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FOREWORD

Research in Science Mathematics and Technology (SMT) education is a complex process that is influenced by reciprocal interaction with learners, educators, parents and other stakeholders. One aspect that bring us together as SAARMSTE family is the belief that we are able to provide explanations to some of the challenges we encounter within this complexity. As a way to respond to this complexity, most countries are repositioning themselves within the context of global trends and campaigns such as Millennium Development Goals (MDG) and Education For All (EFA). They are reflecting on their education systems. For instance in South Africa (RSA) there has been a launch of Action Plan to 2014 – Towards the Realization of Schooling 2025. One aspect that has become more evident is how mathematics and science features in the goals of the Action plan as well as in the MDG and EFA. MSTE is acknowledged as playing a pivotal role as a link and solution to some of the 21st century challenges hence a bridge to the future.

The proceedings consists of Mathematics, Science, Chemistry, Physics, ECD and Technology papers. The papers in various strands reflect on some aspects that may need to be taken into consideration in order to address the challenges through creation of sustainable empowering learning environment as well as being sensitive to issues related to social justice within the context of SMT education.

The success of a conference depends on collective efforts by various people and stakeholders. Sincere gratitude is extended to the plenary speakers, reviewers for their willingness to assist even at times when we thought the “ship was sinking”. Their willingness to go an extra mile is heartily noted. May the spirit be extended to future conferences. We owe a debt of gratitude to Regional SAARMSTE EXCO for their consistent support and guidance from start to the end. To the Local Organising Committee (LOC) who were the “foot soldiers” that had to engage with issues at grass root level attending numerous meetings as we were getting everything into shape. We are particularly indebted to Susan van Rooyen and her team for their expertise and for taking care of the non – academic but core aspects of the conference.

Andrew Mutsvangwa, Noma Mokakale and Evelyne Ribane we wish to express our sincere thanks for your direct active role in assisting with the compilation of the proceedings and prompt response to queries on daily basis. Lastly but most important our thanks are also due to Prof Dan Kgwadi, the Campus Management, Dr D Gericke – Executive Dean: Faculty of Education and Prof Maselesele – Executive Dean:FAST, for making it possible for the conference to finally materialize. Ditebogo (gratitudes)) are also extended to various sponsors for their generous support.

We feel very privileged to have been involved in the proceedings and to have read a number of submissions because the contributions by various authors bring such diversity
and alternative lenses of looking at challenges within SMT education. Although SAARMSTE is a regional body it is increasingly attracting more international participants and SAARMSTE - North West chapter regards itself as honoured to be granted an opportunity to host this important conference.

RE LEOGOA GO MENAGANE

L.T. Mamiala

Chairperson: LOC
MESSAGE FROM THE PRESIDENT

It is a great pleasure to welcome you all to the 19th annual SAARMSTE Conference held at the North-West University in Mafikeng. At the outset I wish to thank the members of the LOC and many others who have given so generously of their time to organise this event. The SAARMSTE conference is a pivotal event in the annual calendar of SAARMSTE. It provides an opportunity for our researchers to come together and share our work. It also provides an opportunity for us to participate in and as a community of practice. It is important that our work is disseminated, critiqued and engaged with. Our theme this year is Mathematics, Science and Technology Education: A bridge to the future. We are all too aware that the future of our planet hangs in the balance – we are on an environmental knife’s edge. Governments the world over are struggling to provide adequate and appropriate leadership to set us on a path that will ensure sustainable peace and harmony. The role that the MST community plays is thus pivotal in building bridges to and for a sustainable future. As we deliberate our role in building a sustainable future, let us be mindful of our responsibilities as researchers and creators of new knowledge and understandings in the context of MST education.

The collection of papers in these proceedings is the result of commitment, dedication and hard work. I wish to express my gratitude to the authors, the reviewers and the conference organisers for all that they have done in the publication of this work. The proceedings reflect a diverse and rich research culture in the fields of MST education in Southern Africa - the SAARMSTE community is vibrant and dynamic.

I also wish to take this opportunity to thank our funders who have given so generously in supporting SAARMSTE to achieve its aims and objectives. Without their assistance this conference and this publication would not have been possible.

Marc Schäfer
SAARMSTE President
January 2011
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This collective case study undertook to explore learners’ proficiency to formulate conjectures about and state definitions of simple geometric shapes like triangles, rectangles, squares and rhombuses in high school mathematics. Of the 44 grade 10 learners that participated in the study, 22 came from a state high school in Lagos, Nigeria (NS) and the other 22 from a ‘township’ high school in the Eastern Cape, South Africa (SAS). A stratified sampling technique was used to select the participants. Data was collected using an instrument called the Conjecturing in Plane Geometry Test (CPGT). The van Hiele theory of cognitive thinking levels provided the framework for data analysis within the broader theory of constructivism. The low mean score of 17.4% obtained by the learners in the CPGT was interpreted as evidence that these learners had difficulty in conjecturing and stating definitions regarding simple geometric shapes. The difference between the mean scores of the NS (9.59%) and SAS (25.2%) learners in the CPGT, in favour of the latter, was found to be statistically significant at the 0.001 confidence level. Stating a definition for a triangle, a square and a rhombus was generally difficult for the learners, since no learner from the NS subsample was able to define any of these shapes, and only 1 learner from the SAS subsample was able to define a rectangle and a square, and 1 other learner was able to define a rhombus. Based on these results, some recommendations are offered.

INTRODUCTION

Truly I begin to understand that although logic is an excellent instrument to govern our reasoning, it does not compare with the sharpness of geometry in awakening the mind to discovery (Galileo, as cited in Hart & Picciotto, 2001, p.ix).

The opening quote above underscores the importance of geometry and foregrounds why geometry in one form or another continues to be a cherished component of school mathematics in many countries across the world. In South Africa, for example, the National Curriculum Statement (NCS) for high school mathematics indicates that one of the objectives of geometry teaching in grade 10 is for the learner to be able to: “Through investigations, produce conjectures and generalizations related to triangles, quadrilaterals … and attempt to validate, justify, explain or prove them using any logical method (Euclidean, coordinate and/or transformation)” (South Africa, Department of Education (DoE), 2003, p.32). The objective of geometry teaching in grade 10 in Nigeria appears to be consistent with that of South Africa, but with a greater emphasis on learners’ use of geometrical construction to investigate and make conjectures about the properties of plane shapes such as triangles and quadrilaterals (Atebe, 2008). These objectives corroborate Senk’s (1989) assertion that making and verifying conjectures are valuable skills to acquire in mathematics generally and geometry specifically.

The above objective of geometry teaching in Nigeria and South Africa may seem plausible especially in the wake of a new movement in mathematics education with a shift in focus from teacher-centred instruction (the so-called behaviourist approach) to an approach that places the learner at the heart of instruction (often referred to as constructivist approach) (Stoker, 2003). There is, however, little empirical evidence that learners in these countries are acquiring the prescribed outcomes of being able to produce conjectures and generalizations relating to geometrical shapes and their properties (Siyepu, 2005). Therefore, this study aims to explore
learners’ abilities to formulate conjectures, draw simple inferences and state definitions of simple geometric shapes like triangles and quadrilaterals.

The Theory and Related Research

This study utilizes the van Hiele theory cognitive thinking levels within the broader constructivist theory of education. Traditionally, mathematics instruction has been based on a transmission-absorption behaviourist model in terms of which pupils were expected to absorb unquestioningly mathematical structures invented by others (Orton, 2004). Teachers were perceived as holders of the mathematical knowledge to be learned, while pupils were treated, often through drills and practices, as passive recipients of knowledge. This approach has often been criticized by mathematicians and mathematics educators alike. Van Hiele (1986, p.56), for example, stresses the point that teachers “should treat pupils as dignified opponents, opponents capable of introducing new arguments”.

The constructivist approach suggests that knowledge is an individual construction and that each learner must construct knowledge for and by himself (McInerney &McInerney, 2002). From the constructivist perspective, knowledge is not acquired passively. The mind of the learner is not a blank slate ready only to receive impressions, information or knowledge ‘copied’ on it by the teacher. Rather, learners actively and creatively construct their own knowledge of the experiential world through organization and reorganization of their internal cognitive structures (Piaget & Inhelder, 1969).

