully. The role and goals of laboratory work in science education cannot be fully realised in the resource-strapped schools.

Methodology

The research approach is qualitative and is in the form of a phenomenological study. Qualitative research is concerned with the meanings people make of the world around them (Ritchie & Lewis, 2003). Accordingly, in this phenomenological descriptive study, human experiences are viewed through the eyes of the people who are living them (Cohen et al., 2007). The study describes the laboratory instruction experiences and the opportunities of scientific inquiry engagement in seven schools set in different contexts. Semi-structured interviews with physical sciences teachers, focus-group interviews with learners, laboratory activity observations and field notes were used to generate data. Purposive sampling techniques were used to select one school from seven different contextual settings. The seven schools are an African township school (AT), an African rural school (AR), a former coloured school (FC), a former Indian school (FI), a former Model C school (FM), a private school (PV) and an independent school (IN). One physical sciences teacher was chosen from each school to participate in the study. A physical sciences class taught by each of the teachers participated in the laboratory activity that was observed and video recorded. Six learners were chosen from each class to participate in the focus-group interviews. The field notes, transcripts of the interviews and the videos of the laboratory activities were subjected to qualitative content analysis methods. Qualitative content analysis methods are used to analyse text data generated during research designs such as phenomenology, grounded theory, historical research and ethnography (Hsieh & Shannon, 2005). The method involved reading the text data and assigning headings to it on the edges of the page. The reading process is repeated with the aim of collecting the headings into larger groups called
categories. The process is stopped when it is no longer possible to reduce the number of categories. The categories are then used to describe the data (Elo & Kungas, 2007).

**Findings of the study**

In this section, the findings from each school context are discussed separately. A summary of the findings is however presented at the end.

**AT school**

This is an African township school. Learners from African origins only, constitute the school enrolment. The school has one science laboratory containing mostly donated materials and equipment. It is difficult for the school to replenish consumables because of lack of sufficient funds. The teacher explains the situation in the following excerpt from the interview transcript.

> The equipment that we received in the laboratory that we are working with was donated by (a multinational company in the motor industries). Without them it was very, very bad but now we have these tables with all the equipment inside through the support of [the company] [...] There’s also another donation that we received from (another organisation). We received some chemistry kits and some first aid kits. These are the people who have supported us and [the multinational company in the motor industries] they have really supported us.

The teacher saw the need for the laboratory to be improved in terms of equipment installation. The following is part of his reflections about how the laboratory can be improved.

> If ever my laboratory can be well equipped with mounted projectors and screens, fume cupboards to extract the gases and running water because up to so far we don't have running water. We are just using... We bring water inside and then if ever there is an emergency if there is a fire there will be a problem we need fire extinguishers.

In the laboratory activity that was observed, the teacher mounted the experiment apparatus for the learners. He was extra cautious so that the learners would not damage the equipment. He first did a demonstration of how they should execute the steps of the experiment procedure before the learners could conduct their own experiments. The single laboratory in the school could not ensure frequent learner engagement in laboratory work activities. Therefore, the development of the learners’ handling and manipulative skills were compromised.

**AR school**

In this African rural school, the enrolment consists of learners from African origins only. There was no laboratory in the school. The school only had two recently built blocks of classrooms. Each block had two classrooms. These were complemented by a few more classrooms built of corrugated iron sheets. Learners occasionally conducted practical work in a classroom. This was done by bringing in equipment and materials and setting up the
apparatus for experiments on tables. The laboratory experiences were rare for learners because an external agent facilitated them. He brought the equipment and materials with him because the school did not have any. It meant that the physical sciences teacher in the school could not conduct teacher demonstrations. The learners also expressed anxieties about how they will cope if they find themselves in proper laboratory settings in their future study endeavours. They expressed fears that they may not be able to name and identify laboratory equipment and materials. The laboratory activities facilitated by the external agent integrated technology in the form of computers and software. He however assisted them by first doing a demonstration before the learners could conduct their own experiments. This was very challenging for learners who did not know how to operate computers. One learner pointed it out in the following excerpt from the interview transcript.

Researcher: What do you think is most challenging when you are doing experiments?
Learner: The one thing that gives me fear? For me it’s this thing, it’s the computer for me.
Researcher: The computer?
Learner: Yes. We don’t have computers in our school and I don’t even understand how to operate it… I don’t understand, I am just like okay this how it’s done. I am just quiet but I do not really understand and I am looking at how it’s done.

Learners were not familiar with proper laboratory settings. They rarely engaged in laboratory work. Consequently, the learners’ handling and manipulative skills were poorly developed.

FC school

This school is a former coloured school but presently enrols learners from multicultural backgrounds. However, coloured learners formed a significant majority. There were two science laboratories in the school. The laboratories were also used as classrooms to teach subjects other than science. Consequently, the laboratory equipment and materials were locked away in adjoining storerooms. They were only taken out when they were needed. However, the teacher felt that although they had materials to engage learners in laboratory work, it was not sufficient. This is reflected in the following interview transcript excerpt,

We are averagely stocked in as far as the equipment is concerned. Some of the equipment is not being used but we are also short of the other equipment. We will place an order very soon I think also to accommodate for the grade 12 CAPS, which we should be implementing next year.

Under the circumstances, laboratory activities were mainly conducted as teacher demonstrations. In the laboratory activity that was observed, the teacher set up one apparatus and the learners took turns to conduct the experiments. The teacher was also hands-on, assisting the learners to execute the steps of the experiments. It appeared as if the learners needed the assistance in order to conduct the experiment successfully. The two laboratories, which were sometimes used as classrooms for other subjects, were not adequate for learners
to have meaningful laboratory work time. Consequently, the learners’ handling and manipulative skills were poorly developed.

**FI school**

In this former Indian school, learners came from multicultural backgrounds. There were four science laboratories in the school. However, they were not properly set up because they looked like classrooms with cupboards to store materials, equipment, learners’ desks and chairs. For practical work, 4-6 desks were pushed together to create a working post for learners to work in groups. Despite the fact that the laboratories in the school still needed to be constructed properly for that purpose, the materials and equipment necessary to engage learners in practical work were available. The school had recently received more materials in the form of chemistry kits. It is revealed in the following excerpt from the interview transcript.

> Of late, I have attended a workshop; there are new kits that they make for convenience for places that do not have proper laboratory facilities, like personally the other challenge is this is not a proper laboratory setting … The work benches.

The teacher was aware of some of the shortcomings of the laboratory facilities and suggested ways in which they could be improved. She lamented the lack of equipment to facilitate the incorporation of technology in laboratory work. She said:

> The other support that I would like personally in this era that the kids are in, I think the technology is lacking because fine they have to see but there are some things that I might not want to do because they are dangerous and which can be shown visually on projectors and so on. So here, I don’t have access to those things.

Learners were however frequently engaged in laboratory activities. In the laboratory activity that was observed learners were able to assemble equipment and materials and set up the experiment apparatus with minimal help from the teacher. The learners affirmed their frequent engagement in laboratory work as revealed in the following excerpt from the focus group interview transcript.

> Researcher: How often do you conduct chemistry experiments in the lab or let’s just say physical sciences experiments in the lab?

> Learner: I would say at least twice in a week.

**FM school**

This is a former Model C school and was established over a century ago. Being a former white school it is now a multicultural school. There are four well-equipped science laboratories in the school. The school also recently received chemistry micro kits to augment the materials they already had in the laboratories. Despite the availability of laboratory facilities, the teachers and the learners revealed that practical work in which learners were hands-on was not conducted too often. The following excerpt from the teacher’s interview transcript reflects this.
Because we don't do practicals that often we do a lot with them quite often in the form of demonstrations…

In the laboratory activity that was observed, learners were able to follow instructions from a worksheet, set up the experiment apparatus and conduct the experiments with minimal help from the teacher. In one of the experiments, the water bath used to trap the gases escaping from boiling liquids was too low. Learners were able to improvise by putting two lunch boxes under the water bath so that they could continue the experiment. The teacher confirmed that her learners were able to handle and manipulate materials to conduct experiments when she said:

And then on that day as a teacher I am just an observer I walk around and make sure everything is safe but they can’t ask me questions about the actual practical. Safety issues I will address but nothing else.

In this school, science laboratories were well equipped and continually replenished with materials. During the laboratory activity, learners displayed well-developed skills in handling materials and manipulating equipment. The learners went as far as being able to improvise as they set up the apparatus.

**PV school**

This is a private school enrolling learners from multicultural backgrounds. However, learners from African origins constituted a significant majority. The school has four well-resourced science laboratories although the working posts were made from joining learners’ desks. The laboratories had equipment to enable integration of technology during laboratory work. The teacher revealed how he used technology to enhance the laboratory experiences of learners in the following excerpt.

If we realise there is not enough apparatus I can just do demonstrations in class and then we use the projectors to collect the information and then they analyse the results.

The observation of the laboratory work activity lasted three hours. Learners worked in groups to design steps for experiment procedures and conducted the experiments afterwards. They received minimal assistance from the teacher. The teacher was confident about the learners’ ability to handle materials and manipulate equipment by themselves. The learners successfully completed their laboratory work tasks.

**IN school**

This is an independent school enrolling learners from multicultural backgrounds although white learners constituted a significant majority. Learners in the school write examinations administered by the Independent Examinations Board (IEB). However, according to the teacher the physical sciences content that they teach learners is not very different from the content prescribed in the National Curriculum Statements (NCS). She had this to say about it:
IEB is Independent Examinations Board you see it’s just the same syllabus as the government schools but the exams are administered not by the government or the department but by the IEB.

The school has four well-equipped science laboratories. Two laboratory assistants work in the laboratories. The teacher expressed her satisfaction when she said,

We are very lucky in the school because we have nice apparatus. We have laboratory assistants so it’s very, very easy to do practicals. We are a very privileged because the material is available.

The learners frequently engaged in hands-on laboratory activities and were scheduled to do practical examinations periodically. The teacher said, “They do their practical exam. The Form 3s do it twice a year, the Form 4s and 5s do it three times a year”.

In the laboratory activity that was observed learners were able to select materials and equipment for the experiments and set up the apparatus. They did not struggle with handling and manipulating materials and equipment. They also demonstrated that they understood the scientific method of inquiry. The following conversation that the researcher had with the learners reflects this.

Researcher: Do you think there's anything challenging when you are doing practicals? Anything that you feel is challenging?

Learner 1: Sometimes they would ask us to do something and we are not sure how to do it exactly like how to control like variables and stuff. I think like that previous experiment we don’t know exactly what the results were supposed to be. It may be contaminated water and then you have a different reading than what you are supposed to have and you are not sure whether it’s the right answer or not.

Learner 2: Good answer.

Summary of the study’s findings

Schools from African townships and African rural contexts were the hardest hit in terms of the scarcity of laboratory facilities. The conditions of laboratory facilities in the former coloured schools were not conducive to laboratory work. There was no science laboratory in the African rural school with an enrolment of about 400 learners. There was one science laboratory in the African township school with an enrolment of about 1500 learners while there were two science laboratories in the former coloured school with an enrolment of about 1500 learners. The lack of proper facilities for laboratory work resulted in the poor development of the learners’ handling and manipulative skills. Learners heavily depended on the teachers’ assistance to select the materials and equipment, set up the apparatus and do the experiment. The situation was different for the former Indian, former Model C, private, and the independent schools. There were four science laboratories in each of those schools. Materials and equipment to engage learners in meaningful laboratory work was available. During the laboratory activities, learners demonstrated that they could handle materials and manipulate equipment very easily. This could be attributed to the increased number of opportunities the learners had to experience laboratory work instruction. The
learner enrolment figures are provided just to give a picture of the size of the school because not all learners study physical sciences in grades 10-12.

Discussion

Physical sciences learners experience laboratory work instruction differentially in South Africa. Access to laboratory work bears the scars of the apartheid legacy. Formerly disadvantaged schools still lag behind in terms of providing quality laboratory experiences to learners. African township, African rural and former coloured schools lack the laboratory facilities and resources to place laboratory work in its rightful place as a central feature in physical sciences education. Christie et al. (2007) affirm that learners in post-apartheid South Africa differentially experience education because many formerly disadvantaged schools continue to be resource-strapped. The question of what learners lose when they do not experience laboratory instruction in physical sciences has to be confronted. Learners are denied the opportunity to develop important laboratory skills and knowledge namely, (1) manipulative, inquiry, investigative, organisational and communicative skills, (2) important concepts such as hypotheses and theoretical models, (3) cognitive abilities such as critical thinking, problem solving, application, analysis and synthesis, (4) understanding the nature of science, and (5) positive attitudes towards science (Blosser, 1990). The findings of this study revealed that learners in schools with better laboratory facilities at least had well developed manipulative skills and had better chances of experiencing scientific inquiry. Branson et al. (2012) attribute the enduring inequalities in accessing educational facilities to continued disparities in earning potentials among the different cultural groups. Unemployment is rife in the formerly disadvantaged sectors of society and they have limited opportunities to improve facilities in their schools. Since the building and maintenance of proper laboratories is very costly for poor communities, this study recommends that the government, stakeholders and schools make an attempt to avail low cost physics and chemistry kits that can even be used in ordinary classrooms. It also recommends the incorporation of technology in ways that reduce the costs of laboratory instruction. Laboratory instruction should be a central feature of science teaching and learning as affirmed by the literature.

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Part C
Technology
Long Papers
A comparative analysis of beginner and veteran teachers’ procedural and pedagogical knowledge in ICT-enhanced classroom

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This paper presents the results of a quantitative and qualitative study which comparatively assessed 117 beginner and veteran Office Data Processing (ODP) teachers’ procedural functional and pedagogical knowledge in an Information Communication Technology (ICT)-enhanced classroom in 11 Technical Vocational Education and Training (TVET) colleges in Gauteng Province, South Africa. The data collection instrument that was used in this study is a procedural functional and pedagogical content knowledge (PrFPACK) framework self-report survey questionnaire, with 65 items in 13 subcategories and classroom observations. The survey was validated through confirmatory factor analysis. The main findings revealed that teachers’ experience is an important construct that moderates the dynamic relationship between procedural knowledge (PrK) and pedagogical knowledge (PK). While both beginner and veteran teachers had access to the same ICT tools, they had different experiences teaching with (and without) ICT tools. The qualitative analysis explicitly revealed that beginner teachers lack PrK as they avoided the use of ICT tools because of their inability to solve technical problems. While experienced teachers learned to solve technical problems from the technicians over the years. Based on the discussion of the results, this paper concludes with recommendations.

Keywords: Computer integration, ICT training, TVET College, Procedural Functional Knowledge.
Introduction
The integration of technologies has become a policy choice in educational development and reform in South Africa. The emergent trajectory reinforces the belief that conventional approaches to teaching cannot cope with the high skills shortage in the country. Teachers today are expected to develop lessons that not only teach students academic content knowledge but also equip them with the 21st century skills that will enable them to be effective inventive thinkers, active problem-solvers and digitally literate citizens (Partnership for 21st Century Skills, 2004). Educators across South Africa and in many other developing countries are encouraged to use technology in innovative ways to enhance the learning experience across the curriculum. The benefits of such innovation can only be realised if educators are integrating technologies effectively in their pedagogical practices.

ICT comprises a complex set of applications and services used to produce, process, distribute and transform information (United Nations, 2005). The ICT sector consists of diverse segments such as telecommunications, television, radio broadcasting, computer hardware, software, services and print media, electronic media including web technology such as the Internet. The term ICT has been used to encompass technological innovation and conveyance in information and communication leading to the development of information and knowledge societies with resulting changes in social interaction, economic and business practices, political engagement, education, health, leisure and entertainment (United Nations, 2005).

Globally, lack of ICT-related knowledge and skills among beginner and experienced teachers has been seen as a major obstacle to realising ICT-related objectives of colleges and schools (Pelgrum and Anderson, 2001). Generally, both beginner and experienced teachers feel confident about the basic skills but less about addressing some technical applications problems. This claim is backed up by numerous challenges that exist in literature about the integration of technologies in an ICT-enhanced classroom instruction. Flanagan and Shoffner (2011) studied two experienced and beginner English teachers’ method in solving the computer technical problems and discovered that both beginner and experienced teachers rely on trial-and-error methods and often avoided using ICT tools when they did not have access to technological skills and resources. Schmidt and Allen (2001) suggest that perhaps the most difficult challenge for teachers is lack of training and preparation for technology use in ICT-enhanced classroom instruction. Ruthven, Hennessy and Brindley (2004) report that often teachers that are trained with obsolete technologies lack in-service technological training, as well as a desire for the better preparation as pre-service teachers and continued preparation as in-service teachers. The new technologies are perceived as a catalyst for change in teaching and learning styles, and access to information. It is argued that the use of the technologies in the formal subject-based classroom benefits the learner as he/she is able to learn the technological skill with real tasks (Watson, 2001).

Nevertheless, there are factors that can either enhance or hinder educators from integrating new technologies effectively in their pedagogical practices. Therefore, it is imperative to understand the level ODP educators’ procedural, functional and pedagogical knowledge towards the effective integration of ICT. Following on the study’s context presented above, the background to the study, from which the specific research problem ensues, is provided. This is followed by a discussion about the conceptual background, then the methodological design and theoretical framework.
Background to the research problem
In the first decade of democracy, the South African government embarked on radical reforms to the apartheid education system. One such set of reforms involved the restructuring of the Further Education and Training (FET) now Technical and Vocational Education Training (TVET) sector. A New Institutional Landscape for Public Further Education and Training Colleges: Reform of South Africa’s Technical Colleges Department of Education (2001) was released in September 2001. The reorganisation of the TVET colleges sector brought with it the prospect of meeting the objectives of the country’s Human Resources Skills Development Strategy (Department of Education (DoE) & Labour, 2001). TVET colleges would be transformed so that they offered learners “high-quality, lifelong learning opportunities that are essential to social development and economic competitiveness in a rapidly changing world” (DoE, 2001:5).

The TVET college sector continues to be a challenge in South Africa’s education system. It is still seen by some as an institution where students who do not fit anywhere else go. However, in the last few years several attempts have been made to turn the sector around and ensure it provides South Africa with the necessary skilled personnel as a developing economy. The TVET colleges in South Africa now have more access to the new technologies than in the past. In addition, much investment is being made into the ICT infrastructures in these colleges where vocational and technology-based subjects are being offered for artisanal skill development Beatty, (2001). Nevertheless, research evidence has shown that educators in TVET colleges are not integrating ICT effectively in their pedagogical practices Beatty (2001). It is therefore, necessary to understand the level of ODP educators PrFK and e-skills towards the effective use of ICT infrastructures as pedagogical tools for productive teaching and learning.

The understanding of ODP educators’ knowledge and e-skills levels are pertinent issues that could help to improve and develop strategies to better prepare them to use the new technology tools in their ICT-enhanced classroom instruction effectively. A mixed method approach was chosen as a suitable methodology to explore pertinent information that will increase our understanding of teachers and enable us to empirically measure their knowledge and e-skills level. In South Africa context, e-skills means the ability to use ICT within an emerging information society and the global knowledge economy in which ICT has become an essential requisite for advancement in government, business, education and society at large Mitrovic, Taylor, Sharif, Claassen and Wesso (2013). ICT, when used as a pedagogical tool, should include the use of software applications to solve problems and provoke student capabilities as well as to communicate and share their perspectives with each other. Research conducted in Saudi Arabian schools also concluded that “ICT can remove barriers that inhibit educators’ and learners’ access to information” (Almaghlouth, 2008:32). The focus in this study is on the ability of teachers to use ICT resources to create solutions to the problems in the content in order to motivate and stimulate students’ interest in an ICT-enhanced classroom teaching and learning. The guiding questions examined in this research are the following:

a) What is the level of ODP beginner and veteran educators PrFK and e-skills in the use of ICTs as pedagogical tools?
   
   $H_0$: There is no significant relationship between beginner and veteran ODP educators PrFK and e-skill in the use of ICT as pedagogical tool.

b) What relationship exists between beginner and veteran ODP educators’ PrFK and PK in the use of ICT?
Research purpose
The aim of this paper is to report the findings of the study that comparatively assessed the beginner and veteran ODP educators’ technology use in an ICT-enhanced classroom in TVET colleges in Gauteng Province, South Africa. To the best of our knowledge not much qualitative research has been conducted that directly addresses the level of the PrFPK of veteran and beginner teachers in the use of ICT in TVET colleges for effective teaching and learning outcome.

Conceptual background
The term ICT has been used to encompass technological innovation and conveyance in information and communication leading to the development of information and knowledge societies with resulting changes in social interaction, economic and business practices, political engagement, education, health, leisure and entertainment (United Nations, 2005). The concept of ICT, however, as an important development mechanism, is still a fairly recent phenomenon in many developing countries (United Nations, 2005). There is demand for a highly skilled workforce that uses ICT tools for innovation, creativity, improved performance and societal transformation is enormous. The ability to use ICT in this manner is known as E-skills. The European e-skills forum defines e-skills and its associated competencies as the ability to develop and use ICTs within the context of a knowledge environment, which will enable the individual to successfully participate in a world in which ICT is an essential requirement for advancement in activities of government, civil society and business (Mitrovic, et al. 2012). Teachers today are expected to develop lessons that not only teach students academic content knowledge but also equip them with the 21st century skills that will enable them to be effective inventive thinkers, active problem-solvers and digitally literate citizens (Partnership for 21st Century Skills, 2004).

Knowledge needed to use ICTs as pedagogical tools
The essential types of knowledge that can enhance effective teaching and learning in an ICT-enhanced classroom have been identified as PrFPACK Adegbenro, Mwakapenda & Olugbara, (2012). Adegbenro, Gumbo & Olugbara, (2015).

Procedural knowledge (PrK)
According to Biggs (1999), this knowledge is the ability or skills of the knower to choose and perform some actions in an appropriate and effective manner. Procedural knowledge is the skill to know the appropriate ICT equipment to choose as instructional materials and to understand the procedure to follow in using the equipment to transfer knowledge to the learners and be able to solve basic recurrent troubleshooting problems from the computer without disrupting the lesson. According to Schneider and Stern (2010), Gavota (2010, p. 496), Nissen (2006), and Biggs (1999), procedural knowledge is development of skills and knowing how to perform a task correctly at a given time. Many researchers concluded that the only test of this type of knowledge is to set a practical “skill” test in which the candidates perform the action effectively. Gavota, Cattaneo, Arn, Bolrini, Motta, Scheider and Betrancourt (2010: 495-511) in their recent study of instructional method to promote professional skill development in the Swiss vocational education and training (VET) system,
posits that procedural knowledge represents the knowledge that can be directly applied to a task, to perform it correctly.

**Procedural Functional Knowledge**

As Niess (2006) and Biggs (1999) reported, “Procedural Functional Knowledge PrFK is the actual application of e-skills and rules in using technological tools”. Without effective application of right procedure, steps and principles, teachers cannot have successful classroom instruction in ICT-enhanced classroom that will ensure the students acquire the necessary skills. Claro, Presis, Martin, Jara, Valenzuela & Nussbaum (2012) in their recent assessment of 21st century ICT skills in Chile define functional skills in an ICT-enhanced classroom as the mastery and understanding of ICT applications and the understanding of the general principles, rules and concepts of how to use Computers. Functional Knowledge is defined by Ryle (1958) as “know how”, having the ability to know how to describe a function and rules but not to articulate description of what is known and put it into practice effectively. Biggs (1999) describes this kind of knowledge as “functional”.

As Selinger and Kirschner (2003) confirm, the “Majority of teacher training students are graduating in an information age without proper guidance on how to use technology tools in the classroom effectively and solving recurrent technical problems. Shafer and Bruewer (2011) reported “Tasks are designed to be pleasantly frustrating when there is no just-in-time technical support, and the strategy learned in one task becomes a skill in subsequent tasks, leading to a cycle of novice-expertise problem solving activities.”

**Pedagogical approach in ICT-enhanced classroom**

According to Osuala (2004), demonstration is one of the modern methods of the teaching strategy in ODP instruction. Demonstration is most suited for showing manipulative operations of any equipment, for explaining a process and the teaching of principles. Osuala (2004) argues that little has really been accomplished for the prospective ODP in-service teachers to have a reasonable understanding of the modern teaching methods, system analysis and office skills with modern ICT tools. As Richard and Rodgers (2001) reports, “using small group work as a teaching strategy promotes active participation in learning and motivation.” It improves learners’ depth of understanding and develops communication skills as the peers speak in their home language; it improves problem solving skills and helps the learners to discover multiple solutions to problems. Richard and Rodgers (2001) report that teachers should show ability in using approaches and methods flexibly and creatively based on their own judgments and experience.

**Procedural functional knowledge (PrFK)**

As Niess (2006) and Biggs (1999) report, PrFK is the actual application of e-skills and rules in using technological tools. The whole content of the 10 unit course in National Certificate Vocational (NCV) level 2 in FET colleges is computer system based and is taught with the computer system connected to the Interactive Teaching Box projected on the white smart board with internet connectivity and functional windows media to teach Audio Typing. Without the effective application of the right procedure, steps and principles, teachers cannot have successful classroom instruction in an ICT-based classroom that will ensure the students acquire the necessary skills. According to Selinger and Kirschner (2003), majority teacher trainees graduate in an information age without proper guidance on how to use technology tools in the classroom effectively and solving recurrent technical problems. Shafer and Bruewer (2011) claim that the designed tasks frustrate students when there is no
just-in-time technical support and strategy learned in one task becoming a skill in subsequent tasks, leading to a cycle of novice-expertise in problem solving activities.

Theoretical framework
PrFPACK is a theoretical framework proposed to holistically explore the technological knowledge and e-skills of teachers in an ICT-enhanced classroom. According to Adegbenro, Olugbara and Mwakapenda (2012, 2015), this framework extended the classical Technological Pedagogical and Content Knowledge (TPACK) by replacing "technological knowledge" with PrFK to give the framework a precise clarity. Mishra and Koehler (2005) updated and built on Shulman’s (1986) idea of PCK. Mishra and Koehler proposed the necessity for the integration of technology with PCK and named the resulting amalgam knowledge TPACK. Authors such as Yilmaz-Ozden, Mouza Karchmer-Klein and Glutting (2013) confirm the need to provide more clarity about TPACK and to revisit measurement inventories built directly around it. The PrFPACK inventory consists of a set of 65 comprehensive measures that were re-organized into thirteen sub-domains of knowledge.

We defined a measure as comprehensive if it is unambiguous and it directly measures what it intends to measure in clear terms. The knowledge sub-domains relate to specific theoretical constructs such as PK (pedagogical knowledge), CK (content knowledge), FK (functional knowledge), PrK (procedural knowledge), PCK (pedagogical content knowledge), PrPK (procedural pedagogical knowledge), PrFK (procedural functional knowledge), FCK (functional content knowledge), PrFCK (procedural functional content knowledge), PrFPK (procedural functional pedagogical knowledge), PrPCK (procedural pedagogical content knowledge), FPCK (functional pedagogical content knowledge) and PrFPCK (procedural functional pedagogical knowledge). Figure 1 shows PrFPACK that was used in this study to empirically explore the level of ODP teacher’s knowledge and e-skills in the use of ICT as pedagogical tools. The PrFPACK framework specified a set of common items, which is outcome-based in scope, which measures specific technological proficiency and expertise with the computer and data projector for pedagogical practices.
In the next section we discuss the methods that we used in the study.

**Methodology**

The study addressed the above stated research questions by adopting a mixed-method explanatory approach. A survey was conducted among 117 ODP educators in 11 TVET colleges in Gauteng Province. It by comparison assessed beginner and veteran educators’ level of PrFPK with regard to the use of ICT infrastructure as part of their pedagogical practices in an ICT-enhanced environment. A quant-qual mixed-method (Creswell, 2009) assisted us to come up with more comprehensive and holistic findings which integrate various aspects of the problem investigated. The observation portion was used to explore the relationships found in the survey for the proper understanding of the e-skills and PrFPK of ODP educators. Information was collected about the teachers’ gender and years of teaching experience, pedagogical approach, PrFPACK, competency in solving basic technical problems, and challenges in using ICT infrastructures.

**Sample, instruments and procedure**

A total of 117 ODP educators from 11 TVET colleges in Gauteng Province participated in the study. The survey addressed knowledge and e-skills in specific domains such as Word processing, spreadsheets, audio typing and advanced database, computer file management, PowerPoint presentation, interactive teaching box (ITB), Internet and World Wide Web Technology. This is in line with the requirements for the NCV (DoE, 2007:2-4). Each point had responses on a five-point Likert-type scale: (1=highly incompetent, 2=incompetent, 3=fairly competent, 4=competent, 5=highly competent). The survey questionnaire was pilot tested with 24 ODP educators in 5 TVET colleges in Gauteng Province for validity and internal consistency. The findings from the pilot test revealed that all 65 items addressing 13 knowledge constructs were reliable since Cronbach Alpha’s were all greater than 0.7. The teaching experience of these teachers ranged from 1 to 25 years. The ODP educators’ responses from the 11 TVET colleges in Gauteng Province influenced the selection of the cases, i.e. factors such as years of teaching experience and availability of all ICT tools. Six beginner and six veteran teachers participated in 2 classroom observation each. The survey data template (SDT) of teachers’ e-skills and PrFPACK and observation checklist were designed for data collection. The extended PrFPACK SDT consists of a five-point scale with the above Likert Scale.

In the second phase, purposive sampling was used to select 6 beginner and 6 veteran ODP educators from 3 TVET colleges that are fully equipped with ICT tools and internet connectivity responded to the interview questions. Qualitative data collection occurred through ODP beginner and veteran educators’ interviews and classroom observations for six ODP educators. During the ODP instructional periods in ICT-enhanced classroom, each ODP educator had 30 students in NCV level 2 with 30 computers in each class, 30 Dictaphone for Audio Typing, 2 printers, one Interactive Teaching Box with Smart board and data projector. Teachers were interviewed before and after each actual classroom observation. Observation focused on pedagogical e-skills, procedural and functional knowledge, teachers’ reaction to basic technical problems and teachers response to students’ questions and confusions. All observations lasted for 45 minutes with 10 minutes post interview after the classroom observation. Collected data were read and reviewed and sorted into categories and sub-themes for beginner and veteran teacher which emerged during the
analysis. These sub-themes were coded using key words mostly from the above explained framework (Patton, 2002:446). An external analyst also reviewed the data to intensify the rigor, ensure reliability and trustworthiness of the data analysis process.

**The measurement model**

The measurement model was tested for discriminant and convergent validity. Both discriminant and convergent validity are obtained by comparing the values of average variance extracted (AVE) and composite reliability. Hair, Black, Babin, Anderson and Tatham (2006) asset that the AVE value should exceed 0.5 for a model to be declared reliable, whereas the composite reliability should be above 0.7. All constructs exhibited good AVE values, PrK having the higher value of 0.658591. On the other hand, the composite reliability for each of the constructs was high with PrK having a higher value of 0.906002. From the AVE values and composite reliability obtained, we claim that the suggested model has a good discriminant and convergent validity. Hence, it is suitable to be used to access the educators’ level of PrFPK and relationships between procedural, functional knowledge and pedagogical knowledge constructs.

**Results**

The results of the study are discussed based on the research questions and related hypothesis:

(a) What is the level of ODP beginner and veteran educators PrFPK and e-skills in the use of ICTs as pedagogical tools?

H₀: There is no significant difference between beginner and veteran ODP educators PrFPK and e-skill in the use of ICT as pedagogical tool.

(b) What relationship exists between beginner and veteran ODP educators’ PrFK and PK in ICT-enhanced classroom?

**Testing the relationships**

After reaching an acceptable, valid model the hypothesised relationships of the model were assessed. Figure 2 illustrates the hypothesised relationships between the constructs of the model.
Figure 2: The hypothesized relationships between the constructs of the model

Figure 2 illustrates the hypothesised relationships between the constructs of the model regarding the ODP beginner’s and experienced teachers’ knowledge categories. SK1 – SK5 represents the five questions used to assess PrK; FK1–FK5 represents the five questions used to assess FK; PK1-PK5 represents the questions assessing PK and method of teaching. The standardized parameter estimates are demonstrated in the model (see figure 2). The Latent Variable Correlations are shown in table 1, and the critical ratios illustrated in table 3 were compared to deduce the strength of the paths and the interpretations of hypotheses within the model.
Table 1. Latent Variable Correlations

<table>
<thead>
<tr>
<th></th>
<th>CK</th>
<th>Experience</th>
<th>FK</th>
<th>PK</th>
<th>SPrK</th>
<th>SPrK * Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>CK</td>
<td>1.00000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experience</td>
<td>0.278143</td>
<td>1.000000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FK</td>
<td>0.746098</td>
<td>0.245295</td>
<td>1.000000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK</td>
<td>0.698504</td>
<td>0.266688</td>
<td>0.700572</td>
<td>1.000000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PrK</td>
<td>0.737770</td>
<td>0.302079</td>
<td>0.849740</td>
<td>0.773131</td>
<td>1.000000</td>
<td></td>
</tr>
<tr>
<td>PrK * Experience</td>
<td>0.006070</td>
<td>0.080145</td>
<td>0.048183</td>
<td>0.123240</td>
<td>0.089360</td>
<td>1.000000</td>
</tr>
</tbody>
</table>

Table 1 shows the correlation between variables and table 2 below demonstrates the extracted standardised significance levels of the structural model. The values for the critical ratios between the variables that were needed to test the hypothesized relationships were obtained as shown in table 2.

Table 2. Extracted standardised significance levels of the structural model

<table>
<thead>
<tr>
<th>Paths</th>
<th>Estimate</th>
<th>S.E.</th>
<th>CR</th>
<th>P</th>
<th>Implication</th>
</tr>
</thead>
<tbody>
<tr>
<td>FK &lt;--- CK</td>
<td>.746</td>
<td>.106</td>
<td>3.829</td>
<td>***</td>
<td>Supported</td>
</tr>
<tr>
<td>PK &lt;--- CK</td>
<td>.268</td>
<td>.122</td>
<td>3.934</td>
<td>***</td>
<td>Supported</td>
</tr>
<tr>
<td>PrK &lt;--- CK</td>
<td>.234</td>
<td>.150</td>
<td>3.853</td>
<td>***</td>
<td>Supported</td>
</tr>
<tr>
<td>PK &lt;--- FK</td>
<td>.035</td>
<td>.097</td>
<td>1.556</td>
<td>.060</td>
<td>Not Supported</td>
</tr>
<tr>
<td>PrK &lt;--- FK</td>
<td>.675</td>
<td>.131</td>
<td>3.852</td>
<td>***</td>
<td>Supported</td>
</tr>
<tr>
<td>PrK &lt;--- PK</td>
<td>.576</td>
<td>.122</td>
<td>3.965</td>
<td>***</td>
<td>Supported</td>
</tr>
</tbody>
</table>

*** p < 0.001; ** p < 0.01; * p < 0.01

Table 3 illustrates the value of critical ratios between the variables that were needed to test the hypothesised relationships. It also demonstrates the extracted standardised significance levels of the structural model in Figure 2. McDonald and Ringo (2002) recommended that for significance, the critical ratio (CR), also known as the t-value, must be ±1.96. The hypothesised relationship that was suggested to exist between PK and CK exhibited a standardised estimate of 0.268, and CR of 3.934 which shows that this relationship is significant. PK as the method of teaching is directly connected to the CK. PrK and CK also exhibited a standardised estimate of 0.234, and CR of 3.853 which shows that the relationship is supported since CR level value is above the threshold and estimate value is positively high. PK and FK exhibited a low value of standardised estimates of 0.035 which suggest that the relationship is weak and the CR of 1.556 which is below the threshold and the estimate value is negatively low, indicating that the relationship between PK and FK is not supported. The ability of the teacher to be able to describe the rules that govern the appropriate selection of ICT as instructional materials and use the right procedure to teach the content on a data projector and procedures in the content through the use of appropriate methodology and strategies is thus weak. Prk and FK exhibited a standardised estimate of 0.675 and a CR of 3.852. This relationship was proved significant. PrK and PK exhibited a standardised estimate of 0.576, and a CR of 3.965 which indicates that the relationship is significant. Thus, PK as the method of instruction is directly connected to the procedure and
actual performance of the action. The method of instruction will enhance the appropriate
skill performance which leads to clear comprehension of the content.

The difference significance was tested at p < 0.05 (βa-exp-βa-inexp).

<table>
<thead>
<tr>
<th>Details</th>
<th>Veteran</th>
<th>Beginner</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effects of moderating factor to CK</td>
<td>0.662</td>
<td>0.372</td>
<td>0.251</td>
<td>0.461</td>
</tr>
<tr>
<td></td>
<td>7.633</td>
<td>4.781</td>
<td>1.721</td>
<td>1.881</td>
</tr>
<tr>
<td>Effects of moderating factor to PK</td>
<td>0.437</td>
<td>0.322</td>
<td>0.226</td>
<td>0.314</td>
</tr>
<tr>
<td></td>
<td>6.321</td>
<td>1.8642</td>
<td>1.154</td>
<td>1.531</td>
</tr>
<tr>
<td>Effects of moderating factor to FK</td>
<td>0.362</td>
<td>0.307</td>
<td>0.064</td>
<td>0.342</td>
</tr>
<tr>
<td></td>
<td>5.522</td>
<td>1.754</td>
<td>0.923</td>
<td>5.216</td>
</tr>
<tr>
<td>Effects of moderating factor to PrK</td>
<td>0.166</td>
<td>0.104</td>
<td>0.101</td>
<td>0.442</td>
</tr>
<tr>
<td></td>
<td>1.993</td>
<td>1.366</td>
<td>1.384</td>
<td>1.789</td>
</tr>
</tbody>
</table>

Findings and Discussion
The findings will be discussed under two categories in relation to the responses of the
research questions outlined above: (1) what is the level of ODP educators PrFPK in the use
of ICT as pedagogical tools? And (2) what relationship exists between beginner and
veteran ODP teachers PrFK and PK in ICT-enhanced classroom?

Procedural Functional knowledge in the use of ICT tools
According to Niess (2006) and Biggs (1999), procedural knowledge is the actual application
of skills in using technology tools. Educators may not effectively use ICT without having
the relevant knowledge and skills to solve basic technical problems during the lesson. It was
observed that most of the ODP beginner educators with 2 to 3 years teaching experience
struggled to achieve their lessons objectives due to recurrent basic technical problems which
often frustrated their efforts and caused embarrassment that often led them to abandon the
equipment. While veteran ODP educators with 7 to 15 years teaching experience promptly
address recurrent basic technical problems as the need arose based on the skills learnt from
the technologists over the years of teaching at TVET College. Selinger and Kirschner (2003)
state in this instance, that majority of teacher trainees who graduate in an information age
lack the proper guidance on how to use technology tools in the classroom. Almaghlouth
(2008) also found that when support to the teachers using technologies for teaching was not
readily available, the teachers lacked motivation to integrate the ICTs into class. However,
the context is now changing as shown by a veteran teachers’ remark:

I was actually trained during my professional teacher training with manual and
electric typewriter. Since there is no in-service training, I learnt to use these new
technologies through self-development over my years of teaching here.
Veteran teacher 4 (VT4) was teaching using Interactive Teaching Board ITB in ICT-enhanced classroom B - 23, VT4 was teaching the topic ‘Bullet numbering Skill’. Suddenly the Smart board went blank and the text disappeared. VT4 immediately checked the power cable connecting the ITB with the computer; found that the power cable was disconnected. The teacher is competent in her PrK to use ICT tools and solve basic technical problems competently without disrupting the lesson. She fixed the power cable firmly and the screen was restored and the lesson was not disrupted. By contrasts, beginner teacher 2 (BT2) had taught the students on how to start and shut down the computer after use. He instructed the students to start their computers and two students were unable to do so. The Central Processing Unit (CPU) was on but the monitor was blank. These students struggled to start their computer, even though the CPU was on, the monitor was blank. The technical staff intervened as the teacher was unable to start the machine. It was then found that the previous user had not shut down the computer properly, the technical staff used the F8 help key and used the Windows advanced help menu to restore the functioning. BT2 lack PrFK.

By contrasts, beginner teachers were hindered by the lack of technical skills to solve basic technical problems which made them to always abandon the ICT tools, despite the awareness of the benefits and importance of the technology tools. Shafer and Bruwer (2011) report that designed tasks can frustrate teachers in the absence of a just-in-time technical support, and that the strategy learnt in one task becomes a skill in subsequent tasks leading to a cycle of novice-expertise problem solving activities. The veteran teachers’ classroom practice supports Shafer’s and Bruwer’s (2011) findings.

The findings in this study give: (1) an in-depth understanding of beginner and veteran ODP teachers’ level of PrFPK and skills demonstrated in their classroom instruction in an ICT-enhanced classroom environment; (2) what beginner and veteran ODP teachers do to address basic technical problems in actual classroom practices. There is significant difference between beginner and veteran ODP educators PrFPK in the use of ICT.

**Relationship between ODP educators’ PrFK and PK in the use of ICT tools**

The method of instruction that was used by both veteran and beginner ODP educators in this study is demonstration method of teaching. According to Osuala (2004) and Aggarwal (1999), this method is one of the modern methods of teaching strategies for the ODP instruction. Demonstration is most suited for showing manipulative operations of any equipment and for explaining a process and the teaching of principles. Analysis of results in Table 3 indicates that experience has a significant influence on the three suggested relationship. This implies that teachers with experience will demonstrate competency in PK (i.e. competent in choosing the appropriate method of teaching and strategies as the need arises), FK (i.e. competency in being able to describe the concepts, rules and functions of ICT tools). For example, during the classroom observation, Veteran Teacher 2 (VT2) was teaching computer keyboarding as a topic in ODP. She described to the students the steps and rules they need to follow for speed and accuracy after she introduced the topic with clear explanation. One student encountered a freeze keyboard; the student could not type the task at the given period of time. The VT2 checked the keyboard cable connected to the CPU and the keyboard was restored without disrupting the lesson (PrK, i.e. having the ability to choose and use the appropriate ICT tools and able to solve recurrent basic technical problem and achieve lesson objectives, compared with Beginner Teacher 1 (BT1) who often have her lesson disrupted because of basic technical problems which could not always be solved by the teacher.
In Table 3 the PLS analysis of the moderating effects are in agreement with many research findings (Tozoglu & Varank, 2001; Olsen, 2000). These studies showed that veteran teachers are able to effectively enhance students’ motivation in ODP and also promote interest and attention in classroom activities. Olsen (2000) asserts that the effective use of technology by veteran teachers is one of the major strategies in improving throughput. Pierson (2001) concluded that it is crucial to have experienced teachers who can effectively use ICT tools to benefit students’ learning. All these researchers established that there exist significant interacting effects between the teachers’ experience and his/her PK and PrFK.

It was also observed that BT1 verbally explained the topic “Word Processing” during the classroom observation as typing words from a manuscript with speed and accuracy by also paying particular attention to all manuscripts signs and making all necessary corrections as instructed or indicated in the documents. While VT2 explained “Word Processing” with demonstration on the smart white board to explain the reasons while she was able to use the data projector and the smart white board effectively to teach her lessons. This teacher, who had 14 years teaching experience remarked:

Yes, I was trained on the content and concepts of ODP in my professional teachers’ training but I was not trained on how to use these new technologies; I learnt the skills through technical mentoring from the technologists on-the-job I also learnt the skill to address minor technical problems by asking questions from the technologists whenever they come around to fix all the recurrent technical problems over the years.

BT 2 with two years teaching experience commented:

Why I used verbal instruction as my method of teaching which waste a lot of time instead of demonstration on the data projector is because I was never trained on how to use ICT tools to teach a lesson in my teachers’ professional training. Although, demonstration on the data projector and the use of Interactive Teaching Board is the best to motivate students and make them to understand the skills you want to teach. But to avoid embarrassment I avoided the data projector!

In an ICT-enhanced classroom, it is imperative for educators to understand the relevant procedural and functional knowledge for the integration of ICT tools effectively. The reason for the low value of standardized estimates of 0.03 in the PK and FK as indicated in table 2 may be accounted for by lack of professional teacher training on the appropriate strategies in the use of ICTs to transfer knowledge to the learners as clearly stated by BT2.

Conclusion and recommendations
The objectives of this study were to access the level of beginner and veteran ODP educators’ PrFPK in ICT-enhanced classroom and to determine differences in their PrFPK in the use of ICT as pedagogical tools. The findings in this study give: (1) an in-depth understanding of the level of ODP educators’ PrFPK and the differences between beginner and veteran educators PrFPK demonstrated for their classroom instruction; (2) the understanding of the relationship between beginner and veteran ODP teachers’ PrFK and PK in the use of ICT infrastructures. The classroom observation allowed the understanding of the level of PrFPK and e-skills of teachers in an ICT-enhanced classroom. In addition, it enabled us to determine the depth of teachers’ professional competency. However, in order for us to be able to
determine the level of teachers’ PrFPK and e-skill, there was a need to observe them in the actual practice of teaching. The current findings reveal that beginner and veteran ODP educators have not received sufficient technological skills and training in the effective use of ICT tools in the technologically equipped classroom environment. Although the findings show that both the beginner and veteran teachers lack some training in the use of ICT for the enhancement of their teaching, the findings also revealed veteran teachers having an edge over beginner teachers evidenced in the observed veteran teachers’ ability to use ICT and solve basic technical problems compared to their beginner counterparts.

Based on the findings in this study, the following recommendations are made: the professional development of both beginner and veteran teachers in the use of new technologies in the digital age as pedagogical tools should be an on-going effort in all educational institutions. Teachers’ professional development is a catalyst that allows change and innovation in pedagogical practices. Educational stakeholders and teacher training institutions should include in their curriculum innovative methods of using new technologies as pedagogical tools and the understanding of procedural and functional knowledge in the use of ICT infrastructures in the digital classroom context.

References


Evaluating the Perceived Motivational Effect of 3D Support Lectures on Students’ Academic Performance in Higher Education

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Higher education (HE) students are growing up with technology devices and require an education system that can provide effective student academic performance and exposure to technology. Several studies indicate that using 3D technology support methods in class can enhance students’ learning. Cognisant of studies detailing successful 3D learning, along with first-year students’ poor academic performance and low class attendance, the researcher employed 3D technology support methods in lectures to establish the possible impact on teaching and learning. The study aimed to determine the perceived effect of 3D on students’ learning and to establish whether technology-orientated 3D lectures can improve students’ academic performance.

Student teachers (n=260) of a South African university participated in the study. The same content was taught to two classes using different lecturing methods in a Life Science Didactic class. The difference was that Class A (n=135) received extra support by viewing 3D images (using 3D glasses) during lectures, while Class B (n=125) did not view 3D images during their lectures and were taught in the traditional manner. At the end of the lectures for both classes, students were assessed by completing the same assignment. The scores of the assignment were compared to establish the effect of 3D lectures on students’ academic performance. In addition, class A also indicated perceived advantages of 3D lessons and completed a questionnaire on their experience with the 3D learning support method. The results revealed that low and high-performing students excelled in the assignment while there was no significant difference for the average-performing students. The reasons might be that the 3D lectures piqued their interest and encouraged them to learn more about the topic while enabling the low-performing students to solve problems (critical thinking) which they might not have been able to do without the additional 3D support method. It could be concluded that 3D contributed to students’ understanding and retention of abstract concepts and the development of critical thinking skills to solve problems.

Key words: 3D, abstract concepts, active learning, critical thinking, methods, motivation, technology.

Introduction

The demand for higher education (HE) is expanding globally and the needs of students are changing in relation to a developing technology-orientated world. Most students are growing up with mobile technology devices and require an education system that can provide for the development of their technology skills. Prensky (2001) refers to the new generation of HE students as digital citizens, with the implication that lecturers experience students differently from two decades ago. Digital citizens spend most of their lives surrounded by digital devices such as cell phones, computers, music players, video cams, and other tools. Gibbons (2007) indicates that the way they communicate, socialise, think and learn has an impact on their skills and learning style preferences in education. In agreement with Prensky (2001),
Oblinger (2003) states that these digital citizens prefer to be actively involved in lectures rather than passively relying on the lecturer to convey information to them. In addition, Prensky (2001) expresses his concern regarding a lack of digital competency skills among lecturers in HE, referring to them as ‘digital immigrants’. Prensky (2001) and Kennedy, Judd, Churchward and Gray (2008) emphasise that such lecturers need to adjust their pedagogical methods to meet the needs of the new digital generation. HE institutions should therefore actively respond to the demand for technological changes. Eaton, Guerra, Corliss and Jarmon (2011) argue that students not only want a good return on their investment but demand high quality learning experiences and exposure to technology. The transformation of the teaching and learning pedagogy and the extra support students need in using technology devices and programmes ought to be acknowledged. Lecturers should know which of the many stimulating new technologies can effectively be used for learning.

Research by Wang, Lin and Liao (2014) indicates that the needs of students and technology demands in HE could be addressed by designing 3D virtual rooms and applying lecturing methods supported with 3D illustrations. Their findings are supported by various research studies on the effect of 3D on students’ learning. Empirical evidence reveals that student performance improves as they absorb and understand information more quickly than with traditional teaching tools (Bamford, 2009; Jusko; 2013; Monahan, 2010), that students’ questions are answered immediately (Tao, Molnar Gregory, Das, Boland & Hickman, 2009), and that 3D images assist students in experiencing real-life curricular content, which could contribute to quality and effective student learning (Taylor, Beraldin & Godin, 2001). These positive effects of 3D support methods on students’ learning prompted the author to employ this evolving and exciting technology-supported method in lectures.

By definition, a 3D image can be described as viewing two images through 3D glasses, each eye viewing slightly differently from the other, and then connecting one observed image to the brain (Blanz, Tarr & Bultho, 1993). The two perspectives refresh and alternate various times per second, which the brain combines into one 3D image (Dalgarno, Hedberg & Harper, 2002). Students can thus view the object in depth, height and width, enabling them to experience real-world scenarios.

Despite the advantages of a 3D support method for effective learning, limited research results exist on the effect of 3D illustrations used in HE lectures. To address the needs of digital-age students and establish the effect of 3D support methods on students’ learning, the researcher employed 3D methods during lectures in answering the research questions:

- How do student teachers perceive 3D lectures as motivational to their learning?
- What is the effect of 3D lectures on student teachers’ academic performance?

**Background**

Students are growing up in a digitally-orientated world but are not always sufficiently exposed and trained in using available technological devices (Huang & Russell, 2006). Despite an increase in technology-orientated strategies and methods in HE the past two decades, students are still not always acquiring the knowledge and skills they need to equip them for effective learning (Rodley, 2005). The reason could be linked to a lack of both resources and access to technological equipment in historically disadvantaged universities (O’Connell, 2010). Marmolejo, Gonzalez, Gersberg, Nenonen, Campos, and Calvo-Sotelo (2007) agree that resource scarcity and lecturers not employing technology-supported
lecturing methods could affect students’ academic performance in HE.

Gökalp (2010) emphasises that HE institutions that do not succeed in developing students’ technology skills are seldom able to compete economically with other countries. Frequent changes and development of technology require changes in teaching and learning in HE (Tang & Austin, 2009). However, the influence of other identified factors, such as: large class sizes, diversified students’ needs, different socio-economic backgrounds (Scott, Yeld & Hendry, 2007); poor English second language skills, academically underprepared students, low class attendance (McMillan, 2011); financial constraints (Huang & Russell, 2006); lack of time management skills, self-discipline and motivation (Balduf, 2009); and insufficient exposure to emerging technology tools (Garrison & Kanuka, 2004) should also be considered as possible influential factors affecting student performance in HE institutions.

Although almost all HE institutions have now implemented an online course component, Michael (2001) emphasises that lecturers should be able to use technology support effectively in their courses and progressively change and modernise their teaching methods. Methods of implementing technology in their HE institutions will vary from country to country. For example, in the United Kingdom the three main approaches are:

- The provision of additional support material online.
- The use of interactive information and communication technology.
- The use of research-orientated technology activities to stimulate the development of independent learners (Brouwer & McDonnell, 2009).

In the United States, the Life Project established as early as 2002 that the majority of students already used the internet to do research and acquire knowledge for their studies (Jones & Madden, 2002). In addition, a study executed by Kvavik (2005) on HE students shows that the frequent use of the internet and message system varied according to the major subjects that students opted for in their academic courses. In Australia, research in 2005 indicates that first-year students then already spend at least four hours per week on the internet (Krause, Hartley, James & McInnes, 2005). Furthermore, Australian students’ use of blogs, podcasting, and instant messaging increased between 2005 and 2007, and more than 90% of students used the web for their studies and personal communication (Oliver & Goerke, 2007).

The need for effective technology support to enhance students’ academic performance is undeniable. However, a decline in students’ lecture attendance could also influence the success rate (McGarr, 2009). The tendency not to attend classes could also be attributed to classes not being interesting and thus not motivating students to attend. Keller (2004) propagates that methods employed should comply to the ARCS (attention, relevance, confidence, and satisfaction) model of motivational design strategies, namely: interest students’ and attain their attention in the lesson, be relevant to real-life situations, enhance students’ confidence in interactive class discussions and satisfy students in achieving successful learning.

Conversant with first-year students’ poor academic performance, lack of interest in classes and low class attendance, the researcher was inspired to use 3D methods based on previous studies of 3D learning. For instance, the National Research Council of Canada compared 2D classroom experiences with 3D virtual training sessions for students in wood harvesting. Students involved in the 3D virtual training improved their volume of wood harvesting by 23% and decreased their costs for mistakes made and maintenance with 26% (Taylor et al.,
Additionally, 3D case studies in Texas in the United States proved that students’ learning performance increased with 32%, regardless of their socio-economic status (Monahan, 2010). Bamford (2009) recorded similar findings when she compared the test results of a group taught using 3D technology with those of a control group. Her results indicate that 86% of the students improved from the pre-test to the post-test and individuals improved their results with an average of 17%.

Based on the positive results of the above studies on student performance and the acknowledgement of 3D as an exciting emerging teaching method, the author employed 3D technology in lectures. Additionally, the researcher aimed to use 3D-supported lectures to motivate students and improve their interest in the lectures, and to expose and train student teachers in using 3D in their future classes once they have qualified as teachers. With the demand for higher throughput rates in HE, the findings of the study may provide information on how lectures supported by 3D technology can influence students’ learning and academic performance.

**Learning theories**

Various learning theories underpin 3D learning, including the following: learner difference theory – each student has his/her own learning style (Parent, Forward, Cantor, & Mohling, 1975); cognitivism – the way students process new information (Piaget, 1964); constructivism – thinking critically and solving problems (Crotty, 1998); and social constructivism – discussion and exchanging ideas to solve problems (Vygotsky, 1962). These theories are briefly discussed below.

The learner difference theory focuses on the application of multiple 3D demonstrations of learning content to accommodate students’ multiple learning styles. Parent et al. (1975) propagate that various teaching approaches should be used to accommodate students’ needs. As the students in this study were mostly from a disadvantaged socio-economic background, with limited English second language skills, various images, graphs and stimulations could assist them in the learning and understanding of abstract concepts. For that reason, 3D images were used to stimulate the students’ interest in the lecture and to establish whether these images (resembling real-life objects in 3D format) could clarify concepts that were unclear to them.