Many contemporary mathematics educators have since shown support for constructivism as a theory of mathematics learning. De Villiers (1998, p.248), for example, believes that an ideal didactical approach is one “characterized by not presenting content as a finished (prefabricated) product, but rather [one that] focuses on the genuine mathematical processes by which the content can be developed or reconstructed” by the teacher and/or the learner. De Villier (ibid.) calls this approach reconstructive approach. In identifying with the vital role of definitions in school geometry, de Villiers (1998) maintains the view that learners should be allowed the opportunity to formulate their own definitions of geometry concepts. Learners, for instance, could be made, through carefully structured tasks, to identify properties of simple geometric shapes like triangles and quadrilaterals and then write their own definitions irrespective of whether such written definitions are partitional or hierarchical. The didactical motivation for allowing learners to formulate their own geometry definitions includes giving learners the opportunity to reason critically about the concepts and to make and test conjectures regarding the properties of geometric shapes.

The van Hiele theory makes it clear that learners begin to understand formal definitions and produce conjectures only at level 3, since that is where they begin to notice the interrelationships between the properties of a geometric shape. De Villiers’ (1998), experiment, however, tends to have indicated that through appropriate reconstructive geometry activities, learners at van Hiele level 1 and level 2 can produce their own definitions even when such definitions are usually descriptive, partitional and uneconomical. In this study, we have extended de Villiers’ (1998) notion of reconstructive approach in defining geometry shapes to that of formulating conjectures about shapes and their properties. In doing this, we have employed the van Hiele theory as the lens for research.

The research goals

This paper sought mainly to explore and explicate high school learners’ abilities to formulate conjectures, draw simple inferences and state definitions of simple geometric shapes like triangles and quadrilaterals (rectangles, squares and rhombuses) using reconstructive geometry activities.
Method

This collective case study (Stake, 2000) conducted in Nigeria and South Africa, is oriented largely in the interpretive paradigm and it employs both qualitative and quantitative methods (Creswell, 2003; Brannen, 2004). A qualitative research approach utilizes first-hand accounts of participants’ experiences and tries to describe events in rich details (Terre Blanche & Kelly, 1999). Quantitative research techniques, on the other hand, typically attempts to describe relationships among variables statistically and to present a numerical analysis of the social relationships being studied (Jackson, 1995). In this study, we interacted with the participants in our quest to understand how they interpret their experiential world of mathematics.

The sample

The sample for this study comprised a total of 44 grade 10 mathematics learners, 22 of which were drawn from a state high school in Lagos, Nigeria and the other 22 were selected from a comparative ‘township’ high school in the Eastern Cape, South Africa (see Atebe, 2008 for the parallel of comparison). These learners were selected using stratified sampling techniques. It must be acknowledged here that as this study forms a part of a PhD study that was completed at Rhodes University, the sample described above is, in essence, a subsample of the bigger PhD study. The school involved in Nigerian was designated NS and the one involved in South African designated SAS. Names of participants and the schools mentioned in this study are all pseudonyms.

The instrument

Data for this study were collected mainly through the development and administration of an instrument called the Conjecturing in Plane Geometry Test (CPGT). The CPGT made use of a constructivist investigative approach to explore learners’ understanding of the properties of simple geometric shapes like triangles and quadrilaterals (squares, rectangles and rhombuses). In particular, de Villiers’ (1998) notion of reconstructive approach was employed: Learners were required to investigate (through geometrical construction) and discover the properties of these shapes. Such investigation and discovery should lead the learners to draw simple inferences, formulate conjectures about the properties of the shapes and state definitions for each shape.

A worksheet in the form of a semi-structured questionnaire focusing on tasks relating to the selected geometric shapes was developed for the CPGT. In developing the CPGT, important ideas from the interview schedule of Mayberry (1983) and Burger and Shaughnessy (1986), as well as from the work of Siyepu (2005) were incorporated into its general format and method of questioning.

The worksheet was developed to explore learners’ knowledge of the side-angle properties of triangles, rectangles, squares and rhombuses. It required the learners to discover, through investigation, the side-angle properties of these shapes and to formulate conjectures about the relationship between these properties and between the shapes. The worksheet consisted of 6 investigations:

- Investigation 1 was to lead the learners to formulate a conjecture that *the sum of the (interior) angles of a triangle is 180°*.
- Investigation 2 was to lead the learners to formulate a conjecture that *the base angles of an isosceles triangle are equal*. 


• Investigation 3 was to lead the learners to formulate a conjecture that if all the three sides of a triangle are equal, then all the three angles are equal (to one another). That is, an equilateral triangle is equiangular.

• Investigation 4 was to lead the learners to formulate a conjecture that a parallelogram which has equal diagonals is a rectangle.

• Investigation 5 was to lead the learners to formulate a conjecture that a parallelogram which has equal diagonals that bisect each other at right angles is a square.

• Investigation 6 was to lead the learners to formulate a conjecture that a parallelogram which has unequal diagonals that bisect each other at right angles is a rhombus.

For each investigation, the learners were given guiding instructions that would enable them to complete the task. For example, the stepwise instructions for investigations 1 and 4 are as shown in Figure 1 and Figure 2, respectively.
Investigation 1:

Step 1: Using a ruler, draw any triangle ABC, with each side of length greater than or equal to 5cm.

Step 2: Use a protractor to measure the angles of the triangle.
∠A = ......................; ∠B = ......................; ∠C = .............................

Step 3: Find the sum of the angles of △ABC.
∠A + ∠B + ∠C = ........................................

Compare your result with those of other students near you.

Space for your diagram.

Question:
What can you conclude about the sum of the angles of a triangle?

Answer: ........................................................................................................
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**Investigation 4:**

**Step 1:** Use a ruler to draw any straight line AC (slanting upwards from left to right) which is greater than or equal to 6cm.

**Step 2:** Locate the midpoint of the line AC and label it as M.

**Step 3:** Draw another straight line BD which is equal in length to line AC (slanting downward from left to right) and intersecting (or crossing) AC in such a way that M is also its midpoint. Your diagram from steps 1 – 3 should look like this:

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**Step 4:** Use a ruler to join AB, BC, CD and AD.

**Step 5:** Measure the following.

i) \( AB = \ldots \); \( DC = \ldots \); \( BC = \ldots \); \( AD = \ldots \)

ii) \( \angle ADC = \ldots \); \( \angle DAB = \ldots \); \( \angle ABC = \ldots \); \( \angle BCD = \ldots \)

Compare your results with those of others near you.

**Space for your diagram.**

---

**Questions.**

1. What type of parallelogram is ABCD?

   **Answer:** .................................................................

2. How do you know for sure that ABCD is the parallelogram that you have named in question No. 1 above? List as many reasons as you possibly can.

   **Answer:** i) .................................................................

   ii) .................................................................

   iii) .................................................................

   iv) .................................................................

   v) .................................................................

3. From your diagram and those of others near you, what can you **conclude** about a parallelogram whose diagonals are equal?

   **Answer:** .................................................................

4. Give a very short definition of the shape ABCD.

   **Answer:** .................................................................
**Test grading:** In order to reduce marker’s subjectivity inherent in essay-type questions such as those of the CPGT, we formulated a ‘marking scheme’ with some general criteria for grading the responses of the learners based on the work of Senk (1995). In terms of these criteria, predetermined marks were assigned to specific elements in learners’ responses that reflected the correct answer. See Atebe (2008) for details.

**Results and Discussion**

The results are presented in terms of percentage mean scores and in terms of an illustrative item analysis of participants’ responses to the CPGT. The percentage mean scores in the CPGT were calculated collectively for all the 44 learners and separately for learners in each of the Nigerian (NS) and South African (SAS) subsamples.

The overall percentage mean score obtained by all the learners in the CPGT was 17.4%. Recall that the CPGT was designed mainly to explore learners’ abilities to formulate conjectures, draw inferences and state definitions of simple geometric shapes. Thus, the low mean score obtained in the CPGT by this cohort of grade 10 learners could be interpreted as evidence that the learners’ knowledge was poor in these learning areas. Given that defining, drawing inferences and conjecturing are cognitive activities commonly associated with van Hiele levels 3 and 4 reasoning (see Clements, 2004), the low mean score also indicates the majority of the learners were not yet at these van Hiele levels of geometric understanding. The results generally identify with those of Pegg (1995) when he stated that only about 25% of high school learners in his study felt comfortable with problems associated with level 4 in the van Hiele hierarchy of geometric thinking levels.