Cognitivism implies the means by which the student processes information. Knowledge is considered absolute and fixed and links to existing knowledge are encouraged. The goal is to develop critical thinking and problem-solving abilities while solving a problem (Toohey, 1999). During the 3D lecture, the lecturer provides information in a structured way and students are encouraged to identify sequences to facilitate the processing and learning of new concepts. The students had to complete a problem-solving scenario in the assignment posed to them in this study.

Constructivism implies that knowledge arises from our engagement with the realities around us and that meaning is constructed (Crotty, 1998). In this study, students were engaged in 3D simulations of the real world in which they construct their own interpretations of the knowledge provided. Thus, students would each have their own perspective and experiences of the 3D illustrations. Providing students with 3D illustrative activities should keep them interested and motivated to take charge of their own learning. Active learning is considered necessary to the constructivist approach, in which 3D learning enables students to participate.
actively in the lecture by asking questions and discussing the concepts with their peers.

The social constructivist theory of learning, which originated with Vygotsky (1962), claims that learning centres on social interaction and shared tasks in which individuals build their learning by interacting with the learning environment and fellow students (Parent et al., 1975). Collaboration on meaningful and challenging 3D support methods could promote exploratory learning and be regarded as a highly effective means of encouraging learning (Bigge & Shermis, 2004). The advantages are that students can utilise their strengths and overcome their weaknesses while working collaboratively on a task deriving from the 3D lecture.

**Research methodology and data collection**

The research study employed a mixed-method design that was both quantitative and qualitative in nature. The open-ended question provided useful information on participants’ perceptions of their learning in 3D lectures. Students’ perceptions, existing literature and the ARCS model of motivational design (Keller, 2004) contributed to a theoretical basis for the construction of the questionnaire.

Student teachers of a historically disadvantaged university in South Africa were purposively sampled for this study. In total, 260 student teachers representing 68% of first-year student teachers at the university participated in the study. The majority of participants were aged between 18 and 23 and most of them encountered various learning barriers. Most significantly, the English proficiency test executed by the student support centre for all first-year student teachers (n=520) reflected that only one student had acquired proficient Grade 12 English writing and reading skills, while the majority tested at Grade 9 level. Another possible barrier to student teachers’ learning could be that most (90%) were from poor socio-economic backgrounds and had not been exposed to multiple learning methods supported by technology.

Data was collected during the third semester of the academic year involving two first-year Life Science Didactic classes in the study. The same content was taught to both classes using different teaching methods. The difference was that one of the classes, Class A (n=135), received extra support by viewing 3D images (using 3D glasses) during two lectures, while the other class, Class B (n=125), did not view 3D images during their lectures and were taught in the traditional way. During the lectures, student teachers were allowed to describe, discuss and observe new concepts from various angles of the 3D illustrations, in order to enhance their interest and understanding of difficult concepts. At the end of the lectures, students were assessed by completing the same assignment. The assignment consisted of a problem-solving scenario and questions on newly learned concepts. The results of the assignment were compared to establish the effect of 3D lectures on students’ academic performance. In addition, to establish what motivates participants’ learning when viewing and interacting in the 3D lessons, participants of Class A were requested to reflect and write down what is considered as motivational for constructive learning. The most frequent indicated motivations for learning experienced from 3D learning were grouped and included in a questionnaire.

**Questionnaire:**
The heuristic ARCS model of motivational design was applied as a valid and reliable framework for the design of the questionnaire and the grouping of comments. The ARCS
model of motivational design was created by John Keller and is based on Tolman’s and Lewin’s value theory. This theory assumes that students are motivated to learn if there is value in the knowledge instructed and if there is a positive expectation for successful learning (Keller, 2004). The aim of the questionnaire was to establish what student teachers regard as valuable and motivational when learning in 3D lessons. The questionnaire consisted of the following self-reflection statements of Class A, grouped in the ARCS model of motivational design’s learning strategies: attention, relevance, confidence and satisfy.

Attention (Arouse and sustain interest and curiosity)
1. This was my first experience with a 3D lecture.
2. The explanations and English labels were easy to understand and the lesson interesting.

Relevance (Links to students’ needs, interests and real-life situations)
3. The 3D visuals represented real-life objects and interested me.
4. 3D helped me to understand new content and solve problems.

Confidence (Develop various skills to successfully interact and engage in class activities)
5. 3D assisted me in the development of critical thinking skills.
6. 3D allowed me to interactively engage in the lecture.

Satisfaction (Achieve learning objectives and success)
7. 3D improved and motivated me in learning new concepts.

The objectives of the questionnaire were to:
- Establish if participants’ attention and interest were obtained in 3D learning.
- Determine if 3D lessons were relevant to participants’ learning needs
- Establish if 3D lessons could develop participants’ confidence.
- Investigate if 3D lessons could improve and motivate learning.

After ethical clearance was obtained by the Department of Educational Studies, participants had to respond to the research questions, ticking the ‘strongly agree’, ‘agree’, ‘not sure’, or the ‘disagree’ boxes on the questionnaire.

Data analysis

The statistical analysis of the collected quantitative data was carried out with the statistics and analysis software SPSS (version 23.0) which involved the summarising, and comparing of data in an interpretable format that could contribute to answering the research questions. Statistics are reported in Tables 1 and 2 in answering the first research question. Table 1 indicates the positive responses (‘strongly agree’ and ‘agree’), while Table 2 illustrates the negative responses (‘disagree’ or ‘unsure’).

Table 1 below reveals that a high proportion of students had viewed a 3D lecture for the first time in their lives (76%) and experienced the improvement of learning new concepts (82%). As would be expected, the majority of students viewed the 3D lecture as interesting since they could visualise real-life images in a 3D format (95%), and most of the students (88%) observed the English labels as readable and easy to understand. It was significant that the 3D lecture also enabled students (61%) to engage interactively with the material. Additional analyses reflected that 65% of students felt that 3D could help them to understand and solve problems and 63% were able to develop critical thinking skills.
Table 1. Questionnaire responses of participants who ticked ‘strongly agree’ and ‘agree’

<table>
<thead>
<tr>
<th>Questions</th>
<th>Strongly agree and agree Frequency (n=135)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>This was my first experience with a 3D lecture.</td>
<td>102</td>
<td>76</td>
</tr>
<tr>
<td>The explanations and English labels were easy to understand and the lesson interesting.</td>
<td>119</td>
<td>88</td>
</tr>
<tr>
<td>The 3D visuals represented real-life objects and interested me.</td>
<td>128</td>
<td>95</td>
</tr>
<tr>
<td>3D improved my learning of new concepts.</td>
<td>111</td>
<td>82</td>
</tr>
<tr>
<td>3D helped me to understand and solve problems.</td>
<td>88</td>
<td>65</td>
</tr>
<tr>
<td>3D assisted me in the development of critical thinking skills.</td>
<td>85</td>
<td>63</td>
</tr>
<tr>
<td>3D allowed me to engage interactively in the lecture.</td>
<td>82</td>
<td>61</td>
</tr>
</tbody>
</table>

In Table 2 below only 33 (24%) of the students indicated that they had observed a 3D image before. Not all participants (5%) agreed that 3D visuals could represent real-life objects. Surprisingly, 12% of students (n=16) found that the explanations and English labels were not easy to understand and 18% (n=24) did not agree that 3D could improve their learning. Several students (37% [n=50]) experienced that 3D did not assist them in the development of critical thinking skills and 39% (n=53) felt they were not allowed to interactively engage in the lecture. Thirty-five percent (n=47) indicated that they were not able to understand and solve the problem scenario posed in the assignment. To establish the effect that 3D support lectures could possibly have on students’ academic performance, the scores of the assignment completed by both Classes A and B were compared to identify differences and similarities.

Table 2. Questionnaire responses of participants who ticked ‘disagree’ or ‘unsure’

<table>
<thead>
<tr>
<th>Questions</th>
<th>Disagree or unsure Frequency (n=125)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>This was my first experience with a 3D lecture.</td>
<td>33</td>
<td>24</td>
</tr>
<tr>
<td>The explanations and English labels were easy to understand and the lesson interesting.</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>The 3D visuals represented real-life objects and interested me.</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>3D improved my learning of new concepts.</td>
<td>24</td>
<td>18</td>
</tr>
<tr>
<td>3D helped me to understand and solve problems.</td>
<td>47</td>
<td>35</td>
</tr>
<tr>
<td>3D assisted me in the development of critical thinking skills.</td>
<td>50</td>
<td>37</td>
</tr>
<tr>
<td>3D allowed me to engage interactively in the lecture.</td>
<td>53</td>
<td>39</td>
</tr>
</tbody>
</table>

Results of the assessed assignment of Classes A and B
To establish the effect of 3D support lectures on students’ performance, the results of Class A and Class B were grouped in percentage brackets: 90-100%, 80-89%, 70-79%, 60-69%, 50-59% and 0-49% and compared with one another.

Table 3. Assignment results of Class A (supported with 3D illustrations)

<table>
<thead>
<tr>
<th>Class A:Frequency (n=135)</th>
<th>Percentage</th>
</tr>
</thead>
</table>

510
Not surprisingly, Table 3 reflects that apart from one student failing (0-49%) the assignment, the rest of Class A (n=129) achieved a passing score of 50% for the assignment. It was remarkable that four students scored above 90% and 25 students between 80 and 89%. A large portion of students achieved scores between 60 and 79%. Of these students, 30 scored between 70-79% and 35 scored between 60 and 69%. However, although some students (n=40) received a score of between 50 and 59%, it seemed as though a third of the class did not perform as the researcher had hoped for.

Table 4. Assignment results of Class B (not supported with 3D illustrations)

<table>
<thead>
<tr>
<th>Class B</th>
<th>Frequency (n=125)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>90-100</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>80-89</td>
<td>28</td>
</tr>
<tr>
<td>28</td>
<td>70-79</td>
<td>33</td>
</tr>
<tr>
<td>33</td>
<td>60-69</td>
<td>42</td>
</tr>
<tr>
<td>42</td>
<td>50-59</td>
<td>17</td>
</tr>
<tr>
<td>17</td>
<td>00-49</td>
<td></td>
</tr>
</tbody>
</table>

The results presented in Table 4 illustrate that 17 students failed (0-49%) and a large number of students (n=42) achieved scores between 50-59%. Thirty-three students scored between 60 and 70% and 28 students managed to achieve 70-79% for the assignment. Astonishingly, only five students scored between 80 and 89% and no one averaged above 90%.

To ascertain the possible differences and similarities in the results of the two participating classes, the outcomes were compared as illustrated in Figure 1.

Figure 1 reveals that the vast majority of students obtained between 50 and 59% for the
assignment. No significant difference in scores of the 50-59\% bracket could be identified between the two classes (Class A [n=40] and Class B [n=42]). Even those who achieved 70-79\% and 60-69\% did not vary significantly. Class A (n=30) and Class B (n=28) scored between 70 and 79\% and Class A (n=35) and Class B (n=33) achieved 60-69\%. However, a major difference was established between the students’ who achieved 80-100\% and 0-49\%. Of class A, 25 students achieved 80-89\%, four students even scored between 90-100\% and only one failed (0-49\%). In comparison, in Class B nobody scored higher than 89\% and only five students managed to attain between 80 and 89\%. It was alarming that 17 of the Class B students achieved scores between 0 and 49\%, thus failing the assignment.

Discussion, findings and recommendations

Higher education comprises of a highly diverse digitally-orientated student population with various levels of literacy, skills and needs. The technological support that students need to enhance their learning during lectures cannot be ignored, as a high proportion of first-year students are using digital devices to communicate and do research (Eaton et al., 2011). However, it was found that for many first-year student participants (n=102) this was the first time that they had viewed 3D technology. The ‘first time experience’, images, graphs, labels and stimulations used in 3D lectures might have contributed to the 88\% that found the lesson interesting and explanations and English labels easy to understand. This accords with the learner difference theory (Parent et al., 1975) which propagates that various teaching approaches could accommodate student’s multiple learning styles and needs. Moreover, students indicated that they were not always able to apply the learning of new concepts in real-life situations. The reason might be linked to lecturers using traditional talk and PowerPoint methods without applying new content to the real-life context. However, students felt the 3D-lectures assisted them in connecting concepts to the real world (theory of constructivism [Croty, 1998]) and to construct new knowledge from existing knowledge (theory of cognitivism [Toohey, 1999]) as they could view the concept in depth, width and height, resembling real-life objects. Concurrent with Vygotsky’s (1962) social constructivist theory of learning, some students (61\%) felt that they could engage in the 3D lecture interactively by asking questions on concepts they did not understand and by sharing observations with their peers by means of comments. Thus, students were able to clarify unclear concepts during the lecture. Furthermore, most students revealed that they were able to develop critical thinking (63\%) and problem solving skills (65\%) from the 3D observations. This was by no means an overall student experience, as 35\% of the students felt they were not able to solve problems and develop critical thinking skills because they were unable to solve the problem posed in the assignment. Therefore, 3D technology on its own cannot develop students’ problem solving and critical thinking skills, but can be used as a support method in doing so.

The final set of analyses in this study assessed the effect of 3D lectures on students’ academic performance. The results of Class A (3D support lecture) and Class B (no 3D lecture support) for the same assignment were compared. The pattern showed that the student numbers who achieved between 50\% and 79\% did not vary significantly between both classes. The number of students who averaged below 50\% (n=17) in Class B was exceptional in comparison with one student in Class A. It was significant that in Class A 25 students achieved 80-89\% and four students even scored between 90-100\%. Illustrating the possible impact of 3D on students’ learning, in Class B nobody scored higher than 89\% and only five students managed to attain between 80 and 89\%. Based on the theory of cognitivism (Toohey, 1999), the conclusion can be made that the supporting 3D lectures assisted low-performing students in understanding new concepts, solving problems and
applying critical thinking skills, which enabled them to achieve 50% (a pass score) for the assignment. Alternatively, those who did not receive additional 3D technology support during lectures may not have performed according to their ability, were not able to solve the problem scenario and needed extra assistance. It could also be stated that high-performing students achieved higher marks with the extra 3D support. Thus, it can be said that the low and high-performing students excelled in the assignment while there was no significant difference for the average-performing students.

Concurrent with the ARCS model of motivational design (Keller, 2004), students perceived that the 3D lectures held their attention, motivated them to learn more about the relevant topic, clarified abstract concepts, provided them confidence to apply the newly learned content in solving a problem-case scenario and satisfied them as they achieved successful learning in the assignment.

In conclusion, the following recommendations could be made:

- In-service training of lecturers on how to create their own 3D lessons for academic courses is important to develop digital competency skills and to stay abreast with the development of technology-supported methods.
- Each department at the HE institution could equip a 3D lecturing room and manage the use of the 3D room according to allocated times for lecturers on a timetable.
- Apply multiple lecturing methods supported with technology devices (e.g. 3D) to accommodate different learning styles of students, draw their attention, interest and motivate them, enable them to apply new concepts in real-life situations, enhance their confidence to interact in discussions during classes, and satisfy them in achieving the lesson objectives.

**Conclusion**

The challenge for lecturers is to transform their traditional lecturing methods to accommodate the broad range of digital students’ needs. The importance of integrating significant pedagogical skills with technology applications should be emphasised. It follows that lecturers should be proactive in this regard, which implies that they need to stay abreast with and acquire expertise in both existing and emerging technologies. Based on this need, this study employed supportive technology-assisted visual methods (3D) to accommodate the diverse student body and established the effect on their academic performance. The results illustrated that the grades of high (80-100%) and low (0-49%) achievers improved, while the average-performing students (50-79%) were not significantly influenced. It can be concluded that extra 3D support lessons possibly assisted students with learning weaknesses and motivated others to engage actively in the lectures and achieve above expectation.

**Limitations of the study and future research**

Numerous research studies using various types of technology have been executed to establish the effect of technology on students’ learning years. The results reported in this article could have benefited from a more in-depth, qualitative examination of both lecturers’ and first-year students’ perspectives on the effects of 3D technology in lectures in various universities. A broader range of HE institutions could be more representative of the diverse South African student population and their various needs. Future research could focus on students’ needs, their access to technology devices and their preference for which technology to use that would support their successful learning in HE.
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Understanding socio-technical interaction in implementation of ICT in schools: Case study of Maputo Province, Mozambique

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The role of Information and Communication Technology (ICT) is considered important in enhancing the quality of education, consequently improving socio-economic evolution opportunities in developing countries. Likewise, socio-economic conditions in developing countries are considered to affect effective implementation of technology in education negatively. The interplay of social and technical aspects within the education system is an important consideration in implementation of ICT in education. However, studies on the understanding of technology implementation in education in relation to socio-technical issues affecting the implementation process are few. We address this knowledge gap by focusing on socio-technical characteristics of technology, where the non-human actors and surrounding context are considered in shaping the implementation process. This study addressed the following research question: How do different stakeholders, including socio-technical and economic factors interact in the implementation of ICT in secondary schools? A multiple case-study strategy based on qualitative data was used for data collection between March and May 2015. Data collection techniques included semi-structured interviews, field notes, observation, and official background documentation. The data were analysed using the Actor-Network Theory (ANT) framework, and revealed ways in which non-human actors’ interests could weaken the creation and maintenance of a solid network. The principle of generalized symmetry of ANT offers equal evidence of both human and non-human action in the creation of networks when implementing ICT in the educational system. The study found that the interplay of non-human actors is crucial for building cohesive network of actors. The interaction between technology, and the existing conditions and social context exposed the fragility of the network. Thus, we recommend the involvement of all the entities in the same explanatory view by designing a realistic, achievable and effective plan in accordance to the country and school conditions.

Keywords: ICT, socio-technical settings, actor – network theory, developing countries, ICT in education

Introduction
The role of Information and Communication Technology (ICT) in the education sector cannot be underestimated, in view of the fact that ICT occupies a critical space in social development (Bass & Richard, 2011; Aristovnik, 2012). The use of ICT in education is considered to be beneficial, as it promotes changes in teaching and learning. Harbi (2014), on reviewing the literature on ICT implementation in education, concluded that technology has great potential to enhance students’ achievements, which includes fostering collaborative learning, promotion of flexible learning, and increasing performance.

When technology is implemented in the classroom, students take active roles in their learning activities. Similarly, Andersson and Gronlund (2009) acknowledged the use of technology in the schools of developing countries as a means of overcoming problems such as a shortage of teachers, and accessing geographically distant areas using e-learning.
platforms. Given the expectations of innovation offered by ICT use in the education system, most countries and governments of the world have invested in education reforms, which include technology integration (Andersson & Gronlund, 2009). In spite of the recognized benefits of using ICT to enhance teaching and learning activities, its integration is deemed a daunting and challenging process (Elgali & Kalman, 2010; Harbi, 2014).

A review of the literature reveals the existence of various factors that challenge the integration and effective use of ICT in schools; for example, Deaney and Hennessy (2007) state that integration of ICT in the education system is a gradual and reflexive process, which is influenced by complex and varied factors. Thus, considering the complexity surrounding the integration of ICT into the education system, there is a need to examine the overall structure of the school, the locality in which the technology is to operate, and the various components involved.

The complexities include technical components, for example the availability of hardware, software, data, and a network; social settings, such as people's behaviour, culture, politics, and the school organizational structure; and associations that result when the technical and social aspects interact. Hence, an understanding of social perspectives, or perhaps examining the technical aspects separately, can partially explain the process of ICT integration in the organizational context or technical characteristics (Sawyer & Jarrahi, 2013). Thus an understanding of the schools’ socio-cultural context in which the ICT is to be integrated was studied by Damodaran et al. (2005) and Fenwick and Edwards (2013).

ICT integration, by nature, is considered a socio-technical process involving people interacting with technology to achieve goals – a process not possible by either people or technology working separately. Strong emphasis is placed on the need for further research to understand ICT integration as a package in which social and technical aspects are considered important and mutually dependent (Thapa, 2011; Hammond, 2013). Therefore this study will explore the existing link between the technical and social context, by identifying and understanding the roles of various entities involved in the ICT integration process. The study highlights the critical role of non-human actors and the surrounding context in which the technology is implemented in the understanding of the ICT integration process. This is particularly justified by the economic conditions in developing countries, which contribute to the existing problems of poor infrastructure, lack of resources, and an illiterate populace.

Sound social conditions are considered crucial for the effective implementation of ICT and its use in the education system. This study closely examines the existing social context and its interaction with technology in the process of ICT integration in the education system within a secondary school in Maputo Province, Mozambique. The study will address the following research question: How do different stakeholders, including socio-technical and economic factors interact in the implementation of ICT in secondary schools?

**Research Background**

The study was conducted in Maputo Province in Mozambique. In attaining its objective the Ministry of Education implemented a pilot project in which computers and Internet connection were provided in some secondary schools. As a result, for the first time in 2010 some secondary schools had computers and Internet connections available for learners. However, these schools do not have a policy for ICT infrastructure provision and
maintenance – hence the need for use of a socio-technical approach to gain an understanding of the process of ICT implementation.

**Literature Review**

Given the inseparable relationship between technology and its social context, the socio-technical perspective has been used to investigate the ICT implementation process (Walsham 1997; Angeli & Valanides 2008, Fenwick & Edwards, 2013). Introduction and use of ICT in the education system has been considered dependent on social variables comprising the school setting. The socio-technical perspective accords the social and technical aspects the same significance and priority in the process of technology implementation. As Sawyer and Jarrahi (2013, p. 14) note:

“…ICT can be characterized as emerging, embedded, evolving, fragmented and connected to an ephemeral social presence that is shaped as much by other institutional and contextual forces as by technical and economic rationales.”

Studies based on a socio-technical approach focus attention on the heterogeneity of networks that jointly determine the success of the technology implementation. Similarly, this research takes a socio-technical approach in exposing the relationship resulting from the technology and local context of the education system in Mozambique, a developing country. The connection of the technical elements and the social context in which the technology is situated are framed within the ANT perspective. The assumption of ANT which assists socio-technical studies is that the transition between the social and the technical is defined through a process of negotiation (Hanseth, Aanestad & Berg, 2004). The success of this negotiation determines the way in which technology is implemented in a given context.

According to Harbi (2014), it is not just the technical aspects such as the availability of ICT that determine the successful implementation of technology in schools, but rather how ICT enhances the educational process. The ANT approach has been used in social studies as a framework for investigating the complexity brought by human and non-human – social, and technical factors (Sawyer & Jarrahi, 2013). In ANT studies it is emphasized that the contextual setting is crucial to the understanding of the actors’ behaviour; likewise, human and non-human entities are treated in the same analytical mode.

**Actor network theory (ANT)**

ANT was initiated in the 1980s by Michel Callon and Bruno Latour in the sociology of science (Callon, 1999a; Latour, 2005). Use of this theory was expanded and further developed by its proponents and other researchers (Latour, 1999). This theory incorporates and focuses on technology studies and information technology implementation (Walsham, 1997). ANT is an approach which studies the constructions, maintenance, and transformation of heterogeneous networks, resulting in the way in which actors translate their interest in the network (Latour, 2005).

ANT emphasizes that there is no distinction between technical and social entities. The ANT approach uses the same vocabulary for every actor, regardless of size, form, or competencies in the built network. This characteristic makes the use of ANT suitable for studies in which social factors should be considered as important as other variables in the process of ICT implementation. Callon (1999a, p. 181) noted that “…neither the actor's size nor its psychological make-up nor the motivations behind its actions are predetermined”. Braa,
Monteiro and Sundeep (2004) also describe ANT as a tool providing a language with which to explore how, where, and to what extent technology influences human behaviour.

According to Latour (1987), in science and technology studies the researcher should focus on the dynamics of the entities’ interaction, and not on the stability of their relationships. This shows that ANT explores the associations that emerge when a particular technology is introduced in a certain context, creating the heterogeneous network of actors.

The theory also suggests that an actor may be an effect of heterogeneous relations resulting from the interaction between human and non-human, or between technical and social components. As Callon (1987, p. 93) noted: “an actor-network is simultaneously an actor whose activity is networking heterogeneous elements and a network that is able to redefine and transform what it is made of”. Following Callon’s (1987) remarks, Hanseth, Aanestad and Berg (2004, p. 119) assert that “an actor is also a network, whether this actor is a human carrying out an action using some tools or instruments, or it is a technology supported by an organisation”. Therefore an actor may also be a network from the ANT perspective, which is defined through its interaction with other actors. The ANT approach indicates that an actor may be a human being, a text, or an artefact, provided that it acts in the built network or in an association of heterogeneous elements.

Latour (1996) states that the actor-network concept is used to represent a product of an actor’s connections and associations in which an actor does some work contrasting the engineering networks – which are static connections and topologically designed. Thus, the term actor-network represents a description of the way in which the network is organized, resulting from the process of translation of human and non-human actors through negotiations of their interests (Rhodes, 2009).

The concept of “translation” is key to ANT, which is used to describe the variety of ways in which actors actively seek to interest others in the building of heterogeneous actor-networks. For Latour (2005) translation is granted when the actors translate or enrol in the beliefs of other actors through negotiations in the network. The negotiations include definitions and distributions of roles among the actors, and delineation of a strategic scenario; definition of strategies in which actors render themselves indispensable to others in the built network; and transposition of actors imposed by others to follow the strategy defined in the created network (Callon, Law & Rip, 1986). Thus translation is a dynamic process in which entities and interests are progressively transformed, and consent is achieved with other actors’ interests in the network.

The translation process can offer a deeper understanding of the role of various actors, providing a detailed picture of the actors’ negotiation strategies. For Callon (1999b) the translation of actors’ interests into the network or the construction of an actor-network is deployed over time and space consisting of four moments: problematization, interessement, enrolment, and mobilization. The translation moments are not sequential, which means that the phases may be overlapped. The problematization phase is the first moment of the translation process, in which the focal actor problematizes an issue and acts as an indispensable object to other actors by imposing their definition of the situation and demonstrating its quality to achieve a solution. The focal actor defines the nature of the problem and tries to persuade other entities to accept the defined solution. It is in the problematization moment of building an actor-network that the focal actor is established as an obligatory passage point (OPP), by convincing other actors and enrolling their interests.
for the solution of the problem. Basically, problematization is determined by the definition of actors’ identities, and by the establishment of an OPP in the network of relationships that is being built.

The moment of *interessement* consists of negotiations by means of which the focal actor imposes and stabilizes the definitions and roles proposed in the moment of problematization. Fundamentally, the interessement moment is determined by “a group of actions by which an entity attempts to impose and stabilize the identity of the other actors” (Callon, 1999b, p. 71). This means that the focal actor identifies the problem, attains a solution, and defines the identities of other actors. Callon (1999b) further argues that the focal actor interests other actors in the network by building devices which may be placed between all other entities who wish to define their identities. The focal actor achieves this goal by making himself indispensable to others and to the solution of the problem. The successful interessement confirms the validity of problematization and the interaction and association between actors.

*Enrolment* occurs when other actors accept the definitions and attributed roles proposed by the focal actor. The definition and distributions of roles are the result of multilateral negotiations during which the identity of the actor is determined and tested. Callon (1999b) noted that the device of interessement does not necessarily lead to enrolment, which means that for an actor to be enrolled s/he must be willing to participate. This is achieved through strategic negotiations, by which the focal actor convinces the others to join a solution defined by him in the early stages of translation. Enrolment could be considered a successful outcome of interessement. Callon (1999b, p. 74) stresses that “interessement achieves enrolment if it is successful”.

*Mobilization* of allies comprises methods that certain actors apply to ensure that enrolled actors follow the definitions and interests. It is in the mobilization moment that the proposed solution to the problematization moment is extensively accepted. As the translation process develops, certain actors – especially the focal actor – become important as representative spokespersons for all entities constituting the network. In other words, the focal actor progressively mobilizes the other actors, expressing and using their voices, thoughts, and interests, as a network representative.

**Research Methodology**

*Research context*
This research is part of an ongoing research project, which uses a mixed-method approach in understanding technology implementation and user acceptance in the education system. Specifically, the paper reports on the ICT implementation process using a multiple case-study strategy to assess how the technology has been integrated and how it has been used in the education system. The study sites and individuals were selected purposefully, as they informed an understanding of the research topic, following Creswell’s (2009) recommendations. The principle of case studies is to investigate in some detail one or more cases, providing an analysis of the context influencing the phenomenon under study (Meyer, 2011).

The selection of research approach is based on the nature of the issue being investigated, experience of the researcher and the intended audience (Creswell, 2009). The study investigated the implementation of technology in a socio-technical context, which is not well understood. In order to gain in-depth understanding of actors’ opinions, their relationships
and interactions, the study adopted qualitative research approach techniques, and the data were collected between March and May 2015 in three secondary schools of differing localities.

**Data collection**

To understand the historical background and detailed translation process, semi-structured interviews with school administrators and ICT teachers were conducted. Field notes and observations of ICT usage in class training were employed to capture the socio-technical environment at each site. The emphasis of qualitative studies is that the influence of the local context is taken into account during the study, which potentially reveals the phenomenon’s complexity nested in a real context (Miles & Huberman, 1994). Complementary data were obtained from official documents such as ICT policies, educational strategic plans, and other documentation provided by schools. The use of different sources of data allowed comparison and identification of similarities and differences across research sites.

**Research sample**

The sample for the study was composed of school administrators and teachers in the three public secondary schools. The sample of schools was selected using purposeful sample techniques (Creswell, 2009) – schools with computers and Internet connection in the province were selected. A total of nine teachers and three school administrators were selected on the voluntary basis.

**Data analysis**

The data were analysed using the ANT approach supported by Miles, Huberman and Saldana (2013), with data analysis framework steps of data reduction, data display and conclusion drawing. By applying Miles, Huberman and Saldana’s (2013) techniques, data from different sources were examined to confirm the understanding of the case study and relevant information extracted – i.e. only some conversations informed the findings. For the purposes of this study only one aspect of the analysis is reported on. The ANT analysis traced the four moments of the interplay of different actors during the ICT implementation in schools. The principle of generalized symmetry from ANT offers insight into the socio-technical interaction of technology and its social context.

This strategy offers an equal reflection of both human and non-human action in the creation of a heterogeneous network. The socio-technical aspects of technology and their alignment with the school context are crucial to the success of ICT implementation in education. The use of the ANT approach proved suitable for guiding studies on ICT implementation in education. The translation process allows the tracing of actors' differing interests, which should be aligned with the creation of an actor network.
Ethical issues
Ethical issues (Creswell, 2009) were observed throughout data collection and analyses. The research was approved by Provincial Directorate of Education and Culture of the Maputo province, and the research permit letter was provided. In addition, permission was sought from each school participating in the research. Participants’ rights have been protected and an informed consent form was signed before they engaged in the study.

Research findings and interpretation
The study applies actor-network theory (ANT) to describe the socio-technical settings of ICT implementation in secondary schools. The study makes use of the actor-network translation process to explore ways in which the heterogeneous networks of actors are created and maintained over the various phases of technology implementation in schools. Thus, exploring the contextual school background in which the technology is to operate assists in understanding different aspects that influence the way in which the network of actors was constructed. The research showed how the non-human actors’ interests could weaken the creation and maintenance of a solid network. The understanding of ICT implementation in the local school context, in which interaction among actors were observed, is mapped through the four translation moments as outlined below.

Understanding ICT implementation through the ANT perspective
Problematization
In this phase the initiator or focal actor defines the nature of the problem and convinces others to accept the defined solution (Callon, 1987). The attempt to establish the network was initiated by the Ministry of Education, with the objective of enhancing the quality of education. To fulfil this objective, in 2008 the Ministry of Education launched the educational strategic plan for integration of ICT in all secondary schools in Mozambique (Matavele & Chamundimo, 2009). However, the implementation action followed two years later, when computers and Internet connection were introduced into certain schools as a pilot project. As a result, 60 schools were supplied with several computers and an Internet connection.

Subsequently the negotiation process between human and non-human took place, with identification and definition of actors’ roles. Initially, apropos of the pilot project, use of technology in schools was seen as a promising solution, and workshops to disseminate the initiative among key actors were organized by the Ministry of Education, as was the training. The training involved relevant actors such as the teachers and head of school in each selected site. The participants’ belief was that the use of technology in their schools would contribute to effective delivery of teaching and learning activities, and hence improve the quality of education. One of the participants interviewed declared:

Our school was included in the pilot project, and we attended workshops provided by the ministry … as teacher, and as school board member, I support the use of technology in schools, and I believe in the benefits of computers in the education system. Our teachers and students are encouraged to use technology in their teaching and learning activities. We also inform the community and the students’ parents of the advantages of using technology for the students’ future lives.

The selected schools and teachers with non-aligned interests who attended the workshop and training became aligned, starting to build a new local network of actors which included the use of ICT. Various negotiation strategies were used by the focal actor to persuade other actors to participate. Negotiations included establishment and introduction of another non-
human actor, a curriculum guide, to accommodate ICT use in all pilot sites. The technology is taught as an appendix from Grade 9, but is compulsory for all students. In this way ICT integration into schools implicitly became an OPP. The OPP is observed when a change or innovation is introduced (Rhodes, 2009) which affects the way in which actors are aligned with the network. As one teacher commented: "the Ministry of Education is forcing the secondary schools to change their work practices … We have to follow the procedures."

The involved actors’ interests were aligned, and their roles in the new network were identified. However, constraints such as technical skills and school infrastructure were mentioned as critical actors in the process. In the course of the translation process the initial actors were obligated to become transposed and to act as focal actors in each local network. Each of the actors re-problematized the issue by attaching more actors – training more teachers, and disseminating the initiative to other sites.

**Interessement**

In this stage the focal actor convinces the other actors in the network to accept the defined solution by building an interessement device which may be placed amongst all of them (Callon, 1999b). By imposing the use of a curriculum guide and making it compulsory for all students the Ministry of Education stabilized the pilot project, which represents the interessement device. The relevant actors accepted and acknowledged the role of the new actor, the use of technology in the education system. One of the participants said:

> … we are teaching technology as a compulsory subject as any other subject in the curriculum. From the beginning of the project we are following a curriculum guide provided by the Ministry of Education, even though we do not have good infrastructure to accommodate the teaching of technology use. For example, the ICT subject is being taught in the library because of the lack of space. In the classrooms, there is no power outlet to connect the computers.

Through the interessement device the focal actor made him/herself indispensable to the solution of the problem and, when interviewed, spontaneously mentioned the benefits of using technology in various activities. This confirms the recognition and acceptance of the problematized issue, even though the contextual background seems unsuited to dealing with the defined solution.

**Enrolment**

The enrolment phase requires several negotiations and actions to ensure maintenance and stability of the built network (Rhodes, 2009). In attempting to establish a solid network of actors, the focal actor distributed computers and an Internet connection to all sites. Thus the actors were required to change their network arrangement and align their activities and support with the OPP. However, what must be addressed is the focal actor keeping his coordination role to technical aspects such as distribution of computers, and disregarding other elements. It is noted that the success of interessement does not automatically lead to enrolment Callon (1999b). Several negotiations and organizational arrangements must be in place in order for the actors to be effectively enrolled. Most of the interviewees mentioned the existence of other organizational aspects that could impact stability of the network, for instance:

> We do not have any policy or a written plan to set up this project; however, we are working in order to get the project functioning …. we have problems, there are no technicians working full time on this project. The two teachers who are acting as technicians are also teachers of other subjects. There is no technical maintenance of those few computers that we received.
I think that this school has the capacity to succeed in this project. Somehow, the school must use its own income to pay the technician.

To increase the effectiveness of enrolment each of the selected schools was expected to assume ownership of the project. In attempting to follow the OPP and assume their roles in the network the schools, at the start of the project, offered training for teachers other than ICT personnel. However, because of the lack of clear guidelines, the organizational structure and the differing backgrounds of each school, the actual stage of the project is open to question. Some other actors shared the responsibility and joined the network. One school administrator commented:

The Internet connection was sponsored by the British Council for the first two years of the project … until last year we were sponsored by another organization. This year no one is paying for our Internet connection. However, we received last year from the Ministry of Education more than ten computers.

Another school administrator mentioned:

... our Internet connection is being paid for by a German partner. The technology is used to reduce the distance between the student and the source of information in far-off places. We believe that better days are coming. We are working with other organizations to get our computer room. The ten computers that we received in 2010 are obsolete; some have been stolen.

Despite the scant basic resources for schools in effective use of technology in the education system, the interaction between human and non-human actors in implementing ICT is visible. The integration of technology into education is seen as a means of improving the quality of teaching and learning activities, but also a way of extending the personal goals of the teachers. One of the teachers stated "computers are making my life easier, I quickly perform my activities. With ICT competencies I am feeling powerful. I can easily confront the communities." This illustrates that a human actor has been influenced by a non-human entity and became aligned or linked to the built network, which is shaped by other social artefacts.

Mobilization

The mobilization stage is characterized by establishment of the spokesperson, an entity representing and speaking on behalf of other actors in the network (Callon, 1999b). The emergent spokesperson uses a set of methods which ensure strengthening of the actor-network by linking other actors who were not linked at the beginning of translation (Rhodes, 2009). The Ministry of Education has progressively mobilized other actors, including international and national donors; currently the project is widely known.

The focal actor translated the actors’ interests in the network and the school administrators were given the right to transpose, becoming focal actors in each site. The integration of technology into schools was announced through media channels, radio, television, newspapers, magazines and government websites. Likewise, the Ministry of Education demanded capacity building for teacher education institutions to support the use of ICT for teaching, learning and administration in schools. One of the teachers said, “first, I heard about the use of ICT in secondary schools on television”. Another noted: “I was taught how to use computer when I was at a teacher education institute” … ICT skills were one of the requirements to be a teacher”.

The linked actors accept the OPP – the goal must be achieved, even though they do not know how to succeed. For the teachers, having access to computers and to the Internet in the
schools was beneficial, and their interest was easily translated; however, it will take a long
time for the network to become solid and stable.

Discussion

The mapping of the four moments of the translation process into integration of ICT in
schools exposed the fragility of the built network of actors. The mapping is related to the
extent to which the various actors' interests are enrolled, and the way in which the focal actor
conceived or established the network of actors. The interaction between the built network of
actors, including technology, and the existing local and social conditions, is of concern.

In order to establish a solid network actors must translate their interests into the defined
problem, and the proposed solution must be accepted and incorporated into the work
practices, which involve technology. According to Law (1987) the extent of the network is
determined by the existence of actors able to make their presence felt in the built network.
In this case the ICT implementation project includes the presence of actors such as the
physical infrastructure, power shortages, lack of project-planning implementation, as well
as donors, Internet service providers, and other artefacts necessary to establishment of a
solid network. However, not all the relevant non-technical actors were considered in the
project. The ICT actor may be translated into school practices only if seen as connected to
the non-technical actors and social factors.

The principle of generalized symmetry (Callon, 1999b) indicates that the same explanation
should be used for all components that make up a heterogeneous network of actors, whether
human or non-human. The translation process in this study showed that human actors, such
as the focal actor, need other humans – donors, school administrators, teachers, and students.
Human actors also need objects and material to translate the project into schoolwork
practices. In the case of the education site, the heterogeneous network of actors could be
composed of teachers, technologies, timetables, workplaces, curricula, teaching resources,
students, policies, administrators and other artefacts related to the education field (Fenwick
& Edwards, 2013). Despite the demonstrated enthusiasm by human actors, not all teachers
shared the same feeling (apart from the teachers who attended the initial training and
workshops).

The lack of alignment between ICT actors and the school context could affect level of
commitment to the project initiative, which starts to diminish over time. This could lead to
dissidence – betrayal and controversies (Callon, 1999b), the moment in which actors’
commitment starts to fluctuate, with controversy over the built network. Thus, the manner
in which the ICT implementation project was conceived, and whether the aspects
problematized would be solved through the defined solution, are dependent on the context
and interaction of both human and non-human entities in the school settings.

Conclusion

During data collection it was evident that integration of technology into education is greatly
supported by school administrators and ICT teachers. The importance of technology in the
education system has been recognized over time (Aristovnik, 2012). Being part of the pilot
project, integration of ICT in the teaching and learning activities opened new possibilities
for the teachers and students to obtain information. Remarkably, ICT teachers and students
demonstrated great interest in the use of computers and the Internet in better facilitating their
activities and overcoming obstacles to accessing information. However, the Internet connection, and in some cases computers, were not available for every student all of the time.

The four moments of the translation process reveal that the various actors, both human and non-human, should be held together in order to sustain the built network. In the problematization moment the focal actor established the ICT integration project as an OPP. However, given the reality of the school context, the project is unlikely to become an OPP. In the interessement phase the focal actor sparked the other actors' interest, negotiating their roles through establishment of interessement devices. However, not all of the relevant human actors (for instance non-ICT teachers and non-human elements) were strongly committed to the project. Thus the weakness of the project structure and the limited action of the focal actor became visible in the enrolment moment. In the mobilization moment the built network was given to the needs of the schools, where various actors define the network trajectory, depending how they translate their interests.

In many cases the computers were donated directly to schools without the knowledge of the Ministry of Education. Drawing on the ANT perspective, the social contexts of schools are hampering the built networks which include the ICT actor. In the ANT approach every object that can act in the network has an effect on the same network, as with human actors. Despite the demonstrated interest by some actors in using computers, the translation process showed the need to connect the emerging network to the existing networks of people and the schools' contextual backgrounds.

The study illustrated the importance of an ANT approach to investigating ICT implementation in the education system of a developing country. The translation process used showed that the focal actor designed the project, neglecting to take into account conditions in the existing schools. The study provided a theoretical and a practical understanding of the role of various actors, both human and non-human, in implementation of ICT in schools. The ANT concepts provided insights into understanding ways in which the actor networks should be created and maintained over time. The translation process used in this research outlined the strengths of the ANT to recommend new strategies for successful integration of ICT in the education system.

The study recommends active participation of the all actors (human and non-human) from the beginning of the translation process in order to build a solid network of actors. All of the entities need to be considered in the same explanatory view before starting an ICT implementation project. The study also recommends the establishment of a realistic and achievable implementation plan for ICT infrastructure provision and maintenance in accordance to the local social and economic conditions.

References


After (pp. 15-25). London: Blackwell.
Inspiring and Sustaining Learners’ and Their Communities’ Interest in Science, Engineering and Technology

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The purpose of this study was exploring research questions around First LEGO League as a community engagement activity, justifying importance and relevance for inspiring and sustaining learners’ and their communities’ interest in Science, Engineering and Technology. A literature review draws on the latest and most relevant research findings around this topic. The study is located within a relevant conceptual framework that clarifies issues around community engagement. Methodology described attends to the importance of interpretation for qualitative parts of the research design and considers issues of reliability and validity for quantitative designs. Data collected involved participants in completing questionnaires containing both multiple choice items and longer, open-ended questions. Both quantitative and qualitative results are discussed, providing insight into participants’ responses - these are in some instances connected back to literature. Suggestions are made about what the possible implications of these results for other institutions could be and recommendations about how these could be applicable and useful for them. In conclusion, a summary of the results and the paper as a whole is provided, as well as a reflection on how these results make an original contribution towards scholarly debate in the field and the identification of options for further research.

Keywords: LEGO, community development, robots,

Introduction
Purpose of the Research and Justification of Importance

I-SET is a University of South Africa (UNISA) community engagement project aimed at inspiring and sustaining learners’ and their communities’ interest in Science, Engineering and Technology through fun activities. These activities are mainly centred on learners between the ages of nine and sixteen, who build robots from LEGO blocks and program them to achieve certain outcomes. The purpose of the study reported on in this paper, justifying importance and relevance to this conference, thus was exploring the following research question: How can First LEGO League as a community engagement activity be used for inspiring and sustaining learners’ and their communities’ interest in Science, Engineering and Technology? In this way, the study responds to a call made by Jita and Ndlalane (as quoted in Agamburram and Goosen, 2011, p. 297), that further “work is needed to explore the possibilities and arrangements that are likely to” inspire and sustain communities’ interest in subjects like Science.

Project Objectives

• Regarding community engagement, educators aim to participate in and host events that will inspire and sustain learners’ interest and participation in Science, Engineering and Technology. They therefore present face-to-face training for coaches and teams, host and participate in the First LEGO League (FLL) North Gauteng Championship, and participate in the FLL National Championship and the World Robotics Olympiad.
• In terms of community development, the project aims to use Web 2.0 technologies to create and deliver open educational resources for use by the communities involved.
• With regard to research, further options are being investigated with regard to identifying
pertinent community engagement research questions in the project.

The remainder of this paper will be organized as follows: it will start with a look at a literature review, drawing on the latest and most relevant research findings around applicable topics. The study is located within a relevant conceptual framework that clarifies issues around community engagement. The research methodology used is briefly described, attending to the importance of interpretation for qualitative parts of the research design and considering issues of reliability and validity for quantitative designs. Data collected involved participants in completing questionnaires containing both multiple choice items and longer, open-ended questions. Both the quantitative and qualitative results obtained from a survey that was carried out are described and discussed, providing insight into participants’ responses - these are in some instances connected back to literature. Suggestions are made about what the possible implications of these results for other institutions could be, as well as recommendations that can be made based on these results, about how these could be applicable and useful for educators. Finally, the paper is concluded by presenting a summary of results obtained and the paper as a whole, reflecting on how these results make an original contribution towards scholarly debate in the field and identifying options for further research.

**Literature Review**

In line with the project as described in this paper, Qidwai (2007), in his paper, shared his experiences on a project with the aim of improving the educational levels and standard of education in particular communities where learners were not being encouraged to take up careers in the fields of Science, Engineering and Technology. This was due to these learners either lacking financial resources or focus and motivation, which, in turn, was owing to various social problems related to a vicious circle of poverty and crime. In that study, the use of the LEGO® Mindstorms™ Robotic Invention System (RIS)™ showed a large increase in learners’ motivation and focus towards especially engineering education.

According to Patterson-McNeill and Binkerd (2001), the RIS represents a programmable toy that can be used educationally. The latter authors described the fundamental characteristics of the RIS as it related to the community of LEGO users. Similar to aspects of their paper, one of the purposes of the current paper could also be to act as a resource for educators considering using the RIS in their classrooms. These authors’ paper included a section on how educators were at that stage using such robots in their classes - the current paper adds value by providing an update of these kinds of situations more than ten years after the original, especially in a field where things are continually changing.

The LEGO® Mindstorms™ Robot Command eXplorer (RCX) was a popular robotics kit for providing opportunities to explore embedded software control (Vuittonet & Gray, 2006). Limitations of the RCX provided a direct challenge, which was typical of real-world and embedded systems development. A poster summary by the latter authors described the Java-based development of a robot set, which coordinated for playing the game Tic-Tac-Toe. Also using Java code, together with LEGO Mindstorms robots, for implementing unique assignments, the paper by Jipping, Calka, O’Neill and Padilla (2007) documented a project for injecting some fun into teaching assembly language. Building real-world robots with LEGO Mindstorms, Talaga and Oh (2009) showed how learners’ productive learning could be increased by using coding examples from laboratories for augmenting the functionality of LEGO robots - this allowed such robots to react quickly to their environments.

Bradley, de la Puente and Zamorano (2011) described a set of technologies for fully developing real-time applications using the LEGO® Mindstorms® NXT robotics kit as
target. These technologies can provide real-time and embedded systems educators with alternatives to conventional software models aimed at learning. Similarly, Pedersen, Nørbjerg and Scholz (2009) showed how LEGO Mindstorms NXT could be used to teach embedded team programming, while Hamada and Sato (2010) explained a novel method for using LEGO Mindstorm NXT robots as a learning technology in automata theory. A paper by Agarwal, Harrington and Gusman (2012) illustrated an application that had been developed to demonstrate how it was possible to exploit the built-in features of technology for robotics programming by manipulating LEGO Mindstorm NXT robots. Using these applications, it was shown that this was a moveable, moderately-priced and functional development in robotics programming. As LEGO robots were becoming more affordable, a paper by Koller and Kruijff (2004) argued that this made it feasible for researchers to tackle interesting challenges associated with applicable interfaces - the latter authors showed how talking robots could be built using off-the-shelf components, based on LEGO MindStorms robotics platforms.

Circling back to the engineering education context described in the first paragraph of this literature review section, Gilder, Peterson, Wright and Doom (2003) indicated that finding novel, exciting design projects for computer engineers could be challenging for educators. The latter authors presented an interdisciplinary design project, which incorporated robotics control. They reported that their semester project had been very successful, and could be implemented as model for comparable design projects at other institutions. Behrens, Atorf, Schneider and Aach (2011, p. 553) agreed that engineering subjects, strongly focusing on theoretical concepts, frequently have an unfavourable effect on learner motivation, as these lack illustrative applications for real-world problems. To overcome this challenge, the latter authors pointed to significant pedagogical elements for designing practical laboratories for learners. By using the LEGO Mindstorms NXT Toolbox and robots for development, beginners can foster their programming and engineering skills in a fast and intuitive way. Providing successive tasks and ensuring enough room for creativity, a surprising variety of sophisticated projects is reported by learner teams in their final presentations and competitions, leading to increases in their motivation regarding future engineering tasks.

The purpose of a study described by McWhorter and O'Connor (2009) was investigating the efficacy of utilising LEGO Mindstorms robotic activities for influencing learner motivation in an introductory Information Technology subject. Different aspects in this regard were assessed using the ‘Motivated Strategies for Learning’ questionnaire. A LEGO group showed a larger reduction in extrinsic goal orientation levels - this suggested that they were motivated less to learn material for incentives such as marks. Learners responding to follow-up questions implied that a number of them enjoyed such LEGO Mindstorms activities.

“In a world of ad-hoc networks, highly interconnected mobile devices and increasingly large supercomputer clusters,” Jacobsen and Jadud (2005, p. 431) pointed out that learners need computer models, which assist their thinking around dynamic and concurrent systems. Most of the technologies currently available for introducing learners to concurrency are, however, difficult to use and not intrinsically motivating. For providing authentic, hands-on and enjoyable introductions to concurrency, the latter authors described how to communicate dynamic reactive processes to LEGO Mindstorms. Equally providing users with hands-on experiences, Mendes, Lopes and Ferreira (2011) presented an interactive LEGO application, which had been developed accordingly by adapting building block metaphors for direct multi-touch manipulation.
A paper by Lui, Ng, Cheung and Gurung (2010) described a project aimed at promoting independent learning amongst first year learners, using LEGO Mindstorms robots as tools for building a subject that could engage learners at different levels of learning independence. Using the ‘Staged Self-Directed Learning Model’, LEGO Mindstorms robots proved to be versatile in achieving the objective of guiding learners towards improved levels of learning independence.

An article by Imberman (2004) described a project for artificial intelligence classes, which taught neural networks by using the LEGO® handy board robots, while Stevenson and Schwarzmeier (2007) alluded to possible ways of integrating LEGO Mindstorms robotics into the standard curriculum, with a paper presenting ways of using these robots for teaching image processing to build an autonomous vehicle. In his SAARMSTE paper, Pudi (2009) also referred to the use of LEGO for Technology education.

Finally, in their experience report, Cantoni, Marchiori, Faré, Botturi and Bolchini (2006, p. 187) presented a case study based on lessons learned from their use of Real Time Web (RTW) - an innovative methodology for building team commitment that adopts a playful approach for effectively and collaboratively eliciting and plastically representing communication requirements by extending experiences with LEGO Serious Play.

LEGO bricks are simple to use and provide ready-made, powerful and multi-purpose symbolic pieces, known to most people and used in different cultures. RTW exploited this potential to create a shared vision of strategic high-level design issues in the process of developing a corporate website application.

**Conceptual Framework**

Along the line as discussed by De Beer (2011), this section of the paper will explore conceptual issues against a background of the question ‘What is a community’ and will explain what community engagement may entail, in order to develop an understanding thereof. Ironically in terms of the topic of this paper, the former author used concepts related to building blocks for defining community in ways, which makes it possible to manage and operationalise a safer environment for learning. Dahlberg, Barnes, Buch and Rorrer (2011) agreed with the former author that community engagement should have the mission of broadening and promoting the empowerment and capability of communities, including e.g. women, to participate. The interpretation of communities’ participation, as well as the extent of empowerment in community engagement projects, must, however, be constantly reviewed and reflected upon. In his SAARMSTE paper, Gumbo (2013) therefore recommended that community engagement should be a first point of contact to conceptualise projects in this regard. De Beer (2011), however, also warned that involvement in projects does not equal participation. Involvement means that people are allowed to participate in particular activities in prescribed ways. Engagement only happens when participants are able to join with outsiders in collaborative analysis.

De Beer (2011, p. 19, quoting Hall) stated that the term community can, and does, mean anything from a university’s own staff and students and a community of practice to civic organisations, schools, townships, citizens at large and ‘the people’ in general.

According to this same author, a community can be described in terms of having geographical boundaries, and people who share common interests and/or sets of morals, norms and orientations” with structures that promote interdependence (Agamburram & Goosen 2011). Similarly, in their definitions of a community, the latter authors pointed out that the concept community is frequently used for describing groups of people from different
areas and levels, who are engaged in working together and continually operating collaboratively.

The article by De Beer (2011) reflected on universities’ participation in community engagement in the South African context. In the context of community engagement projects such as the one discussed in this paper, the latter author is of the opinion that universities form part of their societies, have the necessary resources, and as centres of expert knowledge for higher education and excellence, have the responsibility of participating and ploughing back into their communities. This same author therefore called upon universities to demonstrate their social responsibility by committing to the common good to make available their expertise and infrastructure through community engagement projects.

Community engagement activities could act as opportunities for discussing ways of handling problems that the community and their learners could be having, as well as for guiding and assisting with the purpose of providing communities at grass root level with a network to mobilise local resources for achieving the goals they have set, as well as the information they may need for making their decisions meaningful (De Beer, 2011). The enabling and supportive roles required of universities in development have the implication of creating a learning context in which communities and universities learn from one another and are able to exchange ideas and share suggestions for improved implementation, where small discussion groups engage with implications for practice (Goosen, 2004).

**Research Methodology**

As part of the I-SET initiative, any parents, educators or persons who sought to advance their knowledge in “the best interests of their learners” (Agamburram & Goosen, 2011, p. 298), had a particular involvement in the First LEGO League (FLL) and/or were interested in starting or continuing robotics training for a LEGO Robotics team in a specific school or community were invited to attend an I-SET training event on campus. The aim of the event was to introduce potential and existing coaches, mentors and leaders of LEGO Robotics and/or FLL teams to the range of issues that are important to the coaching or mentoring of a robotics and/or FLL team, including:

1) Where does LEGO Robotics fit into education?
2) Issues and reality related to what a team is, setting up and possible team building initiatives, as well as marketing and promoting their teams, and finding sponsorship options
3) What is needed to teach in terms of building and programming of the robots
4) The equipment requirements around the LEGO To Go Box: What is in it and where do they get it?
5) Teaching learners about the importance and focus of research, teaching learners how to do research and how to get learners to do research
6) Competition opportunities with regard to the FLL and the World Robotics Olympics in South Africa, and the FLL Competition registration and website.

Everyone who attended the event as described above was invited to participate in this research project. The contact details of the project leader for this research study were provided to all potential participants. Respondents were informed as to what they would be expected to do, what information would be required and how long their participation would take: If they decided to take part in this study, participants would be involved in a once-off, semi-structured interview. They would also be asked to supply certain biographical information. Either way, their participation did not require more than twenty minutes of their time.
By signing the letter of consent, they understood that their participation in this research was voluntary, their responses would be treated in a confidential manner and their privacy with regard to anonymity as a human respondent would be ensured, where appropriate (e.g. by using coded names of participants and/or their institutions). As research participants, they were free to withdraw from the research at any time without any negative or undesirable consequences to themselves and they would at all times be fully informed about the research process. They were offered no significant incentives to be participants in this study. They would not be placed at risk or harmed in any way, e.g. no responses would be used to assess them, their learners/child(ren) and/or their schools/institutions.