Learners from the NS subsample obtained a percentage mean score of 9.59% in the CPGT and learners from the SAS subsample obtained a percentage mean score of 25.2% (see Table 1). By any standard, these are very low means. Given the objectives of geometry teaching stated earlier for Nigeria and South Africa, these low mean scores would imply that these learners were yet to master that aspect of their geometry curriculum that requires them to be able to make conjectures, state definitions and draw inferences side-angle properties of triangles, rectangles, squares and rhombuses.

**Table 1** Percentage mean scores of the learners in the CPGT

<table>
<thead>
<tr>
<th>School</th>
<th>N</th>
<th>Mean score</th>
<th>Std Dev.</th>
<th>t-value</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NS</td>
<td>22</td>
<td>9.59</td>
<td>7.42</td>
<td>-3.81</td>
<td>42</td>
<td>0.0004</td>
</tr>
<tr>
<td>SAS</td>
<td>22</td>
<td>25.2</td>
<td>17.7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As indicated by the mean scores, grade 10 learners from SAS outperformed their Nigerian counterparts from NS in the CPGT. Table 1 clearly indicates that the difference between the mean scores of the NS learners and that of the SAS learners is statistically significant (t = -3.81, 42df, p < 0.001) in favour of the latter. The variations in the teaching methods of the two countries (as reported by Atebe & Schafer, 2009) may have contributed to the differences in attainments between learners from the two national samples.

**An illustrative item analysis of learners’ responses in the CPGT**

The results presented here are based on the number of learners in each of the NS and SAS subsamples who were able to perform specific activities for each of the 6 investigations that made up the CPGT. The results are as summarized in Table 2.
Table 2 Item analysis of learners’ responses in the CPGT

<table>
<thead>
<tr>
<th>Investigation No.</th>
<th>Expected activity</th>
<th>Number. successful</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>NS (n = 22)</td>
<td>SAS (n = 22)</td>
</tr>
<tr>
<td>1</td>
<td>• To obtain, by addition, the sum of the angles of a triangle to be 180°</td>
<td>21</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>• To conjecture that the sum of the angles of a triangle is 180°</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>• To recognize, through own construction, and name an isosceles triangle</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>• To state, through own construction, that the base angles of an isosceles triangle are equal</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>• To conjecture that if two sides of a triangle are equal, then two of its angles are also equal</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>• To recognize, through own construction, and name an equilateral triangle</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>• To conjecture that if in a triangle all the sides are equal, then all the angles are also equal (with each = 60°)</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>• To recognize, through own construction, and name a rectangle</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>• To list, at least, three properties of a rectangle</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>• To conjecture that if the diagonals of a parallelogram are equal, then the parallelogram is a rectangle</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>• To define a rectangle</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>• To recognize, through own construction, and name a square</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>• To list, at least, two special properties of a square</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>• To list unique properties of a square that a rectangle does not have</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>• To conjecture that a parallelogram having equal diagonals that bisect each other at right angles is a square</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>• To define a square</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>• To recognize, through own construction, and name a rhombus</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>• To list, at least, two special properties of a rhombus</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>• To list, at least, two specific properties common to a square and a rhombus</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>• To list one unique property of a square that a rhombus does not have</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>• To recognize, with justification, that a square is a special rhombus</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>• To define a rhombus</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

As stated earlier, investigation 1 of the CPGT (worksheet) was to lead the learners to formulate a conjecture that the sum of the angles of a triangle is 180°. This investigation involved two separate activities. The first activity was for the learners to draw (or construct) any triangle and obtain the sum of the angles through measurement and addition of the angles. The second activity required the learners to compare their individual result for the first activity with those of others near them and state their observation as a conjecture. The assumption here was that if the learners noticed that the sum of the angles of each of the different triangles they had drawn was 180° then they would be able to formulate the conjecture (or draw the conclusion) that the sum of the angles of any triangle is (always) 180°.

For investigation 1, Table 2 indicates that although 21 (95%) out of the 22 grade 10 learners from the NS subsample were successful in calculating the angle sum of a triangle to be 180°, only 5 (22%) of them managed to generalize their observation that the sum of the angles of a triangle will always be 180°. Because of a possible language difficulty, it was not expected that these learners should...
formulate their conjectures in formally correct statements. For example, Suberu and Abayomi, two of the five learners who conjectured that the angle sum of a triangle is 180°, put it this way:

Suberu: Sometimes the angles may be the same with corresponding answer, and sometimes the angles will be different while the answer will be the same.

Abayomi: What I can conclude about the sum of the angles of a triangle is that no matter the sides [meant sizes] of angles you may have, the addition of the three angles must give you 180°.

Suberu most likely saw both triangles drawn by some students which had the same angle measures as hers (many drew equilateral triangles), and triangles drawn by other students with different angle measures from her own, and noticed that in either case, the sum of the angles (what she called “the answer”) is 180° (what she referred to as “the same”). Abayomi, on the other hand, probably compared his work only with those of other learners who drew triangles that had different angle measures from his own, and observed that each of them obtained 180° as the sum of the angles of their separate triangles. The point being made here is that even with this level of flexibility in accepting as correct such responses from the learners as these, many could still not provide an acceptable response to the second activity of investigation 1. It looks probable that these learners had only had limited experience of the kind that could enable them to successfully make conjectures.

Stating a definition of a shape (investigations 4, 5 and 6) proved the most difficult for the learners from NS, as none of them was able to do this. Many simply avoided responding to that section of the question or task. However, Abayomi, who named the square that he drew a kite (investigation 5), defined his drawn shape as follows: “Kite is a parallelogram in which all the sides and angles are equal”. Where it not for the incorrect name associated with his drawn shape, what Abayomi gave is surely an acceptable definition of a square.

For learners from the SAS subsample, the performance was not much different from that of the NS learners. As could be seen in Table 2, 19 (86%) out of the 22 grade 10 learners from SAS who wrote the CPGT succeeded in computing the sum of the angles of a triangle to be 180° in investigation 1. Only 9 (41%) of them, however, were able to generalize their observation as a conjecture. Like their NS counterparts, many of the learners from the SAS subsample had difficulty formulating conjectures in formal technical language. Having compared his work with those of his peers, Kondile, for example, generalized his observation as follows: “I conclude that when I’m drawing a triangle and add angle A, B and C and I’m going to get 180° all the time”. The language may not be very formal, but the idea is clear: for every triangle that is drawn, the sum of the angles is always 180°.

As with the NS learners, stating a definition of a shape was very difficult for nearly all the learners from SAS as only 1 of them was able to define a rectangle (investigation 4) and a square (investigation 5), while 1 other student was able to define a rhombus (investigation 6). Interestingly though, the two learners stated a hierarchical definition (see De Villiers, 1998) of these shapes, thereby exhibiting traces of level 3 reasoning according to the van Hiele theory. For example, the learner who defined the rectangle and the square stated that “a rectangle is a parallelogram with one angle equal to 90°” and that “a square is a rectangle with two adjacent sides equal”. This learner was, indeed, one of the strongest grade 10 learners (cognitively speaking) in the study sample as well as in SAS for the study year.

The results for investigation 1 further indicate that some of the learners had difficulty determining the measure of an angle using a protractor despite our efforts to guide them. Since assessing what the learners were able to do (as opposed to developing and implementing an intervention teaching program) was the general aim of the CPGT, an effort was made only to explain procedures to the learners rather than to ensure that each and every one of them made accurate measurements. As evident in Table 2, 1 learner from the NS subsample and 3 learners from the SAS subsample were unable to compute (by measuring and adding) the angle sum of a triangle as 180°. For one of the three learners from the SAS subsample, the sum of the angles of a triangle was 170° (with angles 90°, 50°
and $30^\circ$), for another it was $184^\circ$ (with angles $91^\circ$, $56^\circ$ and $37^\circ$), and for the third learner it was $140^\circ$ (with angles $60^\circ$, $50^\circ$ and $30^\circ$). The only learner from NS who could not obtain the angle sum of a triangle to be $180^\circ$ represented the angles of his triangle in centimetres ($5\text{cm} + 5\text{cm} + 5\text{cm} = 15\text{cm}$) – revealing yet another form of learning difficulty among the participants. This learner was actually adding the lengths of the sides of her triangle instead of the angles. There were indeed many learners for whom the unit of measurement of angles was centimetres instead of degrees or radians. This situation would require that teachers explicitly direct learners’ attention to the units of measurement for angles, even though they ought to have done work on this at lower levels of their schooling.