Participants were assured that research information would be used only for the purposes of this enquiry. Their trust would not be betrayed in the research process or its published outcomes, and they would not be deceived in any way. They could either give their informed consent to participate in this research or, in line with the principle of voluntary participation, choose not to take part.

**Discussion of Results**

**Demographics of Participants**

**Table 1.** Participants’ ages.

<table>
<thead>
<tr>
<th>Age</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 -34</td>
<td>18%</td>
</tr>
<tr>
<td>35 - 44</td>
<td>27%</td>
</tr>
<tr>
<td>45 - 54</td>
<td>36%</td>
</tr>
<tr>
<td>Older than 55</td>
<td>27%</td>
</tr>
</tbody>
</table>

The overwhelming majority of participants (91%) were female. As indicated in Table 1, although participants’ ages were spread fairly evenly across the options provided, they leaned towards older persons, with no-one below the age of 25. Table 2 shows that almost half of the participants were involved as educators, with equal numbers of coaches and supporters, and only a small number of parents.

**Table 2.** I am involved as a …

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parent</td>
<td>9%</td>
</tr>
<tr>
<td>Educator</td>
<td>45%</td>
</tr>
<tr>
<td>Coach</td>
<td>27%</td>
</tr>
<tr>
<td>Supporter</td>
<td>27%</td>
</tr>
</tbody>
</table>

As specified in Table 3, almost half of participants had no educational qualifications. In terms of those who indicated that they did have such qualifications, however, more than a third of participants had completed a Higher Education Diploma (HED).

**Table 3.** Participants’ educational qualifications.

<table>
<thead>
<tr>
<th>Educational Qualification</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>45%</td>
</tr>
<tr>
<td>HED</td>
<td>36%</td>
</tr>
<tr>
<td>BEd (Honors)</td>
<td>9%</td>
</tr>
<tr>
<td>Other</td>
<td>18%</td>
</tr>
</tbody>
</table>
Although more than a third of participants had no academic qualifications, as specified in Table 4, almost half of them completed some form of Bachelor’s degree. More than a quarter of participants also had post-graduate level academic qualifications.

**Table 4. Participants’ academic qualifications.**

<table>
<thead>
<tr>
<th>Academic Qualification</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>36%</td>
</tr>
<tr>
<td>B degree</td>
<td>45%</td>
</tr>
<tr>
<td>Honors degree</td>
<td>18%</td>
</tr>
<tr>
<td>M degree</td>
<td>9%</td>
</tr>
</tbody>
</table>

Table 5 displays the number of years’ experience with First LEGO League that participants had - these were fairly evenly spread across the options provided, with equal numbers of participants having one, two, or more than four years’ experience respectively, while less than a tenth have three years’ experience. Less than a fifth of participants were novices.

**Table 5. Number of years’ experience with First LEGO League.**

<table>
<thead>
<tr>
<th>Number of years’ experience with First LEGO League</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novice</td>
<td>18%</td>
</tr>
<tr>
<td>1 year</td>
<td>27%</td>
</tr>
<tr>
<td>2 years</td>
<td>27%</td>
</tr>
<tr>
<td>3 years</td>
<td>9%</td>
</tr>
<tr>
<td>More than 4 years</td>
<td>27%</td>
</tr>
</tbody>
</table>

**Qualitative Data**

This section presents qualitative data from the questionnaire used.

**Why are you involved in First LEGO League?**

Almost half of participants indicated that they were involved in First LEGO League in order to educate the “wonderful” learners, to teach them core values and extend their potential. One participant simply loves LEGO, others finds it “fun and educational” and “an interesting and challenging league”, while another have an “interest in robots and electronics”. One parent had a “school kid”. Last, but not the least, one participant indicated that she worked for the College Deanery marketing team, and thus got involved “automatically”.

**What do you like about First LEGO League?**

One participant liked the creativity associated with FLL, while another liked the competitions best. While learners are provided with opportunities to learn about robotics in an interactive way through playing, they build their skills related to problem solving and the programming of robots, with no spoon-feeding involved. Two of the participants liked the way in which FLL contributes to the broad development of learners. One of the participants indicated that she liked the programming best - even though she was struggling at that stage, she was confident that she would “get it”. A further two of the participants had not had their own teams at that stage, but indicated that when they have a team, they think that they would like to support learners in order to see their patterns being turned into real 3D models.

**What do you do to get to know the learners in your First LEGO League team better?**

At least two of the educator participants indicated that the learners in their FLL teams were in the ‘regular’ classes that they teach. Three more participants specified that they use “ice-breaking sessions” and/or team building exercises. While one participant talks to the learners
to get to know them better, another allows the learners to play and then observe them. Yet another participant helped learners individually with the way the game was played.

**What do you do to motivate the learners in your First LEGO League team?**

One of the participants indicated that this should not be a problem, while another believes in self-motivation for these learners. Two more participants referred to fun items being used and having learners relate to young, fun (male) coaches. Yet another brings something new to every meeting - even if it is just sharing the manual information. Finally, one participant makes use of club tournaments, while another relies on learners researching together and sharing their hardships.

**What do you do to encourage the learners in your First LEGO League team?**

It was a pity to hear from one of the respondents that the school that learners in her team came from did not do much to encourage them. Other contributors indicated that they chose to be present as much as possible, and used a club format or credit system for positive reinforcement.

...especially learners with high anxiety levels?

At least four of the participants alluded to using fun, making it fun and showing learners “the fun in the activities”, while another referred to using laughter and jokes. Learners were also reminded that it was “not only about winning toys” and of the LEGO team work values. One respondent allocated some of these learners to a so-called “nurturing buddy”.

...especially learners with low confidence?

Two of the solutions offered by participants referred to giving such learners responsibilities/“important roles” in the team “like playing team leader”, time keeper or refreshments manager for e.g. two weeks. The notions of getting “a nurturing buddy”, fun and the LEGO team work values were again mentioned in this context. Finally, discussions were also sometimes used, as well as incorporating such learners with (more) confident team mates.

**What do you do to help learners in your First LEGO League team develop positive attitudes?**

One of the concepts mentioned most often in response to this question related to the respondents having “a positive attitude” themselves and being positive when speaking to learners, especially while encouraging and praising older learners to do better if they fail the first time. Again, fun, group discussions and simply choosing to be there for learners were mentioned. Sometimes one of the respondents would “invite someone they don’t know to motivate them for 10 minutes”.

**How do you help learners in your First LEGO League team to set achievable aims and goals?**

At least one participant encouraged learners to set high goals. Four more of the respondents revealed that they encourage and help learners to break their main exercises down into smaller tasks and steps, setting parameters and adding challenges in a step-by-step fashion. Others made use of teaching building exercises, posters and/or examples from expert programmers.

**Please describe one of the ways in which you increase your learners’ perception of the usefulness of First LEGO League.**

Some of the participants chose to talk or give presentations about the usefulness of the tasks, while others introduced learners to people with jobs in programming, so that the learners
can see the connections. While one participant achieved this by teaching globally, another pointed to the development of higher and 3D level thinking. Finally, one of the participants indicated that she was known for being professional, and some learners therefore pay attention to anything she does.

**Please describe the things that you do in your team that helps learners to see the relevance of FLL activities to their daily lives.**

Although one participant was not able to answer this question, as she did not have a team yet, others again mentioned giving presentations themselves, or inviting speakers, such as an engineer, to speak to learners on different topics relevant to their everyday lives, problem solving and/or how related activities could become their jobs.

**Please describe one of the things that you do in your First LEGO League team that helps learners to experience pleasure from participating in these activities.**

Learners were reminded that these are toys and it can be so much fun! They were given compliments and exposed to sharing behaviour. Learners also took turns in leading the teams, so that they all feel responsible. Participants let learners take part in knock-out robot games and again mentioned informing learners about robots, electronics and related careers.

**Please describe one of the things that you do in your First LEGO League team to instil a spirit of curiosity in your learners.**

Some of the participants allow learners to solve problems, to build in their free time and/or provide them with additional access to the computer centre, so that they can conduct research on their own team discussions. Respondents also use displays for their learners to explore or emphasize the importance of listening to what learners want. Finally, some participants introduce learners to topics of interest that they have not heard about or use a reward system.

**Conclusions**

In conclusion, results are organised in answer to the original research question posed: the purpose of this study having been to explore such a question around First LEGO League as a community engagement activity, justifying importance and relevance for inspiring and sustaining learners’ and their communities’ interest in Science, Engineering and Technology.

Similar to some aspects that of the study reported on by Agamburram and Goosen (2011), the study discussed in this paper thus explored issues related to participants’ perceptions of community engagement activities, the extent to which these were supported and how they thought these could be improved.

Results obtained in this study were similar to those found in studies such as the one by McWhorter and O’Connor (2009), with especially the qualitative data indicating that respondents felt that robots provided a new avenue to inspire and sustain learners’ and their communities’ motivation by sparking their interest in Science, Engineering and Technology. The recommendation can therefore confidently be made that robots can and should be used towards this purpose.

Like Dahlberg et al. (2011), the conclusions made based on the results presented in this paper reflect that learners enjoyed these kinds of activities and were engaged in debating the efficiency of solutions. Their engagement with the LEGO activities and taking part in these competitions were both motivational and educational. Learners and participants in the research study reported on in this paper had learnt “to view themselves as capable members of a community engaged in” learning (Madusise & Mwakapenda, 2013, p. 123).
Goosen (2004) pointed out that becoming involved in the activities made available to them, as outlined in this paper, provided a structure through which educators, learners and their communities could collaborate to help each other and contribute knowledge and skills to their mutual benefit. This also enabled them to bounce ideas off each other in attempts aimed at presenting material to learners in interesting ways. An original contribution is further made when such discussions could lead to sharing views and an increased sense of responsibility. This same author, however, finally warned that if educators do not receive release time for participating in activities such as those described in this paper, they would have to complete this ‘additional’ work in their own time, and this could make them feel like they do not have sufficient time. It is therefore recommended that authorities carefully consider the interpretation of results as presented in this paper, in order to not only allow, but, instead, actively support, educators’ participation in First LEGO League and similarly related community engagement activities for inspiring and sustaining learners’ and their communities’ interest in Science, Engineering and Technology.

Acknowledgment
The first author wishes to acknowledge the leadership of Patricia Gouws as project coordinator in terms of Community Development, who, together with Dalize van Heerden, had taken on the roles of content developers and coach and mentor supporters and were responsible for a huge amount of on-the-ground-active contributions.

Contact Details
You can ‘Like’ I-SET on https://www.facebook.com/pages/i-set#!/pages/I-SET/266739783402034 and/or follow the project on Twitter @ISETLEGO. You could also have a look at project activities on YouTube: http://www.youtube.com/user/isetcommunity?feature=mhee.

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Bridging the Innovation Chasm: Computer Systems Engineering students’ attitude, biasness and perception towards entrepreneurship and innovation

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In many parts of the world, curriculum reform is a key aspect of the discourse on educating students for the realities of the 21st century. One such reality is lack of employment. It is the universities' duty to prepare students critical thinking skills for resolving lack of employment. The latter, could be achieved through entrepreneurship and innovation. However there are some questions that need to be answered on how what attitude and subjectivity the students have towards entrepreneurship and innovation; and what perception do they hold by do they have about its inclusion in their curriculum. Against this backdrop, this paper contributes to the discussion of entrepreneurial and innovation chasm by reporting on lessons learned from tweaking curriculum of a module, Network Systems IV, offered to Bachelor of Technology in Computer Systems Engineering degree students at Tshwane University of Technology, by including the initial phase (idea generation) of an innovation process as part of module assessment. This paper is part of a doctoral project supported by the same university. It used questionnaires to collect data and used Microsoft Excel to analyse it. The findings showed that most students appreciate the inclusion of entrepreneurship and innovation skills as part of their formal diploma/degree courses. In conclusion students have potential of becoming the entrepreneurs and innovation agents; thereby start companies of their own to combat unemployment.

Keywords: entrepreneurship, innovation, curriculum, Computer systems engineering

Introduction

The curriculum reform of the 21st century is largely influenced by diverse societal challenges at local, national and international levels; and as well by global economical changes. In South Africa, these societal challenges and economical changes create a need for curriculum reform that is shaped by five key government priorities: (i) education; (ii) health; (iii) rural development; (iv) fighting against crime and corruption; and (v) the creation of decent work and sustainable livelihoods and including human settlements, local government and the public service (http://www.thepresidency.gov.za/dpme/qa.pdf).

Based on the latter priorities, South African government identified twelve outcomes that will aid government to deliver services to the citizens (http://www.thepresidency.gov.za). Of the 12 outcomes, two relates to issues of economy and skills development, sustainability and growth, namely:

Economy - decent employment through inclusive economic growth. Inclusive economic growth focuses and takes a long-term approach on economic growth which is a necessary and crucial condition for poverty reduction. Inclusive growth is about
raising the pace of growth and enlarging the size of the economy, while levelling the playing field for investment and increasing productive employment opportunities).

**Development of skills - a skilled and capable workforce to support an inclusive growth path.** According to ILO (2008), skills development is central to improving productivity (i.e. productivity is an important source of improved living standards and growth). It can help countries sustain productivity growth and translate that growth into more and better jobs. Skills development is facilitated by an effective skills development systems (which connects education to technical training, technical training to labour market entry and labour market entry to workplace and lifelong learning).

Both the concepts of inclusive economic growth and effective skills development, cultivate a need for research which could investigate students' training and skills transfer as enablers for addressing their employment and livelihood issues.

Most researchers (Etzkowitz, 2003; Elpida, Galanakis, Bakouros, & Platias, 2010; Hoskisson, Covin, Volberda, & Johnson, 2011; and Bailetti, 2011) provide an advise that universities should involve entrepreneurship and innovation in their curriculum for the aim of developing new ventures emanating from the exploitation of new or existing knowledge and ideas. In return, these ventures could address students’ employment and livelihood issues.

In South Africa, there is a dire need for a new or improved curriculum (Graven, 2002; Jansen and Taylor, 2003; and Naong, 2012) that will incorporate entrepreneurship and innovation in order to train and equip students with the flair of starting–up businesses for their future and that of the country. This calls for strategies towards curriculum and assessment reform.

Using such a watershed backdrop, it is the premise of this paper to report on lessons learned from tweaking a curriculum of a Computer Systems Engineering course (Network Systems IV) by including ideation (idea generation, the initial phase of an entrepreneurship and innovation process) as part of the course assessment.

The rest of this paper will gawk at the paradigm shift of the university's mandate then state the study research questions, briefly discuss two theories that have shaped this study, then discussion of data collection and analysis, idea on inclusion of entrepreneurship and innovation in curriculum, followed by the conclusion.

**Paradigm shift on university core functions**

Universities have traditionally been viewed as a supporting structure and pedestal for production of: (i) trained people, (ii) research and development (R&D), and knowledge creation. Therefore, the traditional mandate of universities included three core functions: teaching and learning, R&D and community engagement (Etzkowitz, 2003; Mashau, 2014).
Universities are in the knowledge business (Holzbaur, 2012). These days, universities have become involved in the formation of firms based on new technologies originating from academic research (Etzkowitz, 2003). This means their core functions have extended from three to four core functions as illustrated by the researchers' figure in Figure 1.

The university duty is to develop solutions for addressing socio-economic challenges. The four core functions of a university are: research and development (development of knowledge), teaching and learning (the transfer of knowledge), community engagement (the application and consumption of knowledge) and entrepreneurship and innovation (the application and exploitation of knowledge).

The four core functions of a university shaped this paper and created a platform for investigating the students' understanding, perceptions and attitudes of entrepreneurship and innovation as part of the technical degrees curriculum. In this regard, the research questions (RQ) which guided this paper were phrased as follows:

RQ1: Do Computer Systems Engineering (CSE) students have an attitude and biasness towards entrepreneurship and innovation?

RQ2: What are the perceptions and attitudes of CSE students towards inclusion of entrepreneurship and innovation content in their studies?

Learning Theories
Bloom (1956) identified three domains of educational activities, namely: (i) the Cognitive domain which focuses on mental skills, (ii) the Affective domain which focuses on affect or likes and dislikes, and (iii) the Psychomotor domain which focuses on the physical skills.
The current educational practice is guided by two cognitive approaches to teaching, namely: Behaviourism and Constructivism (Adams, 2011). Behaviourism is seen as the modernist approach to knowledge as it assume that knowledge has a given structure and it is the task of the lecturer to develop within the student an understanding of this structure and an ability to utilize this knowledge to solve problems (Adams, 2011). A linear learning process is the nucleus of a behaviorism approach. Constructivism is more postmodern in its assumption that knowledge is constructed and therefore the student must develop their own knowledge structure based on personal experience and through discovery and experimentation with the information that exists that surrounds this area of knowledge (Bruner, 1966 cited by Adams, 2011). Recursive active learning process where knowledge is contextualized rather than acquired forms a nucleus of constructivism. Constructivism views knowledge as a product of reality (Adams, 2011).

In the 21st century, constructivist environments are ideal as they allow students to begin thinking creatively and be decisive. It is important to acknowledge that creativity, innovativeness, and self-directed learning are too often acquired by students despite of the traditional way of teaching (lecturer/class oriented). This paper assumed both a behaviourism and constructivism approach. However, with a premise that education makes students to have rationale and critical thinking, be literate, knowledgeable, and have self-sufficiency.

**Theory of planned behaviour**

There are two most prominent theories that have attracted particular attention from researchers that look at entrepreneurship and innovation issues (Nishimura and Tristán, 2011). These theories were formulated by Ajzen (1988; 1991) and they are: the theory of reasoned action (TRA) illustrated by figure 2; and the theory of planned behaviour (TPB) illustrated by figure 3 which is an extension of TRA.

![Figure 2: Theory of reasoned action](image)

TRA argue that intention is expected to predict behaviour only if the intention has not changed prior to performance of the behaviour; and the intension is directly proportional to the weighted sum of attitude toward the behaviour and subjective norm (Ajzen, 1988; 1991).

According to Nishimura and Tristán (2011), TRA argue that an individual’s behaviour is determined by the individual’s behavioral intention to perform that behaviour. Behavioural intention, in turn, is a function of two factors: the individual’s attitude toward the behaviour and subjective norm.
Figure 3: Theory of planned behaviour.

The TPB state that to the extent that a person has the required opportunities and resources, and intends to perform the behaviour, he or she should succeed in doing so (Ajzen, 1988; 1991). Further, it posits that people intend to perform a behaviour when they evaluate it positively, when they experience social pressure to perform it, and when they believe that they have the means and opportunities to do so.

TRA applies to behaviors that are under volitional control. Its predictive accuracy diminishes when the behaviour is influenced by a factor over which at least some people have only limited control (Ajzen, 1988; 1991). TPB deals with such limited control.

Ajzen (1988) says "a person will attempt to perform a behaviour if he believes that the advantages of success outweigh the disadvantages of failure, and if he believes that referents with whom he is motivated to comply think he should try to perform the behavior. He will be successful in his attempt if he has sufficient control over internal and external factors which, in addition to effort, also influence attainment of the behavioural goal".

According Nishimura and Tristán (2011), TPB is based on the assumption that human beings usually behave in a sensible manner; that they take account of available information and implicitly or explicitly consider the implications of their actions. Consistent with this assumption, the theory also postulates that performance of a specific behaviour is a function of the intention to perform such behaviour.

The theoretical framework of this paper is TPB which is an extension of TRA. Since students has the required opportunities (i.e. challenges that need solutions or social pressure) and resources (i.e. knowledge, skills and funding), it follows that they might intend to perform the behaviour (i.e. establish new business venture), they might eventually succeed. As such, arguably students will intent to perform a behaviour when their understanding, perception and attitudes about entrepreneurship and innovation is evaluated.

Research method

This paper is part of a doctoral study that aims to uncover students' interest and readiness in establishing university sponsored student business ventures. It used self-administered questionnaires that were designed by the researchers to explore the understanding, perception and attitudes of technical students regarding the inclusion of entrepreneurship and innovation concepts as part of the assessment.

According to McLeod (2014), questionnaires can be thought of as a kind of written interview and they provide a relatively cheap, quick and efficient way of obtaining large amounts of information from a large sample of people. Questionnaires can be an effective means of measuring the behaviour, attitudes, preferences, opinions and intentions of relatively large numbers of subjects more cheaply and quickly than other methods.
Either or both closed and open questions were used as data collection tools. Closed questions sought to determine answers which fit into categories that have been decided in advance by the researcher and open questions sought to determine answers which are respondent depended (i.e. expressed in the respondent's own words). Data collected through closed question structured questionnaire can be placed into two categories: (i) nominal data (i.e. data restricted to at least two ranking type) and/or (ii) ordinal data (i.e. data can be ranked).

This paper reports on the questionnaires that contained closed questions which were classified as both nominal and ordinal data. For example, it used nominal data concept for collecting demographic data and ordinal data concept to determine if students strongly agree or disagree with the researchers' statements on the understanding of entrepreneurship and innovation.

Since the TPB posits that people intend to perform a behaviour when they evaluate it positively, when they experience social pressure to perform it, and when they believe that they have the means and opportunities to do so. In relation to the theories as discussed above, the researchers designed an 18 questions questionnaire to evaluate students' attitude, biasness and perceptions of their ability to perform entrepreneurship and innovation activities. Of the 18 questions, seven measures students' attitude, six biasness (subjective norm) and five perception.

The questionnaire was design in two folds: it firstly sought to gauge students attitude and biasness towards entrepreneurship and innovation. Students responded to this section before they can engage the assignment. Secondly, it sought to gauge students perception on the inclusion of entrepreneurship and innovation concepts into their curriculum which is scientific, engineering and technological in nature, rather than business. This was done after conducting practical assignments.

The questionnaires were disseminated to 97 postgraduate students registered for a Network Systems IV (NSY401T) course, offered in the second semesters of 2013 and 2014. These students were enrolled for a one year degree programme, Bachelor of Technology (BTech) in CSE at the FoICT in Soshanguve Campus of TUT. The course was a service course offered to the Department of Computer System Engineering by the Department of Information Technology.

Results and Discussion

Of the 97 questionnaires, 85 (88%) were returned unspoiled and 12 (12%) were spoiled. A 5-point Likert scale was adopted to collect data, and for the analysis, responses were coded as follows: Strongly Agree = 1; Agree = 2; Neutral = 3; Disagree = 4; and Strongly Disagree = 5. Two software packages were used to analyse the data, namely: (i) data analysis tool pack of Microsoft (MS) Excel (used 90% of the time), and (ii) the Simple Interactive Statistical Analysis (SISA) software (used only 10% of the time). SISA is an online software allowing users to use a website for statistical analysis (http://www.quantitativeskills.com). Therefore, the results used in this paper were obtained mainly from MS Excel, unless specified.

Participants

The participants comprised of 44 male and 41 female students as summarised in Table 1.

Table 1. The age and gender distribution of participants

<table>
<thead>
<tr>
<th>GENDER</th>
<th>AGE</th>
<th>20 to 25</th>
<th>26 to 30</th>
<th>31 to 36</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td>Male</td>
<td></td>
<td>21</td>
<td>18</td>
<td>5</td>
<td>44</td>
</tr>
</tbody>
</table>
As seen in Figure 4, most students who participated in this study were around their 20s. It has been observed that the age for male students is inversely proportional (i.e. as they grow in age, their participation in this postgraduate course decreases). Hypothetically, this simply indicate that most male students enrolled for postgraduate studies could be in their earlier 20s as compared to their female counter parts.

<table>
<thead>
<tr>
<th></th>
<th>Female</th>
<th>17</th>
<th>21</th>
<th>3</th>
<th>Total</th>
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<tbody>
<tr>
<td>20</td>
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</tbody>
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Figure 4: age and gender of participants Theory of planned behaviour.

RQ1: Do Computer Systems Engineering students have a general understanding of what is entrepreneurship and innovation?

To answer RQ1, a segment of a questionnaire was designed by the researcher to ask conceptual attitude and biasness questions regarding entrepreneurship and innovation. The results are summarised in Figure 5.

Figure 5: Students attitude towards entrepreneurship and innovation.

The questionnaire was developed for a survey purposes, and there were no historical or comparative data sets to base the interpretation on. However, using an advise by Sauro
(2011), a statistical z-score approach (which uses five techniques) was adopted in developing the interpretation. In this regard, the average z-score to a percentile rank of 86% was obtained.

This indicate that majority of CSE students, about 86%, have positive attitude towards entrepreneurship and innovation. It is clearly shown in Figure 5 by a raised bar level of strongly agreed responses; although, the second majority number of students were indecisive.

![Figure 5: Students' positive attitude towards entrepreneurship and innovation.](image)

This indicate that majority of CSE students, about 86%, have positive attitude towards entrepreneurship and innovation. It is clearly shown in Figure 5 by a raised bar level of strongly agreed responses; although, the second majority number of students were indecisive.

Figure 6: Students biasness or subjectivity towards entrepreneurship and innovation.

When analysing the data for biasness, the z-score to a percentile rank of 97% was obtained. This indicate that majority of CSE students, about 97%, are bias or subjective when it comes to entrepreneurship and innovation as clearly shown in Figure 6, by a raised bar level of strongly agreed and agreed responses.

Finding out that the students have positive attitude and biasness towards entrepreneurship and innovation; therefore, it was a proper time to introduce some aspects of entrepreneurship and innovation to their curriculum in order to gauge their perceptions. This led to the development and analysis of RQ2.

RQ2: What are the perceptions of Computer Systems Engineering students towards inclusion of entrepreneurship and innovation content in their studies?

NSY401T is a wireless and mobile communication network course. It's assessments (comprising of two major assignments) were designed to contribute towards students final mark. The NSY401T assignments were designed by the researcher to gauge the students' theoretically and practically. The aim of the theoretical assignment was to build the students research skills. They were expected to prepare and submit an essay or survey document on a wireless and mobile communication network topic using a systematic literature review approach. While the aim of the practical assignment was for students to use their NSY401T concepts and knowledge to suggest designs and solutions that can address societal challenges. In regard to the latter, idea generation phase of entrepreneurship and innovation process (known as ideation) was introduced to students early in the year.

What is Ideation?

According to the Oxford English Dictionary, innovation means introducing something new; the Latin stem ‘innovare’ refers to altering or renewing, and is derived from ‘novus’,
meaning ‘new’ (Little, Onions & Friedrichsen, 1973). For one, to introduce something new, some thinking element or process should be involved. Hence, literature on innovation process starts with ideation, followed by concept definition and feasibility, prototyping, deployment, refinement/formalisation and exploitation (Du Preez and Louw, 2008).

Ideation or idea generation is the beginning of the Innovation Education (IE) which is defined as an innovative school activity with pedagogical values in the context of general education (Thorsteinsson and Page, 2008). It is based on conceptual work which involves searching for needs and problems in the student’s environment and finding appropriate solutions or applying and developing known solutions (Denton and Thorsteinsson, 2003 cited by Thorsteinsson and Page, 2008). Figure 7, illustrates the ideation process.

Figure 7: Ideation within the IE working process (Source: Thorsteinsson and Page, 2008).

Figure 7, suggests that ideation is an interactive process seeking to determine feasible ideas that could be exploited for establishing business enterprises. Little research has been done in evaluating the burgeoning number of techniques used in ideation. Cooper and Edgett (2008) provide different methods (categories into three) that could be used to conduct ideation.

Thorsteinsson and Page (2008) suggest that ideation comprise of completing six tasks that should be conducted under supervision (of a lecturer): (i) finding the needs; (ii) brainstorming; (iii) finding the initial concept; (iv) ideation drawings or modelling to develop the technical solution; (v) making a description of the solution as addition, to the drawing and (vi) make a presentation.