Similar interpretations to that of investigation 1 would hold for investigations 2 through 6 of the CPGT1 (Table 2). As evident in Table 2, formulating conjectures and stating definitions were more difficult for the majority of the learners than the other activities featured in the worksheet for the CPGT, such as identifying and listing the properties of shapes. This of course links up with the hierarchical property of the van Hiele levels.

A point that perhaps deserves separate mention is that none of the learners from the NS subsample was able to identify and name a rectangle (investigation 4) and a square (investigation 5) through their own constructions (Table 2). The difficulty encountered by these learners cannot be excused entirely by the nature of the tasks, i.e. the supposition that they were not used to the constructivist investigative approach to learning. In fact, many of these learners had no problem following detailed instructions on the worksheet concerning how to construct (or draw) the required shape in each of the investigations. The problem they had was rather that of identifying and naming the shapes in a nonstandard orientation (compare Atebe & Schafer, 2008). Abayomi, for example, correctly constructed a rectangle and a square (Figure 2), but without attending to the properties of the shapes or possibly distracted by the orientation of the shapes, he named the rectangle a cuboard (he meant cuboid) and the square a kite. There were many other learners with this learning problem.
Figure 2 Illustrating learners’ difficulty with identifying and naming shape.

Note in Figure 2 that Abayomi had determined (through his own constructions) all that was needed (two pairs of opposite sides equal, 90° angles and equal diagonals etc. for the rectangle; and all sides equal, 90° angles, diagonals bisect each other at right angles etc. for the square) to correctly identify and name the two shapes, yet he named them incorrectly. This was the situation with the majority of the learners in this study.

Conclusion

Learners’ performance in the CPGT was unsatisfactory as they obtained an overall percentage mean score of only 17.4%. This suggests that these learners were yet to master that aspect of their geometry curriculum that requires them to be able to formulate conjectures, state definitions and draw inferences with regard to the geometric concepts of triangles, squares, rectangles and rhombuses. That is, these learners were not yet ready for the deductive study of these shapes.

With adequate guidance, many were able to construct the required shapes. There were, however, a few other learners who failed to name the shapes correctly, possibly because they were easily misled by the orientation of the shapes. Stating a definition for a rectangle, a square and a rhombus was particularly as difficult as formulating conjectures about these shapes for nearly all the learners that participated in this study.

Recommendation

Direct teaching, as is often the practice, appears to have yielded little result in terms of assisting learners to state geometry definitions and to formulate conjectures about geometric shapes. Educators may wish to try out the reconstructive approach in their mathematics classrooms with activities similar to those used in this study, with the focus on assisting learners to acquire these skills.

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References


Using a Computer Algebra System: Conversions and Treatments

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Doing mathematics may be regarded as an activity in which signs are transformed from one representation to another. I argue that these transformations take a particular form when CAS is used as a resource and that Duval’s distinction (2006) between conversions and treatments illuminates these different types of transformations. Related to this, I use Peirce’s (1996) notion of a triadic sign (representamen, object and interpretant), to suggest that the movement between different representamen (representations) of the same mathematical object through conversions or treatments helps the student generate different interpretants (ideas in the mind) for the object. These multiple interpretants, based on multiple representamen, enable epistemological access to the object. To illustrate my arguments I examine a vignette in which two undergraduate university students use CAS while solving a mathematical problem.
Background

In the last three decades, various mathematics educators have advocated the use of technologies such as dynamic geometry systems or computer algebra systems (CAS) as tools in the learning of mathematics. Many educators have argued that the ability of the user to use the technology to move between different representations of mathematical objects promotes conceptual growth (e.g., Heid and Blume, 2008). Others suggest that CAS may be used to reify certain processes into objects. This may afford a new way of working with mathematical processes (for example, one can use CAS to manipulate a function as if it were an object).

At the same time research, particularly from France, shows that the introduction of technology into mathematics classrooms is unexpectedly complex (Artigue, 2002). This research posits that the successful introduction of technology involves the development of a bidirectional relationship in which the user transforms the artefact into a tool for learning and the artefact affects the learning. This process is called instrumental genesis.

Because of potential benefits and despite possible difficulties involved in using CAS as a pedagogical tool, I introduced the CAS, *Mathematica*, into the Mathematics I Major course at the South African university where I was teaching mathematics. *Mathematica* is software which transforms the computer into a powerful calculator which the user may use to do symbolic algebra, generate graphs, define functions and so on; it also has many inbuilt mathematical functions.

A semiotic approach

While observing students, I was aware of the well-known epistemological problem: it is impossible to see or know what anyone is thinking. The researcher has access to the student’s production and transformation of signs (for example, utterances, algebraic symbols, numbers, or graphs). That is all. Accordingly, the idea of using a semiotic perspective, which looks at the production of signs, became an attractive possibility as a means to an understanding of the students’ mathematical activities.

What is a sign?

C.S. Peirce (1839–1914), one father of modern semiotics, proposed that all thinking is performed upon signs of some kind or other, imagined or perceived. He argued that signs are not only a means of signifying or referring to an object; rather they are “means of thought, of understanding, of reasoning and of learning” (Hoffmann, 2005, p. 45). Thus a sign must be experienced meaningfully; it must signify to someone something other than itself. For example, a red traffic light is a sign that tells one to stop; its purpose is not to make one think of ‘red’. In the phrase ‘\(a=b\)’, ‘\(=\)’ is a sign which tells us that \(a\) and \(b\) are equal; its purpose is not the shape ‘\(−\)’ or the combination of shapes ‘\(−\)’ and ‘\(−\)’.

According to Peirce (1998) all signs have a triadic structure: a representamen (inscription) which refers to the form which the sign takes (not necessarily material), an object (a physical thing or an abstract concept) and an interpretant (the idea or meaning of the object for an individual).

Examples of mathematical representamen are symbols, words, graphs. Examples of mathematical objects are definitions of the derivative, the function, the rectangle. Examples of interpretants are ideas or interpretations generated in an individual’s mind by the representamen of the object. For example, a graph of an exponential function is a particular representation (the representamen) of the mathematical object, exponential function. Different individuals may construct different interpretants for this representamen (for
example, the shape of the function, the symbolic equation $y = a^x$, and/or the idea of rapid change). The role of the interpretant in the making of meaning is crucial where the word ‘meaning’ is used “to denote the intended interpretant of a symbol” (Peirce, 1998, p.218).

Peirce viewed the “signification and construction of meaning as an ongoing process in which an interpretant of one sign becomes a representamen of another” (Sfard, 2000, p. 45). The interplay of signs leads to the possibility of a process whereby the representamen stands for an object which entails an interpretant and this interpretant in turn becomes the representamen for yet another object and so on. This process is called semiosis. In ‘good’ learning, semiosis continues until the learner is able to use the mathematical sign in a way that is meaningful to herself and is commensurate with its use by the relevant mathematical community.

**Mathematics as a semiotic system**

During the last decades, a semiotic perspective has been developed and applied to the nature of mathematics and mathematics education by, for example Rotman (1993), Radford (2006), Duval (2001, 2006). Duval (ibid.) provides a particularly useful formulation of the learning of mathematics using a semiotic perspective. He argues that signs play several fundamental roles in mathematics: they refer to mathematical objects, they allow one to communicate about mathematics and they are necessary for mathematical processing. Furthermore there are a variety of semiotic representation systems, such as natural language (as used in proofs), the registers of numeric, algebraic and symbolic notations, plane or perspective geometrical figures and Cartesian graphs, each with its own possibilities, that are used in mathematical activity. Duval argues that mathematical activity is the transformation of one semiotic representation into another in the same or different register (2006, p. 107).

According to Duval, mathematical comprehension involves the capacity to change from one register to another “because one must never confuse an object and its representation” (ibid., p. 7). Duval calls the process of transforming the representation (representamen) of a mathematical object from one register to another, a **conversion**. He argues that two representations of the same mathematical object in two different registers do not have the same content (for example, the symbolic form of a function and its graph): they may denote the same object but different registers make different properties of the object explicit. Duval also claims that transforming a representation within the same register is a process intrinsic to mathematical activity. He calls this transformation a **treatment**. An example of a treatment is solving an equation given symbolically within the symbolic register. I will illustrate inter– and intra–register transformation of signs later.