Students in the NSY401T class were requested to implement the first three ideation tasks as part of their assignment and report back towards the end of the semester. They were divided into groups of four-to-five. Good wireless and mobile networking ideas that could solve societal challenges were brought forward and reported by different groups to the researcher. The ideas were presented in confidentiality since some of the ideas could lead to the establishment of big businesses.

Most ideas were on application development. For example, one group presented a "wow" idea but when thoroughly discussed certain challenges emerged. They reported that they firstly inquired from baby carers (i.e. mothers, babysitters and nannies), on what are their challenges towards taking care of the babies. The baby carers posed a lot of challenges. The group then selected a challenge that could help baby carers on how to monitor babies buttocks wetness. The group came-up with an idea of developing a wireless sensor orientated application that will monitor the babies buttocks and frequently report on the nappies moisture level. This could be a good health solution. The other group used a technique of searching for ideas through patent search (i.e. patent mapping process). The
last group presented an idea that could help resolve losing DSTV's signal during rainy and cloudy days.

The students were advised to seek further guidance from TUT's research and innovation division, in order to get more help on the protection of their systems. Unfortunately, no follow up was done with students with regards to their visit to the research and innovation division.

In a form of a feedback, a brief discussion was also held in class and it focused on challenges, opportunities and the process of completing the assignment. Secondly, students were provided with a last segment of the questionnaire which seek to determine their perceptions regarding the assignment. The results are presented in Figure 8 below.

![Figure 8: Students perception towards inclusion of entrepreneurship and innovation as part of curriculum.](image)

Most students strongly agreed and agreed with the idea of inclusion of entrepreneurship and innovation in their studies as illustrated in Figure 8. Students thought inclusion of entrepreneurship and innovation in their studies matters because it could develop an entrepreneurship interest in them, introduce them to the foundations of business theory, help them to explore the development of business ideas, make them employers instead of employees.

**How can entrepreneurship and innovation concepts be included in the existing curriculum?**

It is the researchers thesis that some activities of the entrepreneurship and innovation form a platform that could cut-cross different course/module curriculums. In this regard, entrepreneurship and innovation courses/modules should be made a compulsory option for science, engineering and technology students. This could be achieved by adopting a teaching practise which embed the activities of entrepreneurship and innovation within the existing course/module curriculum. The latter could be implemented by giving students practical assignments that will allow them to engage in entrepreneurship and innovation activities. Academics are in a good position to practise the inclusion of entrepreneurship and innovation in their courses.

Education in entrepreneurship increases the chances of start-ups and self-employment; and also enhances individuals’ economic reward and satisfaction (Etzkowitz, 2003; Elpida, et al., 2010; Hoskisson, et al., 2011; and Bailetti, 2011). A good preparation increases the chance of success. It this paper's thesis that strengthening students’ ideation skills in a general educational context could give them skills to take active part and tackle societal
challenges. It recommends that ideation be embedded to the existing curriculum through assertive type assignments.

**Conclusion and Future studies**

A learning environment that promotes the development of creativity, innovativeness and capability for self-directed lifelong learning in students will have a strong flavour of constructivist learning, rather than that one of lecturer-dominated declarative learning (Moyle, 2010). Since TPB state that to the extent that a person has the required opportunities and resources, and intends to perform the behaviour, he or she should succeed in doing so (Ajzen, 1988; 1991). Further, it posits that people intend to perform a behaviour when they evaluate it positively, when they experience social pressure to perform it, and when they believe that they have the means and opportunities to do so.

In this paper, students attitude, biasness and perceptions were reasonably investigated and the findings showed that most students appreciate the inclusion of entrepreneurship and innovation skills as part of their formal diploma/degree courses. In this regard, contributing to the discussion of bridging the innovation chasm, this paper provides the argumentative conclusion that if students can be afforded a platform of fostering and harnessing their entrepreneurship and innovation ideas, chances are that some of them may end-up establishing business ventures. This could then be one of the solutions towards the scourge of youth unemployment since students have potential of becoming the entrepreneurs and innovation agents.

For future studies, this paper draw attention to two thoughts that could be investigated: firstly, it will be interesting to investigate the pedagogy of developing the culture of entrepreneurship and innovation; and secondly, it will be interesting to investigate existing methods and models of ideation and how they are used to improve students’ critical thinking.

**References**


ILO see International Labour Organisation.


Imperatives to consider in the teaching of design skills in Technology: An indigenous perspective

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This is a conceptual paper which studied the infusion of indigenous knowledge (IK) in the Technology as an attempt to enhance learner’s design skills. Literature was reviewed on motivating the infusion of IK into Technology teaching. The Southern Theory (ST) helps to advance the discourse on this issue in the paper. The Cornell Southern Theory (CST) demonstrates how knowledge from different parts of the world is alienated from the centre to the periphery by colonial practices and aggrandizement. This paper goes on to discuss three aspects which can play a significant role in infusing IK in Technology for purposes of enhancing learners’ design skills. These aspects are about culture, pedagogy and indigenous technologies. This study could add value to the body of knowledge in the field by raising awareness of the aspects which can facilitate the acquisition of design skills through integrating IK. This study will also help Technology teachers to be aware of the value of these aspects in their attempt to include IK in their practice in the Technology classroom.

Key words: Indigenous knowledge, Cornell Southern Theory, National Curriculum statement

Introduction
This study is an investigation into the infusion of IK in Technology to enhance learners’ acquisition of design skills. Education is a precursor of development in the modern societies. The importance of this claim is backed up by Cheru (2002:64), who claims that education is the cornerstone of human development in every society. Cheru (2002:64) takes this backup further by arguing that a sound development of strategy aimed at promoting economic development, democracy and social democracy and social justice must be fully cognisant of human resource development. To put development into educational perspective, any country that is serious about human development should strive to promote effective teaching and learning. It should be noted that the infusion of IK is a herculean task as the western worldview has made every effort to silence the African worldview f or many years. Cheru (2002:64) admits that the mobilisation and management of the necessary human and material resources to ensure that children receive appropriate and good quality education is a complex challenge, and one which requires the collaboration of many partners – teachers, parents, administrators and community leaders. All the stakeholders in education should cooperate in order to promote the infusion of IK for providing quality education. Puri (2007:358) concedes that IK is acquired by local communities through the accumulation of experiences, informal experiments, and intimate understanding of the environment in a given culture. It is an aspect of indigenous knowledge systems (IKS) and can thus be better understood from the perspective of IKS. According to Mapara (2009:140), IKS are bodies of knowledge of the people of particular geographical areas that they have survived on for a very long time. Mapara (2009:140) adds that IKS are those forms of knowledge that the people of the formerly colonised countries have been utilising to make a living. It is the
knowledge that the indigenous people use to solve their day-to-day problems. IK can play a crucial role in helping local people to make valuable products.

From an educational perspective, then, South Africa should concentrate much on delivering quality education in the primary and secondary school education in order to promote economic and social development. Since the focus of this paper is on the infusion of IK into the teaching of Technology, we note that, according to Department of Basic Education (DBE) (2011:5), the National Curriculum Statement Grades R-12 aims to produce Technology learners that are able to demonstrate an understanding of the world as a set of related systems by recognising that problem solving contexts do not exist in isolation. Since the Technology curriculum fronts the methodology of teaching Technology through the design of solutions to the technological problems, we are of the view that designs exist in contexts – thus, there are indigenous contexts to which most learners in South Africa belong and as such their IK should inform their design ideas. Technology learners should thus be made to understand that problems exist in different contexts which offer different flavours to how we think about designs. Whilst the current curriculum and teaching still promote the western worldview, every effort should be made by Technology teachers to make learners appreciate their African worldview as well in order to succeed in life.

According to the International Technology Educators Association (ITEA) (2000:242), Technology is human innovation in action that involves the generation of knowledge and processes to develop systems that solve problems and extend human capabilities. Technology is about the modification of the natural environment to satisfy perceived human needs and wants. Ter-Morshuizen, Thatcher and Thomson (2001:49) state that Technology is concerned with how to meet people’s needs and to obtain, retrieve, utilise and record information. When we design, we use the knowledge of the past and present to speculate on and plan for new products. The existing IK may help learners to design better products which are needed in the society. Technology learners should retrieve and use IK when they design new products for solving technological problems. According to Ogunniyi (2015:25), most of African countries, including South Africa have formulated good policies to support the integration of IK in Technology but little has been done to ensure that IK is integrated in the classroom real learning. This study was conducted to make Technology teachers to begin to think about the imperatives of the integration of IK in their daily teaching of design skills as the National Curriculum Statement (NCS) and Curriculum and Assessment Policy Statement (CAPS) do not really show how teachers can infuse IK in their practice. This study is also conducted to conscientise Technology teachers about the aspects that can promote the infusion of IK in the teaching of design skills in the Technology subject. According to Gumbo and Williams (2014:481), the Department of Education is committed to integrate IK as part of curriculum transformation. Gumbo and Williams (2014:481) have also observed that as part of curriculum transformation, IK is part of the curriculum principles. According to DBE (2011:5), learners should be taught to value IK; they should acknowledge the rich history and heritage of this country as important contributors to nurturing the values contained in the constitution.

The paper presents the literature-based discussion on motivating the infusion of IK into Technology teaching. It bases the discussion on the Southern Theory. This paper goes on to discuss three aspects which can play a significant role in infusing IK in technology for purposes of enhancing learners’ design skills, which are focused on about culture, pedagogy and indigenous technologies.
Indigenous knowledge in teaching Technology

Mapara (2009:140) indicates that IK is a body of knowledge of the people of particular geographical areas that they have survived on for a very long time. Puri (2007:358) concurs that indigenous knowledge is acquired by local communities through the accumulation of experiences, informal experiments, and intimate understanding of the environment in a given culture. Indigenous knowledge is the knowledge that indigenous people use to solve their day-to-day problems. Indigenous knowledge can play a crucial role in helping local people to make valuable products.

According to United Nations Educational, Scientific and Cultural Organisation (UNESCO) (1983:97), education does not take place in a cultural vacuum. Fraser (2007:16) proffers that a more formal understanding of the subject matter should be built on the learners conceptions of the world around them. UNESCO (1983:97) adds that all teaching and learning has a geographical, historical and social context. Fraser (2007:16) states that a learner is not a clean sheet of paper on which knowledge is written. Each learner starts school by possessing background knowledge which has been acquired from the first space and second space (Evans, 2013:79-81) of his/her context. Learning occurs in different contexts in different parts of the world. Each context is unique, thus Technology teachers cannot solely depend on the western world for teaching design skills.

According to Jegede (1998:153), learning is knowledge-dependent, and the learner uses existing knowledge to construct new knowledge. Technology learners may use their IK as their prior knowledge to facilitate the acquisition of design skills. According to Fraser (2007:16), IK is knowledge that is local and unique to a particular culture and community. Gondwe (2014:31) argues that in schools, there are learners whose everyday life knowledge relies heavily on cultural knowledge passed down through family and community. Gondwe (2014:31) adds that effective teaching must acknowledge these cultural perspectives. Jegede (1998:154) concurs that in the construction of new knowledge, learning is dependent on the existing knowledge base. For the indigenous learners to acquire design skills, they should be able to use their IK. Glaser cited by Jegede (1998:154), asserts that cognitive activity is inseparable from its cultural milieu.

Maluleke (2013:17) states that teachers should always try to give learners activities that they can relate to from the point of view of what they know. Technology teachers should accommodate IK of their learners so that they can be able to relate the classroom activities to IK. According to UNESCO (1983: 94), Science and Technology Education should be linked with the world outside the classroom. Nieman and Pienaar (2007:75) concur that teachers should refer regularly to previous experiences and knowledge for building bridges between the known and the unknown. Nieman and Pienaar (2007:75) add that new learning content can be linked to previous experiences by finding similarities and differences between the old and the new, pointing out analogies and relationships, or experimenting with new applications. Unesco (1983: 94) alludes that in the past, the school and the world outside have tended in many countries to remain separate and this situation needs to be remedied. Technology teachers should use the world outside the class to simplify learning. Ordinary indigenous technologies should be used in teaching Technology classes to facilitate the acquisition of design skills. Kaino (2013:83) posits that the artifacts that are available in the traditional environments are important tools that can be used to bridge the gap between what is usually taught in the classroom and what exists outside the classroom, that is, in society. Kaino (2013:83) adds that in various tribes around the world, there exists indigenous knowledge that can be integrated into the school curricula.
South Africa is a multicultural country which possesses a lot of IK from different tribes which can assist Technology learners. The different IK found in different tribes or communities may play a role in the acquisition of design skills. According to Gondwe (2014:31), within and across classrooms, there is a spectrum of worldviews that students bring into school. Many teachers in South Africa exclude IK in learning. Technology teachers should try to accommodate the worldviews that learners bring to their classroom for promoting smooth learning of design skills. According to Jegede (1998:160), the learner’s understanding of any new meaning is strongly influenced and determined by prior knowledge that is determined by cultural beliefs, traditions and customs governed by a world-view.

Kaino (2013:83) complains that IK that exists in society has historically been ignored, from colonial times to the present regimes, where the school curricula are designed without including such knowledge. It is unwarranted that IK is usually excluded in the formal learning. The exclusion of IK in the formal learning militates against quality education which the country aspires. In order to promote effective learning, Technology teachers should infuse IK into their teaching. The infusion of IK may facilitate the good acquisition of design skills as learners will be able to relate the concept of design to their indigenous environments.

According to Mudaly and Ismail (2013:181), IK is conceptualised as a dynamic, complex human system comprising experiences of trial and error, practical wisdom, applied knowledge and historically acquired experiences, embedded and shared locally through collective structures and diverse learning modes. According to Kincheloe and Steinberg (1997:45), indigenous knowledge is a specified form of subjugated knowledge that is local, life-experience based and non-western science produced. According to Kincheloe and Steinberg (1997:45), such knowledge is transmitted over time by individuals from a particular geographical or cultural locality.

IK is marginalised as it is regarded as valueless. Kincheloe and Sternberg (1997:45) dissent that IK is useless in learning. These scholars argue that subjugated knowledge helps to produce new levels of insight by making use of IK. IK may assist learners in generating new ideas for designing new model. Yishak and Gumbo (2014:188) allude that at present IK is not well established and is not on an equal level with the hegemonic western knowledge, hence western and IK must be afforded equal status. Mudaly and Ismail (2013:182) conclude that western science dominates the National Curriculum Statement and that the worldviews of indigenous people of South Africa in education continue to be relegated to the margins. According to Jegede (1998:153), in Africa, the knowledge base for schooling should draw from traditional and current beliefs, taboos, superstitions, customs and traditions.

Parents may play a pivotal role in the education of their children. Schmold cited by Toulouse (2013:12) states that parents are first and primary educators of their children. Toulouse (2013:12) states that schools and school system exist to support the child-rearing and education efforts of parents in a mutually beneficial partnership. Toulouse (2013:5) explains that indigenous student success requires educators, administrators, policy makers, leaders and other stakeholders (indigenous and non-indigenous) to deconstruct those shadows of colonial effects that permeate our actions and relations. According to Gumbo (2015:25), there is a need for African leaders to prioritise internally designed solutions which can be sourced from the indigenous Africans who are naturally pioneers of the local knowledge.
The Department of Basic Education should encourage interaction between teachers and African elders who are custodians of indigenous knowledge. According to Gumbo (2013:436), “within communities, parents and elders can actually be seen educating their young ones in terms of their cultural notions”. Technology teachers should try to create a mutual relationship between indigenous and western knowledge. The mutual relationship between indigenous and western knowledge can promote the smooth acquisition of design skills.

According to Gondwe (2014:53), provided no links between scientific knowledge and cultural knowledge may make learning difficult for learners. Providing no link between scientific and IK may be problematic to indigenous learners. According to Gondwe (2014:53), using Aikenhead’s (1996) terminology these students may experience hazardous border crossings where they do not see any connections between their everyday life and science they learn in the classroom. Teaching should attempt to infuse indigenous knowledge in their teaching of technological knowledge. Gondwe (2014:53) states that the links provide a mental bridge on which to engage learners in science learning and demonstrate how cultural knowledge and science can complement each other in students’ everyday experiences.

The Southern theory
According to Imenda (2014:189), a theoretical framework refers to the theory that a researcher chooses to guide his/her research. Thus, a theoretical framework is the application of a theory or a set of concepts drawn from one theory to offer an explanation of an event, or shed some light on a particular research problem. The theoretical framework can play a role of giving direction or in guiding a particular study. Since we deal with a matter that promotes the inclusionist perspective, we advocate for the ST to inform our discourse in this paper. According to Khoo (2013:150), ST is undoubtedly a major work from a writer who has made distinctive contributions to the debate on gender, power and culture. ST explains thoroughly how some global knowledge is displaced to periphery by the Northern Theory (NT). Schatz and Schiffer (2008:6) concur that marginalisation describes the position of individuals, groups or populations outside of mainstream society, living at the margins of those in the centre power, of cultural dominance and economical and social welfare. In the modern world some of the knowledge systems like IK, are relegated. According to Polelo (2010:132), the CST challenges the pretensions to universality in the discourse of NT characterised by the relegation of other theories. The NT claims that western knowledge is universal and regards indigenous knowledge as inferior; consequently indigenous knowledge is excluded from formal learning.

According to Connell (2014:175), it is a very important fact that the mainstream formation of knowledge and institutional practices in the metropole has tremendous influence in the periphery. Polelo (2010:132) indicates this is done through the NT’s ignoring colonial voices and subjects and struggles of the oppressed. Collins (2013:140) speaks of NT as unequal power relations where western theorists have held most if not all of the cards. Boudreau (1996:175) dismisses the claim that, NT has been inappropriately applied to Southern cases is an old perhaps tired complaint lodged against an important endeavour. According to Vessuri(2015:305), increasing number of scientists are uncomfortable with the fact that western theories pretend universal validity although they often do not adequately interpret phenomena in other cultural contexts. Some scholars (e.g. Khoo, 2013; Polelo, 2010; Vessuri, 2015) also question that in pretending to interpret reality through western ideological lenses, many theories produced by social science in the rest of the world fail to
fully understand what happens. Thus, the western theories are not applicable in major parts of the world as they interpret reality through sole western / ideological lenses.

The knowledge that we know is imperialist, metropolitan in its orientation and reductively Northern (Polelo, 2010:131; Khoo 2013:150). The western knowledge which is regarded as universal is indeed metropolitan as it does not represent different knowledge systems found around the world, indigenous communities in particular. Collins (2013:138) concedes that in prior periods where knowledge projects were crafted within stark politics of exclusion, scholars, academics and intellectuals came from homogenous social groups that decided what would be best for everyone else. Blacks, women, indigenous people, poor people and all individuals who could be identified as ‘other’, were routinely excluded from literacy, schooling, jobs and publication venues that legitimate knowledge.

According to Chakrabarty, Smith, Nakato (in Manathunga, 2015:1), the northern knowledge is positioned as the source of all knowledge and theory and all knowledge systems are culturally, historically and geographically situated, as a result, challenge constructions of western knowledge as universal and timeless.

Gale (2012:254) explains that similar distinctions are formed between street and institutional knowledge, with what learners learn informally and from practice not being valued within formal learning environments. The point is that valuable ways of understanding and engaging with the world, which have different understandings of relations between pure and applied knowledge or that do not even make this distinction are hence denied, suppressed or lost to others in the learning environment. One method of translating this theoretical acknowledgement of marginalised knowledge into real world curriculum is through what is known as a ‘funds of knowledge’ approach. IK, which is acquired in different communities, should be accommodated in formal learning in order to promote effective learning of design skills. This includes recognising understandings that can contribute to the education of others. This requires identifying and inviting learners’ IK into the learning environment and using them to develop curricular. Learners are then positioned differently, because they are now experts in the kinds of knowledge systems knowledges that inform learning experience.

The inclusion of IK can contribute immensely in the formal learning. Kaya (2014) states that the foundation of all knowledge systems are local, but due to unbalanced power relations stemming from colonialism and other forms of imperialism, other nations and cultures have universally imposed their knowledge systems, cultures and languages. Green (2012:1) indicates that the IK movement has been vocal in making an argument for the recognition of the plurality of knowledge, yet often via an argument that asserts a universal indigenous knowledge in counterpoint to that of the west.

Green (2012:3) explains that the cognitive justice movement argues that all knowledge is ethnic or cultural. This argument calls for greater tolerance of ethno-knowledge and makes case that science is also ethnic. This argument is for cultural relativism: that one’s truth depends on one’s culture or identity or perspective. A related form of the argument is that all knowledge can be shown to contain elements of science. The cognitive science movement calls for the equality of knowledges based on the assertion that either all ways of knowing the world, including the sciences are beliefs or all are knowledge.

According to Khoo (2013:150), Connell believes that for the knowledge to become properly global, it must include significant Southern theoretical voices and debates. The Southern
theoretical voices and debates have been disregarded and marginalised by practicing an ersatz metropolitan version of universality.

Keim (2010:108) adds that the ST advocates the inclusion of other knowledge systems in the formal learning institutions. ST argues that all knowledges are equal, thus they should be treated equally in formal learning. IK is equal with the western knowledge. Technology teachers should ensure that they infuse IK into their lessons in accordance with the curriculum requirement. Conell (2014:175) proposes a new path for social theory that will help social science to serve a democratic purpose on a world scale. Conell (2014:176) further states that ST is an educational process, mutual learning on planetary scale which is deeper and a more powerful knowledge that is fit for democratic use. Conell (2014:176) explains that the Eurocentric world knowledge economy is premised on that raw material from periphery is imported, processed and transformed by theoretical framework in the knowledge factories of the global North. Conell (2014:177) suggests that the social scientists should be inclusive in reading and work towards the democratisation of knowledge.

Manathunga (2015:1) argues that in order to wrestle effectively with the problems facing our world in the 21st century, we need to draw together the array of knowledge systems that all human cultures have produced. This means creating space for Southern, Eastern and IK and developing more effective forms of intercultural communication. Kaya (2014) suggests that a founding principle for fostering positive interactions between the African IKS and other knowledge systems is that collaboration must be initiated between equal partners. It must be built on mutual respect and understanding, transparent and open dialogue, and informed consent and just returns for the IK holders and practitioners through the flow of rewards and benefits. According to Vessuri (2015:305), today there are significant research communities in many more countries than the old well-known crowd. Everywhere individuals are critically rethinking the relationships between knowledge, and power, contributing to change the architecture of world science and scientific influence. Vessuri (2015:308) asserts that there is a dire need to combine western knowledge with multiple voices.

Let us now locate our argument within the design and design skills. We do this by defining the concept of design first.

Design and design skills
According to Yu, Lin and Hung (2010:436), design is constructive and concerned with how things should be made. ITEA (2000:237) defines design as an iterative decision-making process that produces plans by which resources are converted into products or systems that meet human needs and wants to solve problems. Mourton (2012:3) explains that design is a process through which one creates and transforms ideas and concepts into a product that satisfies certain requirements and constraints. Indigenous people can use resources in their environment to design products for their needs. Technology is about minds-on and hands-on activities, thus when learners design, they must start with minds-on activities and end with hands-on activities to make new products. Technology learners may use IK when they generate new ideas for solving existing problems. They can compare their conceived ideas of new prospective products with the existing products that they know from their contexts when they design technological products.
Yu et al. (2010:437) state that design skills are the ability to implement steps of design process in solving science related design problems. Technology learners should be afforded an opportunity to create new models/products through utilising their IK. The Technology learners may at time have to start with tacit knowledge which exists in the African philosopher (elders) by utilising indigenous skills to solve real problems and meet human needs. Technology learners should acquire design skills which are used by even engineers in indigenous contexts to solve real problems to meet human needs and wants. For example, the Technology learners may develop technological design skills when they are involved in a project which is analogous with their cultural contexts.

Design skills include project management, communication, making, investigation, evaluation, time management, resource, graphics, etc skills.

Aspects which will ensure the infusion of indigenous knowledge in the teaching of Technology are discussed briefly next.

Aspects to ensure infusion of IK in the teaching of Technology

Designing with the cultural world of the end-user in mind

The concept of culture and design are intertwined but research lacks in this area to assist designers to use culture as a catalyst for designing innovative products (Moalosi, Popovic & Hickiling-Hudson, 2010:175). Cultural influence necessitates the consideration of the cultural aspect in design as such, as Balsamo (2005:2) asserts that when developing new technology, culture needs to be taken into consideration at even a more basic level as the foundation upon which the technological imagination is formed. The impact of technology on society and vice versa also creates a need for the designer to take into account the culture of the end-user. Moalusi et al (2010:186) aver in this regard, that, designers need to study users’ concerns in the social context in order to create cherishable user experience.

“Designers should take into account the needs and wishes of users and they must be aware of the fact that they design for diversity of users” (Van Doorn & Klapwijk, 2013:2). It is important for the designer to be aware that a product appeals to a user if it is relative to his or her cultural framework, worldview and daily experiences (Moalusi et al., 2010:186). By interacting with users in their natural environment, designers can uncover and gain insight into users’ beliefs, behaviours, needs, perceptions, desires and values.

According to Purao and Wu (2013:2), designers must design products that can promote the values of the society. Moalusi et al (2010:186) add that products succeed only when they resonate with users’ values, attitudes and behaviours, even if they result in changes to the same values and behaviours. The input from socio-cultural factors is insufficient to generate culturally innovative and acceptable solutions; one also need to incorporate data from physical, cognitive and emotional human factors. Moalosi et al (2007:37) write that designers should work with an understanding of how users perceive their experiences of the world around them. These experiences shape the users’ conceptions and perceptions of their environment. Sun (2013:2) argues that cross-cultural design community should foster a critical design sensibility to understand the postcolonial conditions where we are living through so that we could come up with culturally sensitive designs that are not only driven by market revenues but by mindful listening, ethical standards, social justice and the conscience of design for social good as well.

In the light of these deliberations, designing from a cultural stance has serious implications for the teaching of Technology. Here, teachers have a role to play by tapping into the
learners’ cultural milieu and accommodate it in their planning for learners’ design activities. They should keep the question close to themselves: “Am I designing the design project scenarios relevant to my learners’ cultural appeal?”

Need for a culturally competent pedagogy
According to Jegede (1998:152), badly prepared teachers may contribute to poor student achievement in Science and Technology. With reference to the Australian content, Moyle (in Kitchen & Raynor, 2013:42), states that the teachers’ knowledge and linguistic and cultural competency are critical to supporting Aboriginal students’ educational accomplishment. This implicates the pedagogy for integrating IK in Technology classes. A democratic pedagogy would be required of teachers to allow young children in the early years of schooling greater input into and control of technological tasks set for them (Mawson, 2013:451). Greater ownership of the context and the process would provide a more relevant authentic learning experience for children and result in more in-depth technological knowledge and practice. According to Mawson (2013:451), teachers would need to constantly be aware to look for opportunities to direct children’s attention to the wider social and environmental issues associated with the child’s work.

Children have not had sufficient experience of the world to make these connections without the perceptive guidance of more knowledgeable adults. In guiding them to make these connections, constructivists advocate that learning should involve social negotiation and mediation (Engdasew, 2013:392). This contention refers to the role of social interaction that works for the development of socially relevant skills and knowledge. Furthermore, constructivists assert that contents of skills in lessons should be relevant to the learner and within the framework of the learners’ prior knowledge and skills. The aim of constructivism, then, according to Bryant (2010:25), is to utilize the learners’ prior experiences and perspectives for self-construction of learning. Thus, Technology teachers should try to accommodate the learners’ prior knowledge. Bransford, Brown and Cocking (2004:10) aver that construction is anchored on the principle and framework of learner-centred education that pays attention to the knowledge, skills, attitudes and beliefs of learners. It aims to make science culturally responsive, culturally relevant, culturally appropriate and culturally compatible where language and indigenous knowledge of the learners are respected and utilised in the school Technology curriculum.