Although Duval does not draw directly on Peirce or his triadic structure of a sign, I suggest that Duval’s semiotic framework provides a useful elaboration of aspects of Peirce’s semiotic framework to the mathematics education domain. In particular, Duval’s notion of treatments and conversions exemplifies the process of semiosis.

**Semiotics and appropriation of knowledge**

Since this article is in the realm of mathematics education, as opposed to semiotics, one must ask: Where does the appropriation of knowledge fit into a semiotic account of mathematics? Peirce’s semiotic triad (representamen, object and interpretant), divorced as it is from social practice, context and human interaction is not, on its own, illuminative of cognitive activity (Radford, 2006).

In contrast, socio–cultural theory (Vygotsky, 1978) is a framework in which the appropriation of knowledge is understood as the product of mediated activity within a social and historical
context. The role of the mediator is played by a psychological tool or sign, such as words, graphs, algebra. Vygotsky saw action mediated by signs as the fundamental mechanism which links the external social world to the internal human mental processes. Vygotsky (1981) called that process by which social processes are transformed into internal processes (through the mechanism of semiotic mediation) ‘internalisation’. Implicit in Vygotsky’s formulation of internalisation is the idea that social processes are mutated and developed by the individual, not just absorbed in their original form: “It goes without saying that internalisation transforms the process itself and changes its structure and functions” (p. 163). In a related fashion, the interpretant is the transformation by the learner of the representamen into a personally meaningful sign in the mind. As such Peircian semiotics melds well with Vygotskian principles: the external sign (the representamen) is mutated into an internal sign (the interpretant) which itself may become the representamen for yet another interpretant. The object is the scientific concept or a physical object.

Expanding on these principles, the appropriation of mathematical knowledge, is the outcome of the students’ activities with signs. These activities depend, inter alia, on the tools used to generate the signs (such as CAS), the pedagogic processes in the mathematics classroom, the cultural context of the learners (for example, their familiarity with computers), the text with its implicit pedagogical intentions, the institution (for example, the institutionalised attitude to, say, problem-solving) and the particular history of the student. Thus mathematical cognition is a semiotically-mediated activity in a particular historical context which involves the internalization by the learner of culturally and historically sanctioned mathematical discourse (Berger, 2010).

For example, the activities designed by the teacher or selected from a textbook invoke students to engage in certain mathematical activities sometimes using a tool such as CAS. As a result of these sign-orientated activities (which are situated in a particular social, cultural and historical context) the student is expected to internalise the signs in the form of interpretants; these in turn may lead to further activities and hence further interpretants. Ideally this semiosis continues until the signs become meaningful to the learner and the use of these signs by the learner are consistent with their use by the mathematical community.

**CAS and semiotics**

CAS is a tool that can transform mathematical signs in accordance with the standard rules and procedures of mathematics. As such it may be used to mediate in the construction of mathematical knowledge by the individual. To understand how this happens, it is necessary to consider how its use may enable or constrain the generation of a variety of signs and what the existence of CAS-based representamen may mean for the individual’s internalisation of mathematical objects. For example, a user may be able to use CAS to effect a conversion from a symbolic to a graphic representamen, a transformation which the user may not have been able to do using paper and pencil alone. The new CAS-generated representamen may be more epistemologically accessible than other representamen of the object, thus enabling the production of a more useful interpretant. In particular the student may notice important properties of the particular object not previously perceived. Likewise seeing different objects in the same register may help the student discriminate between properties of these different objects.

The word ‘may’ is used advisedly throughout the previous paragraph: the use of a CAS does not in itself guarantee that a user gains access to more powerful representamen. For example, the learner may be unable to interpret the CAS output or she may not know the correct CAS syntax to generate a representamen.
Nonetheless the user’s task of generating conversions and treatments may be enabled by the use of CAS. For example, the use of CAS may allow the user to generate representamen of mathematical objects before she has any substantial knowledge about the properties of the objects she is representing. This differs from the pencil and paper environment. Duval (2006, p. 124) argues that a conversion of representation requires “the cognitive disassociation of the represented object and the content of the particular semiotic representation through which it has first been introduced and used in teaching”. I suggest that certain forms of conversion in the CAS medium may involve different cognitive processes. Indeed, at one extreme, the user may be able to use CAS to convert an object with which she is completely unfamiliar into a new register. For example, she may use CAS to convert the logarithmic function represented by \( y = \log x \) into a graphical representation without having any idea about the properties of the log function. Of course, such a conversion does not guarantee an internalisation of the new object, the logarithmic function. But it may help. For understanding, the student would need to perform further conversions, probably under the guidance of a teacher or textbook – for example, isolating certain properties of the logarithmic function, and describing these properties using language or symbols (a further conversion). It is these further conversions which may require the cognitive dissociations of the mathematical object from its semiotic representations.

Duval’s distinction between conversions and treatments, and his argument that it is the transformation of one sign into another that constitutes mathematical activity, is very useful for an analysis of activity with a CAS. In the analysis below I show that both conversions and treatments assume a specific role in CAS–based work with particular cognitive implications.

**Research Question**

How does the use CAS promote intra– and inter–register transformations? How do these transformations enable or hinder the construction of appropriate interpretants by the learner?

**Analysis of students using CAS’ sign transformations**

I demonstrate how a pair of learners engaging in a mathematical task with CAS use various signs (utterances, CAS–based signs, text–based signs) to generate new signs. These new signs (with their new interpretants) permit mathematical activity which may eventually lead to an internalisation of well–established mathematical concepts and rules. I frame my analysis in terms of the way in which the use of the CAS enables or constrains conversions and treatments, both core aspects of mathematical activity (Duval, 2006).

**Data gathering**

Five pair of students were audio–taped and screen–recorded while doing several tasks. I (the researcher) received printed outputs of their computer work as well as their final assignments. The students were volunteers from the classes that I tutored in the computer laboratories. They came at designated times to my office and I sat in the office throughout their session which was about an hour long.

In the vignette below, a pair of learners, Sipho and Temba, from the first–year Mathematics Major course engage in a particular task. This task was part of a longer assignment which was given to the students to work on in pairs, near the end of the 2007 academic year. It was adapted from a laboratory project in the course textbook (Stewart, 2003); its purpose was to introduce students to the concept of the Maclaurin polynomial before the student had been introduced to the concept in regular mathematics lectures. The assignment involved the use of CAS and paper and pencil.
The Task is the following:

Determine the values of $x$ for which the quadratic approximation $p(x)$ found above is accurate to within 0.1. [Hint: Graph the functions, $f(x) = \cos x$, $y = p(x)$, $y = \cos x + 0.1$ and $y = \cos x - 0.1$ on a common screen.]

In order to attempt this task, students need to know, inter alia, that $p(x) = 1 - \frac{1}{2}x^2$. The students in this vignette have found this result in a previous task.

The Vignette

Episode 1

As suggested in the Hint, Temba and Sipho generate a plot of all four graphs on one screen. They use domain $(-4\pi, 4\pi)$. As a result all four graphs are very close together; it is consequently difficult to distinguish one graph from another. Despite this the students are able to generate several meaningful signs from the CAS-generated graphs.

![Figure 1: CAS-generated graph of $\cos x$, $\cos x-0.1$, $\cos x+0.1$ and $p(x) = 1- \frac{1}{2}x^2$](image)

\[1\] Temba: No! What’s happening there (referring to screen, ie Figure 1).
\[2\] Sipho: I’m not too sure. Okay, oh ya.
\[3\] Temba: Oh ya.
\[4\] Sipho: I can see what is happening. It’s shifted in two directions.
\[5\] Temba: Oh. The centre one. The one in the centre. If you can see. That’s probably the Cos one, Cos $x$.
And then minus 1 for the bottom one. Minus 0.1, I mean. And plus 0.1.
\[6\] Sipho: They are saying: which values of $x$… its accurate to within 0.1. Wouldn’t that be where they intersect? Do you see what I am saying? Like you have this one.
\[7\] Temba: Um

**Interpretation:** Temba and Sipho use CAS to transform part of the language–based description given in the task (the Hint) into new representamen in the graphical register. Initial interpretation of this CAS–generated representamen (Figure 1) presents its own difficulties (lines 1 –2) but in line 4, Sipho claims that he “sees what is happening” (the interpretant) which he partially explains using the language register. Sipho’s explanation, “shifted in two directions”, whilst not clear to the outsider, clearly has some value for Sipho. After all, he asks: “Wouldn’t that be where they intersect?” (line 6). Meanwhile Temba generates a new interpretant with a new language–based representamen: that is, he explains (line 5) that the centre graph is Cos $x$, and that the lower graph is Cos $x – 0.1$.

**Analysis:** In this episode, we see how a use of CAS enables a conversion of the representamen in the language register into the graphical register and back again. Although the students are unable to use CAS to effect an optimum conversion (the graphs in a more appropriate...
window), they use CAS to gain access to an alternate representation of the mathematical objects (the different functions, the interval of interest) described in the task. Temba and Sipho move between the graphic (on CAS) and the language registers (both written and spoken) in order to make sense (generate an interpretant) of the objects. This represents the beginning of a conversion; it is a beginning because the language describing the mathematical notion of “which values of $x$… its accurate within 0.1” in line [6] is not yet disassociated from the graphic representation.

**Episode 2**

Sipho uses paper and pencil to generate yet another representamen, a rough sketch of the four graphs (Figure 2).

[8] Sipho: You have, you have a Cos graph coming like this. And you have Cos plus 0.1 and you have Cos - 0.1 (drawing with pencil the four graphs – Figure 2). Then you have this quadratic estimates over here.

[9] :

[10] Temba: Okay do you see at this end… I’d say, um. You see where… what will, what will the quadratic do here. Won’t it cut the Cos - 0.1 there? And then not go into these graphs. Right? (looking at hand-drawing and screen).

[11] :Temba: Like what I am trying to say to you is, we must equate our $p(x)$ to that point there and this point here (darkening points of intersection on Figure 2). So it’s in between there… the values where it is accurate.

**Figure 2**: Hand-drawn graph of Cos $x$, Cos $x$–0.1, Cos $x$+0.1 and $p(x) = 1 - \frac{1}{2}x^2$

**Interpretation**: Sipho spontaneously uses paper and pencil to generate a picture of the four graphs (line 8). This new graphical sign both depends on the previous representamen (with its interpretant) and looks forward to the generation of future signs. The graphs represent a similar mathematical object to that of Figure 1, but with different domain and scale. After further discussion about points of intersection (omitted here), Temba indicates that the $p(x)$ graph will only cut the Cos $x$ – 0.1 graph (line 10). That is, he creates a new interpretant from previous interpretants. A little later (line 11) he is able to transform this sign (the interpretant) into a plan of mathematical activity: “we must equate our $p(x)$ to that point there and this point here”. Although his statement is somewhat incoherent, it functions as a new sign for him and for Sipho since both of them immediately attempt to solve the equation, Cos $x$ – 0.1 = $1 - \frac{1}{2}x^2$ by hand (not shown here).

**Analysis**: In this episode, we see how Sipho’s hand-drawing of the functions affords the students new insights, allowing them to generate new interpretants about the relationships of the different functions (in particular the relationships between Cos $x$ – 0.1 and $1 - \frac{1}{2}x^2$). This illustrates how Duval’s argument (2001) that representations of the same object in different registers make different aspects of the object visible, may be applied to representations of the
same object in the same register but in different media, in this case the CAS–generated graph and the hand–drawn graph. This episode represents a treatment since the students are still working within the graphical register.

**Episode 3**

After trying in vain to hand-solve \(\cos x - 0.1 = 1 - \frac{1}{2}x^2\), Temba suggests using the FindRoot command (in the CAS Symbolic register) to solve the equation. This is apposite since the FindRoot command needs to be used to solve an equation involving a transcendental and an algebraic function.

Temba finds an example of the FindRoot command in the handbook, \(\text{FindRoot}\left[\cos(x) = 1 - \frac{1}{2}x^2, \{x, 2\}\right]\). Temba and Sipho then enter the command \(\text{FindRoot}\left[\text{h}(x) = \text{p}(x)\right]\) into the computer. The syntax is incorrect and they receive an opaque error message which they ignore.

**Analysis:** In this episode we have an example of an unconsummated transformation. Here the students’ attempt to use CAS to effect a treatment (the solution of an algebraic problem) is thwarted by the syntax of the FindRoot command. This episode illustrates how the students’ practices (the students not accessing appropriate resources such as a description of how to use the FindRoot command) constrain their mathematical activities. It evidences the students’ limited instrumentalisation of the CAS.

**Episode 4**

Temba suggests that they use CAS to generate the graphs of \(\cos x - 0.1\) and \(p(x) = 1 - \frac{1}{2}x^2\) only. Sipho agrees and suggests the domain \(-\pi/4\) to \(\pi/4\).

[12] Temba enters Plot command to plot \(\cos x - 0.1\) and \(p(x)\) on domain \(-\pi/4\) to \(\pi/4\).

[13] A window with graph of \(\cos x - 0.1\) and \(p(x)\) appears (Figure 4). But there are no visible points of intersection.


[15] Sipho: No. Its fine. All it means is that they intersect further down.

**Interpretation:** The students attempt to transform their previous graphical representamens (Figures 1 and 2) into a new graphical representamen. Presumably their goal is to make the relevant information (that is, the points of intersection) more visible. However, the domain is too narrow (\(-\pi/4\) to \(\pi/4\)) and the points of intersection lie outside the domain. See Figure 3.

Temba, realizing that the graphs should intersect (presumably based on previous interpretants) assumes that he “did something wrong” (line 14). But Sipho seems to have a more refined internal picture (interpretant) of what the graphs should look like and he correctly states (line 15) that the graphs intersect at a point(s) outside the domain.
Analysis: In this episode we see how use of CAS to effect a treatment may not be straightforward. To draw the graphs in an appropriate domain, the user of the CAS needs to have mathematical awareness of an appropriate domain. More importantly, in order to interpret the CAS-generated graphs (a conversion from graphical register to language or symbolic register), the user needs to have some prior idea of what the graphs should look like (in this case, the graphs must intersect). That is, in order to use the CAS successfully as a tool for conversion or treatment of representation, the user may need to have prior knowledge of the mathematical object she is trying to represent.

**Episode 5**

Temba now re-plots the graph using the domain $-\pi$ to $\pi$. A much clearer picture (Figure 5) emerges.

![Figure 4: CAS–generated graph of Cos x−0.1 and p(x) = 1−½ x²; Domain is (−π, π).](image)

Analysis: Representamen and their interpretants, generated from the previous CAS graphs, together with prior knowledge about Cos x and p(x), enable the users to generate this representation on CAS. This exemplifies a further treatment.

**Episode 6**

Unable to use a symbolic command such as FindRoot, Temba & Sipho now decide to use trial and error to find value(s) of x where $\cos x - 0.1 = 1 - \frac{1}{2}x^2$. Guided by the approximate values of the points of intersection on the CAS graph, they substitute numerical values into the CAS–based functions p(x) and Cos x − 0.1. This activity is not fruitful since their visual estimates from the graph are not accurate. The activity takes place in the numeric register.

**Episode 7**

The researcher intervenes. She suggests that the students use FindRoot command (symbolic register) again. They try to do this but as in Episode 3, they use incorrect syntax.
Interpretation: Temba and Sipho are again severely hindered by poor syntax. They are probably tired and demotivated as well, given that at least fifty minutes has passed since the beginning of the session. This is evidenced by their careless use of the alphabetic o rather than numeric 0.

Finally the researcher helps them use the FindRoot command correctly; the computer outputs the answer 1.26124. The students accept this value as the x-value of one point of intersection.

Analysis: As in episode 3, the students’ attempt to generate a conversion of the graphic representation (Figure 4) to a symbolic representation (FindRoot command) is initially stymied both by their lack of knowledge of syntax and their praxis (not ‘knowing’ how to access information in the manual). However, with guidance from the researcher they are finally able to generate the appropriate FindRoot command.

Episode 8

Later, outside the research session, they use FindRoot command correctly and they successfully complete the task.