Maluleke (2013:17) states that teachers must always try to give learners activities that they can relate to from the point of view of what they know. According to McNair and Clarke (2007:272), teachers seek to address the need for pupils to understand the ever-changing man-made world by developing skills and understanding in its four elements of designing, communicating, manufacturing and the use of energy and control. To be effective in attaining these goals, it is important that teachers allow pupils to have a voice in their learning as they are keen to flash out their design ideas. Hill (1998) conducted a case study through observations, interviews and content analysis over a complete design-and-make project in each school. Hill (1998:11) found out that learners complete their technological problems that affect their world. Hill (1998:11) concluded that learners should be able to think in real-life contexts for Technology.

The role that indigenous knowledge can play in the teaching of design skills
According to Gumbo (2013:440), the infusion of indigenous technologies into the curriculum has the potential to make teaching and learning relevant for learners especially indigenous learners. Indigenous technologies may play a significant role in helping learners
to acquire design skills in the Technology subject. Technology-oriented representations focus on the technological development with no connection to human activities, whereas in human-oriented representations, daily-life technologies are related to human activities and needs especially to the humans either as users or inventors of technological innovations. Solononidou’s and Tassios’s (2007:126) study revealed that the majority of students equated technology with modern tools and appliances whereas experience-based technologies were hardly recognised by participants as technology. The majority of students did not relate everyday life technologies to human activities and needs. Hill (1998:216) points that teaching and learning Technology procedures should be established in authentic, real life problems and situations for effective learning with understanding. This author is supported by Machaisa (2006:125) who states that teachers must be familiar with students’ everyday experiences and the skills they bring to the class. Machaisa (2006:125) explains further that students must recognise that the teacher is not some kind of supervisor who is there to keep them quiet and in their seats, but to acknowledge him or her as someone trying to give them tools which will be useful for the future.

**Conclusion**

Technology as a school subject presents an opportunity for teachers and learners to hone in design skill from a variety of environments including indigenous ones. This paper focused on the infusion of IK into the teaching of the subject and cautioned on the aspects that could help teachers to do just that. It was found from the theoretical framework that western knowledge is more influential in education globally. The counter argument is that western knowledge is not global as it excludes other knowledge. It is revealed from the literature, that the NT is opposed to the ST.

We thus recommend a concerted effort to infuse IK into the Technology teaching so that the indigenous cultural aspect that exists in the learners’ minds cannot be denied expression in the design learning activities. We strongly believe that this effort will help enhance and diversify learners’ design skills.
References
At the cross-roads: Perceptions of barriers to the implementation of learning technologies by in-service teachers in South Africa

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This qualitative study is part of a longitudinal study on design principles that may be used to promote the integration of learning technologies in teaching. It examines the perceptions of in-service teachers regarding the barriers that they face in integrating learning technologies into their teaching. The study used critical discourse analysis (CDA) as its theoretical framework. This involved, in this study, the researcher’s inductive analysis of the views expressed by participants though semi-structured and focus group interviews. This study is of significance since it analyses the teachers’ perceptions of the challenges that they faced, and also solicit their suggestions of what can be done to improve their situations. The perceptions and experiences of the in-service teachers are examined in terms of their simultaneous statuses as university students and teachers who are members of staff in their respective schools. The study concludes that teachers received very little if any coordinated training and support on how to integrate ICT in their teaching both at school level and at University level.

Keywords: CDA, learning technologies, ICT, FET

Introduction

The use of learning technologies has been hailed as offering a multiplicity of advantages to the learning process. Dargham, Saeed and Mcheik (2013) have shown that learning technologies afford learners the freedom to acquire knowledge and develop skills at their own pace since the learning content is made available to them irrespective of the presence of the teacher. Dargham, Saeed and Mcheik (2013) observe further that learning technologies also enjoy the advantage of the constructivist approach that emphasises the need for learners to be active in their own learning. Similarly, Oreški and Savić (2013) note that the use of learning technologies in teaching and learning opens the learning process, enabling learners being able to access materials regardless of limitations of time and place. They elaborate further that the use of learning technologies makes the distribution of learning materials easier and cheaper. It is also their view that the provision of learning technologies makes learning more flexible since assessments can be delivered online and learners can receive rapid feedback upon completing them.

The use of learning technologies in teaching and learning is one of the most contentious issues in South Africa’s contemporary educational sector. Several studies have looked at the need for the government to introduce learning technologies in the classroom (Bredenkamp, 2005; Mlitwa, 2010; Mlitwa & Nonyane, 2008; Nonyane, 2011). Scholars have hailed the use of learning technologies in science learning as a panacea to the shortage of apparatus in the country’s schools (Nkula & Krauss, 2014). For this reason, some researchers suggest that learning technologies should be introduced mostly in township schools to redress the negative colonial legacies of inequitable distribution of resources (Department of Education, 2004). However, the white paper on eLearning has not been successfully implemented. As
such, many teachers are still uncertain of what to do and how to integrate technology in their teaching (Isaacs & Hollow, 2012).

This study nonetheless seeks to examine, analyse and explain the perceptions of the teachers with regard to the challenges they met when they integrate learning technologies into their teaching. It also seeks their suggestions of how the issues could be resolved.

**Theoretical background**

As explained by Fairclough and Wodak (1997), critical discourse analysis (CDA) focuses on language and spoken works to provide analytical tools for understanding an individual’s or group’s thoughts and actions. According to Van Dijk (2001), CDA provides a platform for the analysis of power relations within a group or among individuals, as depicted by the ways in which they use language. He goes further to state that this theory examines how dominance and submission are embedded in and expected from people in the context of social relations. This includes an exploration of the roles that members of social groups perform in order to either constrain or perpetuate power inequalities.

For his part, Lucke (1996) demonstrates that CDA intends to generate and perpetuate systems through which individuals within given circumstances come to understand how the nature of interactions and power relations as they unfold within a system and context of language (Wodak & Meyer, 2001). The approach has been described by Bilal, Akbar, Gul and Sial (2012) as an analytical tool whose primary interest is the analysis of the way in which power is abused, culminating in the dominance of some groups over others. This, they explain, leads to the sustenance of social inequalities. Subjugated groups eventually resort to some kind of resistance that is often implicit in their text and speech as observed during social interactions (Bilal et al., 2012). Bilal et al. (2012) have something missing here to CDA as a dissident research approach which brings to light the ways in which subjugated groups use language and text to combat social inequality.

The main tenets of the CDA theory have been laid down and summarised by Fairclough and Wodak (1997: 271-80) as follows:

1. CDA addresses social problems;
2. Power relations are discursive;
3. Discourse constitutes society and culture;
4. Discourse does ideological work;
5. Discourse is historical;
6. The link between text and society is mediated;
7. Discourse analysis is interpretative and explanatory;
8. Discourse is a form of social action.

The CDA has been found to be relevant to this study given the historical and socio-political contexts of the South African education system. There is abundant evidence in the literature (Mampane & Bouwer, 2011) that township schools in South Africa are largely impoverished compared to suburban schools as a result of the colonial legacy. These schools lack many resources and their teachers face a number of barriers to their teaching. This recalls Van Dijk
(2001)’s view that in CDA, the formation of theories, descriptions and explanations are inherently socio-politically embedded and situated. As such, CDA becomes a fitting theoretical approach for examining the perceptions of the teachers under focus in this study. The language and thoughts of these teachers as they reflect on the barriers that they face are perhaps not necessarily as a result of the situations that they experience currently. Rather, they could be compounded by what they feel have been some historical socio-economic imbalances and prejudices regarding their education and training systems.

**Purpose and research questions**

Given the nature of the South African education landscape, especially that which the current teachers went through, which was characterized by institutionalized segregation and discrimination, prior to 1994, and a series of curricular changes post 1994, teachers have become skeptical of the innovations that the government might attempt to follow. Of late the Department of Basic Education (DBE) is emphasizing the need for teachers to become technologically-literate, and for them to use learning technologies in their teaching. Having realised that the extent to which this innovation would be fulfilled is partly determined by the perceptions that teachers have pertaining to its feasibility, this study investigates teachers’ perceptions of the barriers that they face in their attempt to infuse learning technologies in their day-to-day work. In order to explore the teachers’ perceptions of the barriers that they face in their integration of learning technologies this study which adopted a qualitative approach, was informed by the critical discourse analysis theory. The research question that guided the study was as follows: (1) What are in-service teachers’ perceptions of the barriers that they face in their bid to integrate learning technologies into their teaching? (2) To what extent is there a relationship between their perceptions and the actual ways in which they use learning technologies in their teaching? (3) What do the teachers feel can be done to alleviate their current situation?

**Methods**

**Research design**

Creswell (2015) defines a research design as a typical guide that directs the research, which O’Leary (2004) regards as giving protocol to the research process. Creswell elaborates further that the research design indicates the precise roles that the researcher and the participants have to assume, and the order in which it has to happen. Similar views have been alluded to in the literature (Burns & Grove, 2003). Taking consideration of the point that teachers’ perceptions are partially related to both their beliefs, their assumptions and their experiences (Kuzborska, 2011), it becomes necessary to examine the teachers’ views through interviews. In that regard, it was found necessary to use qualitative methods due to their potential to solicit and interrogate the teachers’ views. Alluding to similar sentiments Creswell (2014) explained further how this approach focuses on the participants’ views, perceptions and experiences in ways sensible to their lives. This study thus followed a phenomenological approach (McMillan & Schumacher, 2006) which seeks to describe the lived experiences of participants. The approach has been described by Mogashoa (2014) as enabling the understanding of the subjective experiences of the participant. To achieve this, the study used semi-structured interviews which included questions pertaining to the teachers’ perceptions of the barriers, and what they felt could be done to address those barriers. The interviews were transcribed verbatim, and the interview transcripts were the main source of data analysed in the study.
Participants

In order to explore and analyse the teachers’ perceptions, 25 in-service teachers were recruited from a group that was doing part-time Honours degree in education from a South African University. The sampling technique used was convenient sampling, based on the willingness of the teachers to participate. It was also convenient in order to cut costs, since these students were easily accessible during the days when they visited the university every fortnight to attend to lectures. This would essentially cut travelling costs, and the need to negotiate with authorities in order to get access to the schools. The selected teachers had each more than 10 years experience of teaching various subjects. Since this study is general in terms of the subjects that the teachers taught, it as such selected an assortment of teachers based on the subjects in the following order: Mathematics (3 teachers), Geography (3 teachers), Natural Sciences (3 teachers), Physical Sciences (3 teachers), History (2 teachers), Life Orientation (4 teachers), Life Sciences (4 teachers) and Mathematical literacy (3 teachers). The selected numbers of teachers in the given subjects were partly subject to their availability. All of the selected teachers came from public schools although there some differences in terms of whether the schools were township or suburban. All of the teachers also taught in the Further Education and Training (FET) band, except the Natural Sciences teachers who were in the General Education and Training (GET) band. The reasoning for the selection was because of the emphasis of the curriculum framework for the integration of technology in teaching and learning (Kritzinger & Padayachee, 2010). The average age of the teachers was 35 years.

Semi-structured interview

According to Cohen, Manion and Morrison (2000) an interview is a planned interaction through dialogue between at least two people, one the interviewer and the other the interviewee. In an interview, the directing role is often preserved by the interviewer whose intention would be to get as much meaningful information as possible form the interviewee (Charmaz, 2007; Kvale, 1983).

In a bid to explore the teachers’ perceptions of the barriers they faced in their integration of learning technologies into their teaching, an interview guide compiled up. An interview guide is a pre-compiled list of areas and questions that have to be covered in a semi-structured interview (Given, 2008). The rationale is often to allow the interviewee sufficient space to think out their response whilst at the same time maintaining focus (Boyce & Neale, 2006; Denzin & Lincoln, 1994; DiCicco-Bloom & Crabtree, 2006). The interview questions were piloted with other in-service teachers so as to improve them. The questions were also reviewed by a group experts including senior researchers. Examples of the finalised were: (1) What do understand about learning technologies? (2) Do you think learning technologies may be used in teaching? (3) Have you ever infused learning technologies in your teaching? (4) If so, what problems do you encounter in your attempt to use learning technologies in your teaching? (5) What do you think can be done to address the problems that you face in our attempt to infuse learning technologies in your teaching? The order of the questions was however determined by the course of the interaction during the interview during which further probing questions were asked. The interviews took place at the university in isolated secure places to minimise disruptions. Permission to audio-record the participants was sought and it was granted. In addition, all information pertaining to the subsequent
transcription and analysis of the interviews was made clear to the participants. In the interests of time, each interview was limited to approximately 30 minutes.

**Data analysis**

**Development of the coding scheme**

Coding takes place when the researcher combs through the data with the intention of finding outstanding issues that tend to lend credibility to what the respondent was saying (Saldana, 2009). Saldana (2009:3) defines a code as a “word or short phrase that symbolically assigns a summative, salient, essence-capturing name for a portion of language-based or visual data”. He explains that the coding process is essentially informed by a chosen analytical lens. In this study, the coding was influenced by the discourse of learning technology integration in teaching. Related codes were grouped into categories and related categories into themes. The entire process of moving from codes to categories and from categories to themes is illustrated in Figure 1 on the below.

![Figure 1: The Saldana coding scheme (Saldana, 2009)](image)

**Data analysis procedure**

The interview data was analysed inductively according to the Saldana model shown in Figure 1 above. This happened to the interview transcripts of all the 25 teachers who participated in the study. Efforts were made to refine the coding multiple times, and this was done by 4 coders. The inter-rater agreement was found to be 91%, a percentage significantly very high to confirm the validity of the coding process. The software Atlas.ti was used to analyse the data. After the generation of the themes, efforts were made to answer the research questions using the themes, in the form of assertions. The data corpus was there to confirm the validity of the assertions.

**Findings**

In this section, an overview of the teachers’ responses to the interview questions is given.

**Teacher interviews**

Interviewer: What do you understand about learning technologies?

The majority of the teachers failed to give a clear understanding of what is meant by learning technologies. Some of them tried to explain their understanding of learning technology in
their vernacular. However, their explanations were still wrong. However, asking this question was important since it had the potential to give the overall impression of how much the teachers knew about learning technologies. Such a revelation would essentially give an impression of the teachers’ potential to use the learning technologies in their teaching. The closest explanation of learning technologies was from teacher 20:

Teacher 20: Learning technologies to me talk about electrical appliances such computers that may be used for learning. These things are normally expensive and are often used by the children of the rich, there in the suburban schools.

Teacher 6 had this to say: Learning technologies include, I think items like televisions, such as DSTV and radios. They are not common.

Interviewer: Do you think learning technologies may be used in teaching?

There was a multiplicity of responses from the 25 interviewed teachers. Though some of the teachers were not certain about what and how learning technologies could be used, they were certain that they were used. This could be discerned from their emphasis that the major problem was that the devices were not available. Given below are some of the responses from the teachers:

Teacher 1: I am sure that learning technologies are very much usable in teaching. We just hear that in some schools, they no longer use books a lot.

Teacher 5: I am sure learning technologies would be of great help. One day on television, when I was watching MindSet, I saw how the teacher was used what is called a white board.

Teacher 8: Learning technologies are the thing. When you use them, you can see your learners following as you teach. If only we could be provided with more.

To establish the extent to which the teachers were using the learning technologies, the following question was asked:

Interviewer: Have you ever infused learning technologies in your teaching?

The majority of the teachers indicated that they are willing to infuse learning technologies in their teaching. They however indicated that they faced problems when it comes to the availability of these technologies. The impression was that the motivation to infuse the learning technologies was quite high. Given below are some of the responses from the teachers:

Teacher 9: I wish that one day I would be able to use learning technologies in my teaching. We have received a lot of promises form the Department of Education about giving us training, and also to avail some devices to us.

Teacher 10: I try a lot to infuse learning technologies in my teaching. Sometimes, I use my laptop and use my own data to download some important simulations to show to my learners.

Based on the literature study and the responses from the teachers, it becomes imperative for one to conclude that very little had been achieved in terms of the infusion of learning technologies in teaching. This could reflect a backlog on the planning of the Department of basic education as promulgated in the White paper on e-education (Department of
The parallel implication that can also be drawn is that the University has not adequately met the specifications of its mandate to provide its students with ICT-driven learning skills. This is apparent from the students’ insistence that they lack training in the integration of learning technologies in their teaching. The next question sought to establish the problems that they faced in their attempt to infuse learning technologies in their teaching.

Interviewer: What problems would you encounter in your use of learning technologies in your teaching?

Teacher 4: We lack the skills to use the learning technologies. We have not been trained, both at work and here at the University. We ultimately won’t use them.

Teacher 5: We lack the support from the schools administration authorities. The other problem that we face is that most of children come from very poor family backgrounds. As such, they cannot afford to buy items that we might need to implement teaching and learning via technologies.

Teacher 20: Our main problem is time. We are under a lot of pressure for us to complete the designated sections, since our learners write cluster examinations. We won’t have such time.

Teacher 15: One problem is the sizes of our classes. Besides we face a lot of disciplinary issues; some of our learners come to school on drugs.

The problems that the teachers highlighted are reported elsewhere in the literature. It would be objective to mention that the teachers felt that though they would feel prepared to infuse learning technologies in their teaching, they however lacked the skills, the support and even the time to do so. Issues related to contextual factors such as class size have also been mentioned. The issue of the lack of support cuts across all the other problems that were mentioned; for instance, teachers found the integration of learning technologies as a daunting task perhaps because they have not been sufficiently guided on how to use them.

The next question looked at what the teachers suggested as a solution to the problems that they indicated as hindering them from infusing learning technologies in their teaching.

Interviewer: What do you think can be done to address the problems that you face in your attempt to integrate learning technologies in your teaching?

Teachers mentioned a multiplicity of suggestions of what they thought could be done to help them implement the integration of learning technologies in their teaching. The majority of them however concurred that there is a need for training and re-training to be done to them, so that they might be able to use learning technologies in their teaching. They also encouraged the government to draw up a blue-print framework that they might follow to integrate learning technologies in teaching. The following responses bear testimony to this:

Teacher 7: In my view, we need thorough training. That’s all we need so that we can feel very confident to use them.

Teacher 12: In my view, both we the teachers and the learners need to be trained on how to use the learning technology gadgets. Some of the learners are actually much better than us.

Recommendations and Conclusion
The introduction of learning technologies could be a hallmark of the transformation of the South African education system. This is mentioned, bearing in mind the extent of curricular changes that the country has experienced since 1994 and the low achievement in subjects such as the sciences and mathematics. The integration of learning technologies could help improve the levels of motivation towards learning of South African learners (Mbodila, Ndebele & Muhandji, 2014) which has been reported to be significantly low (Schulze & van Heerden, 2015; Wilburn, 2013) and has been partly attributable for the low performance of learners in local and international benchmark assessments (Howie, 1997; Reddy, 2006).

The aim of this study was to find out teachers’ perceptions of the problems that they face pertaining to their integration of learning technologies in their teaching, and what they thought could be done to alleviate those problems. During the interview, the teachers gave the impression that they were quite aware that the use of learning technologies could potentially improve both their teaching and their learners’ understanding. They however lamented the shortage of these learning technologies in their schools. In that regard, it is highly recommendable that the responsible authorities should make the learning technologies available to the education system before assuming that the teachers would be able to use them. The authorities should be committed to the maintenance and upgrading of projects such as the Gauteng-on-Line project which is mandated to avail learning technologies to schools.

The study also indicated that though the teachers are willing to integrate learning technologies in their teaching, they however lack the skills required for this. Integrating learning technologies would need more elaborate understanding of how the technologies work in general, and how that may be harnessed pedagogically to enhance learners’ understanding (Chai, Koh, Tsai, & Tan, 2011; Robinson, 2003). If training is not sufficiently target-focused and need-based (Vannatta & Nancy, 2004), the desire of the government to use learning technologies to redress some colonial imbalances (Butcher, 1998) may not be realised. Under the circumstances where the teachers lack the basic skills and understanding of the use of learning technologies, it would be essential for the government to undertake continuous, gradual yet targeted professional development that would enlighten the teachers on how to integrate technology in their specific domains.

This study has indicated further that though in-service teachers are willing to integrate learning technologies in their teaching they however lacked the necessary support. In the context of this study, the teachers implicated both the Department of Education and the Faculty of Education in their learning institution. Both of these structures have mandated in their policies that every student would be given sufficient training in the use of learning technologies in their teaching. The two organisations intended to equip the teachers with sufficient knowledge. Perhaps one problem that caused this dual failure, is that the two organisations were working independently despite having a common goal. A recommendation in this regard would be that the government and the higher education institution should perhaps set up a task team that is mandated to make recommendations on the strategies of integrating learning technologies that could be followed. In my view, one such strategy would be for the higher education institutions to introduce teaching methodology modules that specifically deal with the integration of learning technologies in teaching specific subjects and specific concepts. This view alludes to the Department of Education’s policy framework (DoE, 2007), which seeks to ensure that teachers have undergone elaborate professional development which would make them skilled enough to
be able to select appropriate technology to teach specific content. According to the findings of this study, the policy framework remains unimplemented, eight years later.

Whilst the above approach could work with in-service teachers who are enrolled in a university for further study, a different strategy would have to be devised for those teachers who will not be enrolled by any university for further study. It is my recommendation that in such a case, the Department of Education should plan professional development programs to cater for those teachers. The professional development programs could be implemented at cluster level, or at district level. It would be very important in that case that such a program must not be generic, but should rather be subject specific and specifically tailored to introduce teaching approaches for that subject (Vescio, Ross, & Adams, 2008). Essential lessons could be learnt from the problems that were observed in the training of teachers in how to implement the CAPS curriculum, where Coetzee (2012) reports that the training was hurried, of short duration and generalised. The inefficacy of such strategies in the implementation of professional development programs has been alluded to by Luneta (2012), in his analysis of what essential ideals have to be followed to achieve successful professional development programs.

One of the issues that the study has confirmed, which has been mentioned by earlier studies (Nyabanyaba, 2006; Robinson, 2003) is that as long as the teaching remains examination-focused, the use of learning technologies in teaching will not be taken seriously by both the teachers and the learners. To overcome this issue, the education system and the examinations in particular should not be totally focused on the achievement of higher pass rates by schools. Effort should however be directed towards how learning can be achieved by the learners. In that case, in subjects, such the sciences, practical examinations should be included as part of the formal assessment.

With regard to the arguments presented in this paper, it is highly recommended that future studies should look at not only the views of the teachers, but rather also the views of the Department of Education and the Faculties of Education in higher education institutions, to find solutions to how the professional development of teachers in the integration of learning technologies could be achieved. Such a direction would avoid the enacting of a top-down approach in professional development, which (Rout & Santosh, 2014) has reported to be mostly unsuccessful. Future studies could also focus on how teachers could be introduced to blended learning, an approach that also immensely regards their current teaching approaches.

References


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A sociological analysis of the South African foundation phase numeracy workbooks

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This paper employs Dowling’s (1998) sociology of mathematics theoretical framework and specifically draws from his modes of signification and textual distributing strategies, to analyse South Africa’s foundation phase numeracy workbooks. An analysis of the numeracy workbooks reveals that these textual resources mainly recruits aesthetic and lithographic illustrations which emphasises physical and manual activities and skills, and these have low mathematical saturation. Furthermore the deployment of closed visual icons in the local workbooks ensures that non-mathematical activities dominate in the text. These closed visual icons and lithographic textual distributing approaches exhibit context-dependent localising strategies that background the mathematical esoteric knowledge, whilst foregrounding public domain activities and project a mathematically detached subaltern learner. Such recontextualisation and textual distributing strategies have limitation in bringing forth the intended national numeracy learning outcomes. Thus the paper argues for the need for numeracy workbook writers to consider the generalising mathematical translating potential and effectiveness of open visual icons and graphs and tables representations.

Introduction

In the context of the primary maths challenges the South African Department of Basic Education (DBE) introduced numeracy workbooks in 2013 for all primary school learners. The numeracy workbooks, is one of the department’s system-wide targeted interventions aimed at both improving the performances of South African learners in the first six grades and offers learners the opportunity to acquire and apply key mathematical concepts and skills (DBE, 2013). Thus it worth noting that, one of the key functions of the numeracy workbooks is to ensure that they provide learners with relevant worksheet activities to independently practice numeracy skills taught in the class. They are two numeracy workbooks per grade consisting of 128 worksheets activities across the four terms. In the foundation phase, the numeracy workbooks are available in eleven different languages and are intended to be supplementary to the textbooks purchased annually by schools (DBE, 2012). The Rainbow numeracy (and also English) workbooks are compulsory and this shows how critical these textual resources are to the South African government’s strategy of improving learning outcomes (Fleisch et al, 2011).

Given the national importance and centrality of the numeracy workbooks, this study intends to analyse these learner textual activity resources using sociological mathematical strategies (Dowling, 1998; 1996). Drawing from Dowling sociology of mathematic theory my textual analysis of the foundation phase numeracy workbooks will interrogate and address these two key research questions;
-How does the South African foundation phase numeracy workbook select and distribute the modes of relay of mathematical knowledge?
-What kind of mathematical learner voices are (re)produced by the numeracy workbooks?
My main focus is on the textual analysis of the numeracy workbooks in relation to the nature of pictorial, photographic and diagrammatic representations recruited and deployed to convey and transmit numeracy concepts and skills. It is also paramount to investigate the expressed intentions and effect of such modes of representation upon the local primary maths learner’s subjectivity and their positioning. Thus this study specifically draws from Dowling’s (1998) modes of signification, namely icon, index and symbolic which are interrelated to modes of practice and textual distributing-positioning strategies to illustrate these two research questions.

In my literature search I could not find studies that have sociologically analysed numeracy workbooks. Studies employing the sociological framework are limited to the comparative analysis of mathematical textbooks (e.g. Dowling, 1998). On the other hand closely related studies have tended to compare the effectiveness of mathematical textbooks - either in a specific country or between countries; or to evaluate textbooks and workbooks (for example Fleisch et al, 2011). The contribution of this study thus firstly relates to illustrating Dowling’s (1998, 1996) sociological mathematical framework through an analysis of numeracy workbooks. Theoretically the paper extends Dowling’s modes of signification to include ‘lithographic icons’ and skills which it deductively and inductively develops and argues are uniquely projected in workbooks and through workbook activities. The paper also makes recommendations relating to the recontextualisation potential of open visuals and diagrammatic representations numeracy workbooks. Such suggestions are intended for both the local numeracy workbook writers or authors and primary maths education policy makers.

A sociological textual analysis of the foundation phase numeracy workbooks reveals that they promote artistic and public domain skills rather than emphasising on primary maths esoteric domain skills. The lithographic skills are evident in the manual, physical and ‘mechanical’ processes that learners partake in and engage with through the numeracy workbook activities. Thus the lithographic skills and its purposes are non-mathematical. The workbook tendencies of recontextualising mathematical concepts through aesthetic and closed visual representations theoretically and empirically results in low mathematical discourse saturation associated with context-dependent localising practises and depict subaltern and mathematically ‘detached’ learners (Pausigere, 2014, p. 114). The emphasis and foregrounding of such skills, practices and distributing strategies in the foundation phase have limitations in bringing forth the intended critical learning numeracy skills and outcomes.