Discussion

In the above vignette, students’ generation of new signs via treatments (transformations within a register) and conversions (transformations between different registers) in both the CAS and pencil–and–paper media constitute their mathematical activities. That is, mathematical activities are essentially semiotic activities.

Of particular interest is the way in which the use of CAS promotes intra– and inter–register transformations. With regard to conversions, we see how the use of a CAS may afford access to alternate representamen of the objects. For example, in Episode 1 the students use CAS to generate a graphic representamen of the four functions referred to in the task. The students are then faced with an epistemological problem: they need to isolate the attributes of the representamen which relate to the given task. In the vignette they do this through generating further representamen, for example, the hand–drawn graph (Episode 2); the CAS–generated graph (Episode 5); the equations in the CAS numeric register (Episode 6); and finally the FindRoot command in Episode 7. These new representamen enable students to isolate different attributes of the objects (the four graphs and their relationship to the task) and in this way enhance their interpretants of the different objects. Semiotically speaking, the students use CAS to enable a process of semiosis (transforming one interpretant into another) and therein lies the value of CAS.

Furthermore, the use of CAS enables access to representamen which would have been unavailable to the student without a CAS and this broadens the type of mathematical activities available to the student. For example, in Episode 7, the students use FindRoot command to find the points of intersection of \( \cos x - 0.1 \) and \( 1 - \frac{1}{2} x^2 \). Although the students battle to effect this conversion they are able finally to solve the equation and, in this way, to complete the task (Episode 8).

In a CAS environment, the user may generate new signs (the answer to an algorithmic procedure, the plot of a graph, and so on) with CAS rather than with pencil and paper. I suggest that this outsourcing of computation to the computer has a profound effect on the skills needed to interpret the CAS output (that is, to effect a conversion of signs in graphic or symbolic registers to the language register). For example, in Episode 1, the students struggle to interpret the CAS–generated graphs. However, and as discussed above, their interpretation
is ultimately mediated by the generation of further representamen. In this instance, the use of CAS may have promoted interpretation (in terms of providing the user with different representations with which to generate complementary interpretants).

Conversions in the CAS–based environment may also be hindered by the intricacies of the required syntax of the CAS. This is exemplified by the students’ frustrated attempts to compose the FindRoot command (Episodes 3 and 7). Problems with syntax may be a result of poor praxis rather than cognitive difficulties. In these episodes, the students’ difficulties are partly a consequence of ‘not knowing how’ to access information about this command. That is, the students could have turned to the previous page in the handbook to find more information about how to use the FindRoot command. Or they could have used the Help function in Mathematica (both issues of praxis). Related to this, the pedagogical environment should have focused more on strategies to help students instrumentalise the CAS.

Treatments mainly take two forms: transforming graphs into new graphs (through the use of a more apposite domain) and executing algorithms (using the FindRoot command in this vignette). The latter is usually simple, provided the task has been correctly transformed into a suitable register (a conversion). However, and as discussed above, a challenge may lie in the interpretation of the output (a conversion).

Treatments involving the transformation of one specific graphic representation of a function into another graphic representation of that function, usually through change of domain, may be cognitively complex. For example, the user may need to already have an idea of what the graph should look like. In Episode 4 we see how Sipho recognised the inadequacy of the CAS graphic representamen, presumably because of prior knowledge and/or because of exposure to previous representamen of the graphs (see Episodes 1 and 2). As a result the students were able to effect an appropriate treatment of the graphic sign.

Notwithstanding the non–trivial difficulties with the use of CAS, the semiotic analysis illustrates how the use of CAS ultimately affords the students an understanding of which interval they are looking for. Specifically the students use the graphical signs (Figures 1, 2 and 4) to gain crucial insight into which functions need to be equated. They also use CAS to numerically investigate the values at which the quadratic approximation $p(x)$ is within a distance of 0.1 from the Cos graph (Episode 6). Although this numerical approximation is not necessary for solving the problem, it presumably enriches and enhances the students’ understanding of the mathematical task and object. However, the students inability to use the appropriate syntax for the FindRoot command severely hinders their mathematical activity in the latter part of the task (Episodes 3 and 7). This strongly suggests that the level of instrumentalisation of the CAS is profoundly related to the semiotic activity of the students.

Conclusion

The vignette illustrates how the intra– and inter transformations with CAS may promote mathematical activity. With reference to Vygotsky, the signs which the students generate with CAS or paper and pencil or through utterances, mediate the internalisation process. That is, the students internalise different representamen into various interpretants thereby internalising the outside world. These interpretants are further transformed and mutated by the learner into new representamen with new interpretants and so on. Specifically the different representamen of the same object enable the learners to construct different interpretants for that object. This is revealed by the new signs that they generate in their mathematical activities. In turn, these new signs reveal important properties of the mathematical object under consideration. Also, seeing different objects such as the quadratic approximation and Cos $x$ in the same register enables the student to discriminate between properties of these different objects.

We also see that the use of CAS for conversions and treatments is not straightforward. In
particular, we see that the construction of the CAS–based signs and interpretation of CAS output may be particularly problematic. With regard to construction of signs (a conversion), difficulties with syntax may drastically limit the usefulness of CAS. In this regard, teachers need to be aware of the importance of an adequate instrumentalisation of the CAS. We saw in the above vignette, how students’ semiotic activity was severely limited by their lack of knowledge of how to use the FindRoot command. Interpretation of CAS output (a conversion) may also pose its own unique challenges. Unlike in the paper and pencil environment where the user is always actively involved in constructing the output (e.g. hand-drawing a graph), the CAS user is usually not directly involved in generating the output other than entering an instruction into the computer. Thus interpretation may be a paradoxical endeavour: the user needs to know which properties of the object (say, features of a graph, or roots of an equation) to focus on in order to use these attributes to cognitively construct the object for herself; this may be where pedagogic guidance (via specially designed tasks or discussion) is required. Treatments in the CAS–based environment may also be problematic. In particular treatments involving the transformation of one specific graphic representation of a function into another graphic representation of that function, usually through change of domain, may require prior knowledge of important properties of the function. Research involving different students using CAS to do other mathematical tasks, would no doubt reveal other possibilities and different aspects if inter- and intra-register transformations. This research would usefully contribute to the literature around the use of technology in the learning of mathematics.

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A Case study of lecturers’ views on content knowledge and practice

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Abstract
Lecturers’ views on content knowledge and their classroom practices were investigated to confirm or refute existing assumptions and literature claims. The two lecturers were from the education faculty of a South African university. Questionnaires in which these lecturers expressed their views on content knowledge in general were administered to them. Video recorded lessons on rates of change in Calculus were observed to triangulate actual lesson instruction and their views on content knowledge and classroom practice. Data yielded by these research instruments confirmed assumptions and literature claims. Although it was a small scale qualitative research, interesting observations were made that could have pedagogical implications. This paper is intended to contribute to the teaching and learning strand against the background of the conference theme.

Introduction
At the beginning of 2006, the Department of Education introduced a new curriculum for schooling in South Africa. The new curriculum is based on a National Curriculum Statement (NCS) which “aims to develop a high level of knowledge and skills in learners” (Department of Education, 2003, p.3). It has high expectations of South African mathematics learners. Implicit in the development of knowledge in learners would be a high level of knowledge in educators. There is however no explicit mention of this and it was therefore something that this study pursued.

The NCS document also spells out the type of teacher that is envisaged. The teacher is expected to be qualified, competent and a specialist in his field. Here again one sees a subtle
reference to the teachers’ knowledge which this study assumes as extending to university lecturers. This is expected, especially as lecturers in an education faculty, as they become role models to student teachers. Based on this assumption the study interrogated two main areas. These are: a) the teaching of mathematics

“which focuses on matters pertaining to organised attempts to transmit or bring about mathematical knowledge, skills, insights, competencies, and so forth, to well defined categories of recipients,” (Niss, 1999, p.6)

and b) the learning of mathematics “where the focus is on what happens around, in and with students who engage in acquiring such knowledge, skills… (Niss, 1999, p.1). Within these areas of investigation we adopted the aim of generating thick interpretations of data in the form of videotaped lessons, and interviews, in order to explain the lecturers’ perceptions of the link between content knowledge and the activities that they engaged with in the classroom.

The key critical questions that were explored in this study were:

(a). What were the lecturers’ views of content knowledge?