**Theoretical Framing**

This study draws on Dowling's (1996; 1998) sociology of mathematics education theory which was developed through a sociological analysis of British secondary school mathematics textbooks. Dowling’s notion of modes of signification will be used to analyse the South African foundation phase numeracy workbooks. The modes of signification will be related to textual – distributing and positioning - strategies. Dowling identified three modes of signification namely visual icons, indexes and alphanumeric symbols. The iconic signification consists of photographs, drawings and cartoons; the indexical mode incorporates graphs and tables whilst the alphanumeric symbols comprises of textual and numerical figures. Key for the impending numeracy workbook analysis is Dowling’s distinction between open and closed narratives and icons. Generally open narratives give minimal setting detail, ‘fast switching’ between settings and ensuring that the public domain takes no hold in the texts, whilst closed narratives ‘don’t switch’ between settings and
also of relevance to this paper are Dowling’s (1996; 1998) concepts of textual positioning and distributing strategies which, are respectively realised by voices and messages within texts. Equally significant is the modality of practice which according to Dowling (1998) leads to the notion of discursive saturation. Basically positioning strategies constitute superordinate and subaltern voices which accordingly distribute the esoteric and public domain messages. Modes of practice distinguish between high and low discursive saturation. Practices exhibiting high discursive saturation are context-independent and generate generalising textual strategies that characterise the esoteric mathematics domain. These construct dominant and apprenticed positions. On the other hand low discursive saturation practices are context dependent and reproduce localising textual strategies relating to the public domain, such as ‘domestic’ and ‘manual’ activities. Such practices and strategies produce subordinate and dependent voices. The table below reveals the interrelationships between textual distributing and positioning strategies and discursive saturation scaling.

<table>
<thead>
<tr>
<th>Textual distributing strategies</th>
<th>Positioning strategies</th>
<th>Discursive saturation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>voice</td>
<td>message</td>
</tr>
<tr>
<td>generalising context-independent</td>
<td>superordinate</td>
<td>esoteric domain</td>
</tr>
<tr>
<td>localising context-dependent</td>
<td>subaltern</td>
<td>public domain</td>
</tr>
</tbody>
</table>

Theoretically relating the modes of signification to the distributing strategies which affect the distribution of message across the voice topography reveals that the visual icons incorporate localising content-dependent strategies which foreground public domain setting and backgrounds esoteric domain knowledge. However this is likely to be the case with closed rather than open visual icons. The mode of signification of non-iconic (indexical and alphanumeric symbolic) texts facilitates generalising content-independent strategies. Thus generally the dominance of visual icons indicates subaltern (subordinate) learner voices, whilst the prevalence of indexical and symbolic texts connotes superordinate and apprenticed learner positions.

The explained Dowling’s (1996; 1998) sociological textual schemes relating the modes of signification to textual distributing – positioning strategies and the modality of practices will help illuminate my analysis of the South African foundation phase numeracy workbooks and how they select and distribute these modes of relay of mathematical knowledge and the kind of mathematical learner positions depicted by the local primary maths workbooks?

**Literature review**

This section of the study will briefly discusses, from sociological and mathematical viewpoints, the contentious issue pertaining to the benefits as well as the limits of recontextualising everyday social experiences for mathematical understanding. Social constructivists extrapolate the usefulness of everyday experiences such as shopping, manual, street vending, play and domestic activities in inducting and initiating learners into the disciplinary knowledge or esoteric domain of school mathematics (Taylor, 2000; Dowling,
1998). For example John Stuart Mill has “argued that we acquire mathematics through our physical interaction with the World” (see Dowling, 1998, p. 42). This strong social constructivist epistemology is evident in the DBE’s recent educational ideological intentions of recruiting ‘semi-abstract physical representations’ in numeracy workbooks as the basis for mathematical understanding and operations (DBE, 2012, p. 41). However according to (Dowling, 1998) within this genuine cause of translating non-mathematical elements to give expression to mathematical content lies the danger of making the non-mathematical activity the focus of the mathematics. The question also arises pertaining to which everyday experiences are suitable for re-describing mathematical relations?

These ambiguities have led other scholars to argue for discontinuation between school and everyday experiences. Both Taylor (2000) and Dowling (1998) concur that the localising indigenous experiences induces the student to mistake ‘algorithmic’ solutions for generalisable principles and, thus to mistake the nature of mathematical practices. Translations according to Taylor (2000) are noted for always producing discrepancies as they are at variance with the generalising power of the mathematics discipline.

In the light of these different positions Walkerdine (1998) theorised the nature of recontextualisation which provides fruitful points of articulation within school mathematics. The process of dovetailing non-mathematics practices with school mathematics involves a series of transformations that entails, “the formation of complex signifying chains” (Walkerdine, 1998, p. 128). In this chain of relations of signification the external reference (shopping, baking, vending, names etc.) is suppressed, thus shifting the iconic signifiers (e.g. fingers, objects, items price list) into numerical symbols - new signifiers - most appropriate for arithmetical manipulation. Put differently, the text must constitute a mathematical rationalising of the setting rather than one which invites participation (Dowling, 1998). The mathematical sociological insights reviewed herein will be used in the ensuing discussion to illustrate the recontextualisation perspectives dominant in the foundation phase numeracy workbooks.

**Research Methodology – Sociological textual analysis**

The research methodology used in this study could be termed sociological textual analysis and derives from Dowling’s broader project of sociologically analysing school mathematics textbooks. This methodological approach has its origins in textual analysis and contemporary social theorists (e.g. Vygotsky, Bakhtin) and the modern sociologists of education (such as Bernstein, Bourdieu and Foucault). This study thus textually analysed the South African foundation phase Rainbow numeracy workbooks, using Dowling’s interrelated sociological theoretical tools. The empirical texts analysed consisted of 6 foundation phase numeracy workbooks, each comprising of 64 worksheets, translating to a total of 384 worksheets activities that primary maths learners use across the junior primary grades 1 to 3. The textual analysis mainly focused at the modes of relay used to represent and translate mathematical knowledge and the resulting subjectivity reproduced in the numeracy workbooks. The study did employ both a deductive and an inductive analysis of the workbooks.

A deductive quantitative analysis of the numeracy workbooks used Dowling’s (1998) modes of signification categories, which are *visual icons (open and closed illustrations), indexes* and *alphanumeric symbols*. These modes of signification categories informed the analysis of the each numeracy workbook activity sheet. Thus Dowling’s signification scheme provided the study with conceptual, descriptive and analytical tools to examine the
mathematical representation approaches and strategies used in the numeracy workbooks. Therefore from each worksheet page the area measure coverage of each representation mode was noted. Each page of the workbook consisted of a portrait of 22cm X 18cm, that is 396cm². A centimetre grid of this size was prepared on a transparent plastic sheet and the number of grid squares covered by each signifying category was counted and these were added together to reveal the proportional percentage coverage of each category per workbook. The appendix cut-outs were excluded from the deductive analysis. The visual iconic header and the ruler footer on each page of the workbook and the contents and cover pages were excluded in both analyses. The total area measure covered by each numeracy workbook were as follows: - 53 061cm² (DBE, 2011a); 50 292 cm² (DBE, 2011b); 53 064cm² (DBE, 2011c); 53 059cm² (DBE, 2011d); 52 267cm² (DBE, 2011e); 47 487cm² (DBE, 2011f). The first part of the table below shows the modes of signification categories expressed as percentage coverage of each numeracy workbook’s total area.

An inductive textual analysis of the numeracy workbooks revealed the frequent occurrences of verbal terms that implied and instructed the primary maths learner to carry out mechanical, or manual actions such as ‘drawing, colouring, circling, tracing and cutting out’. Other less frequently occurring verbs that implied physical activities include, marking, ticking, match, copying, sharing, sorting, fitting and sketching. Such physical actions were collectively termed as ‘lithographic skills’ – and this is one of the main categories emerging from the analysis of the empirical texts that was subsequently included as a mode of signification peculiar to workbook activities. The frequency of occurrences of each type of mechanical action per workbook was physical counted and verified if it implied ‘physical’ engagement and the results are shown in the second part of table 2. The import and utilisation of lithographic visual icons decreases as one move up the foundation phase grades, however this is not the case with the ‘cut-out’ sub-category were there is an increase of such illustrations and stencilling activities in the grade 3 numeracy workbooks.

Table 2. Analysis of the numeracy workbooks.

<table>
<thead>
<tr>
<th>Analysis categories</th>
<th>Grade 1 w/book 1</th>
<th>Grade 1 w/book 2</th>
<th>Grade 2 w/book 1</th>
<th>Grade 2 w/book 2</th>
<th>Grade 3 w/book 1</th>
<th>Grade 3 w/book 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>visual icons (drawings, photographs, cartoons)</td>
<td>closed</td>
<td>10.6</td>
<td>6.6</td>
<td>13.1</td>
<td>11.6</td>
<td>13.4</td>
</tr>
<tr>
<td></td>
<td>open illustrations</td>
<td>4.9</td>
<td>3.6</td>
<td>3.5</td>
<td>1.4</td>
<td>1.3</td>
</tr>
<tr>
<td>Index (tables and graphs)</td>
<td>0.92</td>
<td>4.5</td>
<td>1.8</td>
<td>6</td>
<td>8.3</td>
<td>14.7</td>
</tr>
<tr>
<td>Symbolic (alphanumeric)</td>
<td>27.7</td>
<td>46.2</td>
<td>49</td>
<td>48.6</td>
<td>56.8</td>
<td>65</td>
</tr>
<tr>
<td>Lithographic icons</td>
<td>55.7</td>
<td>39.1</td>
<td>32.5</td>
<td>32.3</td>
<td>20.1</td>
<td>13.8</td>
</tr>
<tr>
<td>Frequency of occurrence of each manual</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>draw</td>
<td>146</td>
<td>97</td>
<td>58</td>
<td>63</td>
<td>29</td>
<td>34</td>
</tr>
<tr>
<td>colour</td>
<td>67</td>
<td>38</td>
<td>50</td>
<td>53</td>
<td>30</td>
<td>16</td>
</tr>
<tr>
<td>circle</td>
<td>36</td>
<td>35</td>
<td>6</td>
<td>4</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>trace</td>
<td>24</td>
<td>13</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>cut-out</td>
<td>11</td>
<td>10</td>
<td>51</td>
<td>8</td>
<td>13</td>
<td>49</td>
</tr>
</tbody>
</table>

Table 2 shows that the coding and synthesis of textually analysed numeracy workbook data was both theory-driven and informed by emerging representation themes emanating from the workbooks. These two data set categories are transversely related to the modality
practices and textual relaying strategies and these helps interrogate the two research questions and structure the ensuing discussion in this paper. Such information organisation and representation illustrates the language of the theoretical descriptions and reveals the inductive ‘lithographic-findings’ of my reading of the South African foundation phase numeracy workbooks.

**Discussion**

In this section I analyse in great detail the South African foundation phase numeracy textual empirical findings relating to the modes of relay used to represent and translate mathematical knowledge. The first part illuminates the textual analysis findings within Dowling’s transmission theoretical scheme and reveals and exemplifies the localising limitations within closed visual icons and explores the generalising-esoteric translating potentials and possibilities within open illustrations and indexical resources and their effects on mathematical learner voices and discursive saturation. The impact and effect of the lithographic icons - consisting of an average of one third of the foundation phase content - with their exhibition of localised practices that projects a mathematically detached South African mathematical learner identity are also unpacked.

**Visual icons used in numeracy workbooks**

Almost half (45.7%) of the junior primary maths workbooks consist of visual and lithographic illustrations, with closed and open icons making 13.2% of the total workbook content and this translates to 10.7% of closed and 2.5% of open visual codes being deployed in the foundation phase numeracy learner textual resources. Comparatively they are four times more closed icons than open visual icons used to translate and recontextualise mathematical content and operations within the foundation phase numeracy workbooks. I explore and illustrate the shortcomings of closed visual icons and the benefits characterising open visual icons in conveying school mathematical practices.

**Closed visual icons**

Fruits and food, animals, toys, play activities, humans and their body parts (e.g. fingers, feet) and clothes pictures are the most used closed visual icons employed to translate mathematics domain knowledge in the numeracy workbooks. They are theoretical limitations noted in deploying closed icons in translating knowledge and such disadvantages manifest in the workbooks’ dominance of food, fruits, sweets and confectioneries, animals (wild, domesticated, pests), toys and human body parts closed icons. Thus across the foundation phase numeracy workbooks they are a total of 81 food and fruit, 37 animal, 20 toys, 20 play activities, 19 human physical body parts and 11 clothing items pictures or drawings. The drawbacks in the pictorial manipulatives are illustrated and exemplified in the fruit and food images on page 39 in the Grade 1 numeracy workbook 1 (DBE, 2011a), between page 10 and 12 and 134 in the first-Grade 2 and page 50 party-food pictures in the second grade 3 numeracy workbooks (DBE, 2011c; DBE, 2011f). Similarly the toys picture on page 122 of the second grade 1 numeracy workbook (DBE, 2011b), the fingers and feet drawings on page 122 in the first grade 1 numeracy workbook and the pairs of socks pictures spread through pages 58 and 59 of the first Grade 3 numeracy workbook (DBE, 2011a; DBE, 2011f), dominate and overwhelm the mathematical concepts on the respective pages. This dominance of these closed visual icons drawing and pictures “localise and minimises the scope for alternative interpretations” (Dowling, 1996, p. 413) thus ensuring that non-mathematical related issues and activities hold in the text and foreground learners’ educational undertakings and engagements. Following Dowling’s work it can be deduced...
that the frequent use of closed icons is an indicator of the extent of localising within the workbooks. Relating the empirical text illustrations to the theory reveals that, such closed representations allow, “a substantial residue of the non-mathematical setting to remain after the mathematical routines have run their course” (Dowling, 1998, p. 9). Generally closed visual icons mainly import and impart non-mathematical localised activity resulting in mathematical expressions and practices to be backgrounded.

One of the theoretical limitations of recontextualisation in primary mathematics is the inability to exclude the external reference in the signification chain (Walkerdine, 1988). In the farm animal funnelled pictures in page 10 and 11 in the first-Grade 1 workbook – the illustrations and the learner activities remain in the semi-abstract (for e.g. two cats are represented by two round dots - ●●) and don’t shift into the numerical symbolic signifier, thus foreclosing opportunities for systematically translating into the key elementary mathematical skill of writing number symbols and relating it to counting. Such a restriction is also noted by Walkerdine’s (1988, p.126) in her primary maths empirical examples, in which she similarly argues the need for learners to move “from iconic signifiers (e.g. blocks drawings) to the symbolic form of written numerals”. Another fictional and poor illustration is the picture on page 121 in the second grade two numeracy workbooks (DBE, 2011d) in which learners have to count how many worms it will take to reach a butterfly. The worms are weirdly and unimaginatively expected to stand on top of each other. This unrealistically worm-butterfly activity do not ‘suppress’ the non-mathematical aspects, instead it rearticulates and foregrounds the illusionary insects encounter within the mathematical discourse (Walkerdine, 1990, p. 119). These two examples illustrate the limitations in deploying closed mathematical iconic resources as these generally tend to include the ‘external referents’ thus ‘imbricating’ the discourse of school mathematics with public domain activities (Walkerdine, 1990, p. 120; Dowling, 1998, p. 7). These closed mathematical icons and illustrations in the foundation phase numeracy workbooks misrepresent elementary mathematical practices, thus promoting a subaltern and mathematically detached learner.

Open visual icons

The restrictions prevalent in closed icons can be overcome through deploying open illustrations to translate mathematical concepts and skills. On average, a fifth of the visual icons used in the numeracy workbooks consist of open icons, with a surprise decrease in the use of these mathematically-illustrative pictures as one moves up the foundation phase grades. A total of 44 open icons are employed across the foundation phase numeracy workbooks. By their nature open icons fast-switch between contexts, giving very little setting detail to localise the interpretations thus pinpointing to the esoteric domain as the centre of the activity (Dowling, 1998; 1996). In the empirical texts, pages 16, 28, 56 (DBE, 2011a); 78 and 116 (DBE, 2011b); 60 (DBE, 2011d, and page 53 (DBE, 2011f) exemplify and denote a range of setting. Thus page 28’s varying illustrations consists of animals, brooms, ladders, benches, spoons, tape measures, drinking glasses and medicine bottles pictures (DBE, 2011a), whilst page 116 of the second grade 1 workbooks comprises of crayons, skittles, insects, squares and days of the week table icons (DBE, 2011b). Such a wide range of setting helps the learners not be distracted or ‘carried away’ by the visual icons, in fact the text moves between the settings with mathematics being represented as “constituting a powerful language of description” (Dowling, 1998, p. 206). Generally the prevalence of open visual modes constitutes a generalising of a context-independent mathematical gaze and a backgrounding of the setting which promotes a mathematically apprenticed and superordinate learner.
Another advantage of using open illustrations relates to their potential to swiftly shift from the semi-abstract representations into the mathematical discourse. The fact that open illustrations easily ‘dovetail’ and quickly translate into abstract mathematical practices is exemplified on the funneled icons on pages 94 and 98 (DBE, 2011a); 42 and 57 (DBE, 2011b); 36 and 75 (DBE, 2011c), and 123 and 138 (DBE, 2011e). In all these examples the ‘imagined external referents’ is quickly and naturally excluded resulting in an enhanced transition and induction into abstract mathematical relations (Walkerdine, 1990, p. 126). Thus the nature of open illustrations inter-relates with the signification chain as it provides fruitful points of articulation that enables the stripping away of the non-mathematical elements to give expression to mathematical content (Dowling, 1998; Muller, 2000). The mathematical rationalising of the setting objectified through open illustrations initiates and ‘apprentices’ learners into the esoteric domain. Similarly the non-iconic (indexical and alphanumeric) modes of signification exhibit generalising context-independent strategies characteristic of subject disciplinary knowledge.

The deployment of non-iconic text in numeracy workbooks

On average the most used mode of signification in the foundation phase numeracy workbooks are the alphanumeric symbolic texts. The alphanumeric symbols consist of almost half of the workbook contents with a notable and commendable increase in the use of alphabetical and numerical texts as one move up the foundation phase grades. However there is a limited use of written numerical figures and words and the foregrounding of lithographic icons in the first-grade 1 numeracy workbook. To improve learners’ understanding of mathematical concepts through the use of the mother tongue, the foundation phase numeracy workbooks are available in the 11 official languages. It is important to note that alphanumeric symbols are a key resource implicated in generalising strategies. Similarly the indexical resources are also remarked for facilitating generalising strategies and context-independent texts. However whilst the translating effectiveness of alphanumeric symbols is recognised and literary acknowledged in the numeracy workbooks, the transfer potential of indexical icons is underestimated and therefore not fully utilised.

Indexical (tables and graphs) textual resources

Dowling (1998) defines the non-iconic indexical mode of signification as entailing the spatial arrangement of symbols into tabular and graphical form. The non-iconic indexes cover an average of only 6% of the foundation phase numeracy workbook contents, which translates to 111 tables of varying sizes and 11 graphs. Of the 11 graphical illustrations - 6 are pictographs and 3 bar graphs, and 2 small geographical maps used to translate data handling and the time concept. 41 grid tables are used to enable the learner to sort and tabulate data, complete number patterns, to perform the key four mathematical operations and to present key numerical facts such as the grids on page 118 in the first grade 3 numeracy workbook which diagrammatically and numerically represent to learners that 1 row of 6 tiles, 3 rows of 2 tiles and 2 rows of 3 tiles make 6 tiles (DBE, 2011e). 32 number board tables with a number range between 50 and 100 and with some reaching the 1000 mark are utilised in the numeracy workbooks to represent number patterns, multiplication facts, counting and counting strategies and numbers writing. In the first two years 8 insects based flow chart diagrams depicting single mathematical operation such as addition or subtraction are employed with 13 flow sheet representations implying double operations like adding followed by halving being used in the third grade workbooks. To enable the learners’ appreciation of time-table facts 9 multiplication tables are employed across the numeracy workbook. 6 tables of weekly and monthly calendars, 5 fraction boards and 5 number
pyramids are used to translate mathematical aspects relating to time, fractions and number sense. The diagrammatic conveyance of number sense, that is understanding mathematical operations and numerical facts clearly manifests in the illustrations on page 142 of the first grade 3 workbook, especially in the three number pyramids whose apex number is 20 with learners being requested to find three different numerical combinations adding up to the top number (DBE, 2011e). Thus tables and graphs are indispensable representations for illustrating key foundational mathematical concepts and relations.

They are numerous mathematical benefits in deploying non-iconic indexical mode of signification such as tables and graphs in learner textual resources. Dowling (1998, 1996) notes that both alphanumeric symbolic and indexical texts are crucial resources for generating context-independent and generalising strategies which initiates learners into the esoteric domain knowledge. The recruitment of non-iconic textual resources are also recommended for the reproduction of high discursive saturation practices that construct superordinate and apprenticed learner voices. Mathematical diagrammatic representations such as fraction boards, number pyramids, flow chart diagrams, multiplication tables and number boards totally disregard ‘external referents’ and move straight into the symbolic form of written numbers (Walkerdine, 1988, p.126). Given the advantages and potentials within indexical illustrations it is important that local numeracy workbooks recruit a substantial amount of their resources from tables and graphs so that learners appreciate and are inducted into powerful and productive mathematical representations and numeracy practices. These findings are of practical relevance to the numeracy workbook authors and educational officials/units that develops primary maths instructional support materials.

**Lithographic visual icons**

This mode of signification which is particularly prominent in the local numeracy workbooks emerged through an inductive textual analysis of the primary maths learners textual resources. Lithographic visual icons comprises of drawings and pictures within numeracy workbooks comprising of verbal terms that instructs and tells the primary maths learner to carry out ‘mechanical’ actions. The manual activities are evident in the following verbatim: - ‘draw, colour, circle, trace, cut out’. Such physical actions were collectively termed as ‘lithographic skills’ – and this arise because of the presence of aesthetic visual diagrammatic icons that are imported from the public domain into mathematical practices and activities. Through this analysis of textual data a total of 884 numeracy worksheet illustrations, which is about 33% of the workbooks contents, where coded and verified as lithographic visual icons. Other less frequently occurring verbs that implied very low physical activities included visual icons accompanied by such words as mark, tick, match, copy, share, sort, fit and sketch. The lithographic empirically emerging category and its arising sub-categories were subsequently included as a mode of signification unique and distinctive to numeracy workbook activities, see table 2 above.

Lithographic icons carry similar features and limitations noted in closed visual icons. I will exemplify these disadvantages with empirical textual evidence. Some of the lithographic icons and the resulting activities in the workbooks foreground public domain or non-mathematical activities that give local learners the false and distorted impression that mathematical practices entail aesthetic and artistic engagements. The key informing learning principles of the workbooks is to move the learners from semi-abstract representations to the abstract level of using numerical figures and this is similar to Walkerdine’s (1988) signification chain (DBE, 2012). However some lithographic illustrations in the workbooks
contradict the signification chain starting from abstract concept and funnel learners into semi-abstract representations.

The two problem solving stories on page 93 in the second grade 3 numeracy workbook, the addition, subtraction or multiplication sums on page 117 and 121 (DBE, 2011a), page 98 (DBE, 2011b), page 63, 83, 91, 107 and 111 (DBE, 2011c) and page 19 (DBE, 2011d) all culminate with activities in which the learners are required to ‘draw a shape/picture to show…’ how they carried out a particular numerical operation. For example in the first grade 2 numeracy workbook a drawing space is left on page 83 requesting the learner to draw a picture to show what the sum of 26 and 16 is? (DBE, 2011c). Other implicit drawing and colouring activities involving pattern completion are on the following pages - 32, 108 and 122 (DBE, 2011a); page 51, 58, 66, 68, 70, 72, 84, 102 and 110 (DBE, 2011b); page 14, 42, 56, 58, 59, 94, 108, 112 and 118 (DBE, 2011c) and page 59, 84 and 85 in the second grade 2 numeracy workbook. These wide examples show the limitations of translating mathematical concepts through lithographic iconic activities as they result in focusing on aesthetic engagements and not mathematical practices. In these cases the mathematics is being ‘imbricated’ by the drawing activities which theoretically constitute ‘manual’ localising context-dependent strategies of low discursive saturations signifying dependent and subaltern learner voices (Dowling, 1998, p. 7 & 139).

Another constraint relating to the deployment of lithographic icons in workbooks noted in closed icons pertains to their limitations in disregarding the external reference during the recontextualisation process (Walkerdine, 1988). Thus on the positioning activities on page 12, the addition sums on page 44 in the first grade 1 numeracy workbook and the sorting activities on page 31 in the first grade 2 numeracy workbook culminates in learners drawing semi-abstract illustrations and not writing numerical figures. The lithographic icons and activities on page 44 require the learners to add up and draw semi-abstract representations such as coconuts, fish, roses, umbrellas and pencils (DBE, 2011a). The resulting product of this mathematical sum culminates in learners drawing the aforementioned items and objects and does not translate into numerical figures. These examples illustrate the impotency of importing lithographic icons to illustrate school mathematical practices as they tend not to suppress or exclude the external reference thus disenabling the dovetailing recontextualisation potential noted by Walkerdine (1988). Through their localising context-dependent strategies lithographic icons and activities have the dangers of excluding local learners from the esoteric mathematical discourse and practices.

The excessive use of aesthetic icons and activities foregrounds drawing activities - backgrounds mathematical concepts and expressions. The unnecessary and unwarranted use of lithographic icons and activities whose focus seems to be translating aesthetic skill is evident in the following numeracy workbook examples. In the first numeracy workbooks learners are instructed to ‘draw’ three pictures relating to things that they did yesterday, that they will do today and what they will do tomorrow (DBE, 2011a, p. 35). The overindulgence with lithographic activities is also noted in the second grade 1 workbook on pages 7, 9, 11, 67, 69, 71 and 73 where learners are directed to draw twice and in ‘different ways’ objects representing numbers 13 to 19 (DBE, 2011b). However extreme examples of such excesses are implied in the activities on page 21 and 87 of the first grade 2 numeracy workbook were learners are firstly supposed to cut-out ‘feet’ and ‘hands’ from the appended page and use those cut-outs to measure the length and width of a given ‘playground’ and a rectangle. Besides foregrounding aesthetic undertakings this cut-out worksheet activities culminates in measuring using concrete objects and doesn’t provide opportunities to introduce learners to formal measuring units. Like the limitations noted in closed visual icons, lithographic
representations ensure that non-mathematical, everyday or public domain activities hold in the text (Dowling, 1996), thus foregrounding aesthetic skills at the expense of esoteric domain practices. These aesthetic icons and skills like closed visual icons exhibit localising context-dependent strategies that depict a detached mathematical learner removed from the powerful generalising strategies of the esoteric mathematical domain.

Concluding remarks

The prevalence of closed visual icons and lithographic illustrations within the local numeracy workbooks have mathematical conveyance limitations when compared to the potential and effectiveness of recruiting and recontextualising open visuals and indexical diagrammatic representations. 43% of the numeracy workbook contents consist of closed visual icons and lithographic illustrations and this shows that, contrary to the common policy view of an esoteric domain orientation, the workbooks show the extent of localising within the national foundation phase numeracy learner textual activity resources. In the context of mathematical translation impotency of aesthetic and closed visual representations the department of basic education and numeracy workbook author teams must reconsider in the future, redesigning workbooks that demonstrate the potential and powerful recontextualisation effectiveness of indexical and open visual illustrations.

Theoretically there are contradictions within these two classes of representation resources with aesthetic and closed visual icons limiting and grounding learners in localised context-dependent strategies whilst diagrammatic and open visual icons induct learners into generalised context-independent strategies. Consequently the former foregrounds public domain activities of low mathematical saturation and projects a subaltern, mathematically-detached learner. The latter constitutes esoteric domain practices that exhibit high mathematical saturation which creates superordinate and mathematically-apprenticed learners. With less than 10% of the workbook contents consisting of open and indexical diagrammatic representations the department need to increase the coverages of these modes of signification if its intentions of improving the national numeracy learning outcomes and standards are to be met. Thus used on their own without supplementary textual resources and in their current form the numeracy workbooks reflect an ideological myth of mathematical participation which alienates learners from mathematical practices.

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