(b). Did the lecturers engage their students in dialogue around the activities that occurred in the class and how did the nature of the dialogue influence the lecturer’s classroom practice?

(c). How did the lecturers view the link between content knowledge and classroom practice?

**Conceptual framework**

This research was based in the interpretivist paradigm. According to Cohen, Manion and Morrison (2007, p.21) the interpretivist paradigm focuses on the individual, in order to understand the phenomena that is being investigated from within the individual. In this instance the phenomenon that was investigated from within the individuals were their perceptions on the link between content knowledge and classroom practice. “An interpretivist researcher wants to learn what is meaningful or relevant to the people being studied, or how individuals experience daily life” (Neuman, 1997, p.69). These researchers look at social action that is meaningful, not just the observable or external behaviour of people. This characterized this research as it studied two university lecturers and how they engaged in meaningful activities with their students in order to teach a particular topic in mathematics.

The aim of interpretivist research is to offer the perspective of the phenomenon under investigation from the viewpoint of the subject. This is criticized as it provides a subjective view and cannot be generalised. The nature of the interpretivist paradigm is such that although the findings cannot be generalised they can be transferred to similar situations, depending on the reliability of the data. This study also relied on the concept of scaffolding. The implications of Vygotsky’s theory and the process of scaffolding for the teacher, is thus to guide the student’s activity so that meaningful learning occurs. Larkin as cited in Lipscombe et al (2008, p.7) suggests the following effective techniques of scaffolding that teachers can follow:

Teachers should begin by boosting the confidence of their students by introducing them to tasks that they can do quite well with limited or no assistance. Teachers should also provide the right amount of assistance to allow their students to achieve success quickly- this assists with the lowering of frustration levels and ensures that students are motivated to proceed to the next level. Teachers must also help their students to fit in with their peers, as they work harder if they feel that they belong with their peer group. The teacher must be guarded to prevent students from boredom. Once a skill has been learned, the scaffolding should be removed gradually until the skill is mastered. These factors were considered in the design of
the activity sheets.

**Content knowledge**
The conceptions of teachers’ subject matter knowledge or content knowledge has changed from the beginning of the twentieth century. At the beginning of the century it was described in qualitative terms which made it very difficult to measure or evaluate the content knowledge of teachers. Towards the end of the nineteenth century this perception shifted with the emphasis now being placed on the number of courses taken by teachers and also their performance in standardised tests. Shulman’s Presidential Address in 1986 (as cited in Even, 1990, p.322) saw a return to assessing teachers’ subject matter knowledge in qualitative terms. According to Even “analyzing what it means to know mathematics, has some promise to contribute to the improvement of the quality of subject matter preparation of teachers and therefore the quality of teaching and learning” (1990, p.322).

This study extended these notions to university lecturers. The study applied the following terminology within the constraints of the definitions provided:

(a) content / subject matter knowledge

These two concepts are used interchangeably in this research and mean the same thing. Content knowledge refers to the knowing about a subject, the disciplinary knowledge of a subject. “Mathematical content knowledge includes information such as mathematics concepts, rules and associated procedures for problem solving” (Chinnapen, 2003, p.1).

(b) pedagogical knowledge

Pedagogical knowledge refers to the broad knowledge that a teacher requires in order to be effective in the classroom. This includes content knowledge, knowledge about how to teach, knowledge about pupils and how they learn, knowledge about the curriculum and knowledge about discipline and classroom management.

(c) conceptual knowledge

This term is used by Adler, Slominsky and Reed (2002) and refers to the special way that a teacher uses the mathematical content in order to teach mathematics. Adler et al draws a distinction between the way a mathematician would view the mathematical content and the way a mathematics teacher views mathematical content. The teacher has to impart content knowledge to his students.

(d) pedagogical content knowledge

This term was first used by Shulman. It refers to a blend of content knowledge and pedagogical knowledge, this includes understanding why some children experience difficulties learning a concept while others find it easy to understand, the best method to approach or discuss a particular topic or concept, the quality of explanations that teachers give during a lesson.

This study does not draw a distinction between a teacher, an educator and a lecturer, in other words the MKO. These terms are used to refer to those that impart knowledge to their students, learners and pupils. The terms learners and pupils are used to refer to learners in a school and students refer to those studying at a university.

**Classroom practice**

Current research needs to focus on providing an analysis of teaching practices and the mathematical knowledge that is required to improve and also to sustain these practices (Ball et al as cited in Brodie, 2004, p.66). Ball et al also argued that there should be a strong link between the mathematics that teachers have to learn and the activities that define their practice in the classroom. In contrast to this, the PEI report argued that too much emphasis
had been placed on teaching methodology in South African curriculum initiatives, at the expense of content knowledge that needed to be taught and learned. The report argued that in-depth content knowledge would promote better teaching and learning regardless of the teaching methodology that was used. It stressed that of primary importance was content knowledge for without this no meaningful teaching and learning can occur. However, methodology was also important in order for the lecturer to impart his content of the subject in an effective manner to his students as seen in the design of the activity sheets.

Adler (2005) focused on the complex issues of the teaching and learning of mathematics. She felt it was important that we understood “how to make mathematics learnable by all children” (Adler, 2005, p.2). Her own area of interest is to know more about the support and mathematical preparation that teachers receive in order to make them more efficient and skilful in the classroom context. The question that she investigated in one of her studies was “what mathematics teachers (at different levels) need to know how to do, in order to teach well” (Adler, 2005, p.3). By looking at lessons in the classroom context Adler came up with a solution to the problem of how to deal with different learner responses. In order to deal with learner responses she argued that teachers needed ‘mathematical proficiency’ which included content knowledge, reasoning and problem solving skills and fluency in mathematical procedures. Here again content knowledge was included as part of the criteria necessary for skilful teaching. Margolinas et al (2005) used case studies in order to deepen their understanding of what teachers learned from the classroom experience. They focused on the teachers’ didactic knowledge in relation to the observation in the classroom. This phenomenon is out of the ambit of this research, but what was relevant in their research was their use of the ‘usefulness principle’ which referred to the ‘usefulness’ of the teachers knowledge in building knowledge that was more permanent, that which he gained from his observations. They referred to another kind of knowledge that a teacher required and that was observational didactic knowledge. Also an important finding of their research was that teachers lacked didactical knowledge and they felt that there should be further inquiry into this lack of didactic knowledge.

Qualitative research
This research is a qualitative one. Qualitative research attempts to collect data that is rich and descriptive in order to understand the phenomenon that is being studied or observed. It thus focused on how groups or individuals view the world and how they derived meaning from their personal experiences (Niewenhuis, 2007, p.50).

Qualitative research is typically concerned with exploring the ‘what’ and ‘how’ questions of research. It is concerned with studying people in their natural environment and focusing on their perceptions and interpretations. This exemplifies this research as it interrogated the lecturers in their natural environment of their teaching of mathematics lessons. The interviews investigated their views of the phenomenon under scrutiny in this study.

In qualitative research “the emphasis is on the quality and depth of information...” (Niewenhuis, 2007, p.50). This therefore justifies the interpretivist paradigm where the individuals that were interrogated and their interaction with the phenomenon that was being investigated was regarded as being paramount.

Participants in the study
The participants in this research were two university lecturers. The lecturers were chosen for
two reasons: firstly both the lecturers are involved in the ‘calculus project’ and were therefore convenient and accessible and secondly they were chosen purposively. Access is a key issue in research and it is a factor that must be considered early in the research procedure (Cohen et al, 2007, p.109). The two university lecturers were accessible and that made my research practical to conduct. They work in the same university faculty in which this study was carried out.

Validity and reliability
In qualitative research “validity might be addressed through the honesty, depth, richness and scope of the data achieved, the participants, the extent of the triangulation and the disinterestedness or objectivity of the researcher” (Winter as cited in Cohen et al, 2007, p.133). Validity can be improved through careful sampling, using the appropriate instruments and data analysis techniques. Validity is not something that can be achieved absolutely but it can be maximized.

In order to maximize the validity of this research the samples were carefully chosen. The two university lecturers were purposively selected for their in-depth knowledge of the topic that was being investigated. They also provided honest, well thought out and thorough responses. According to Agar (as cited in Cohen et al, 2007, p.134) the rich data and involvement of the participants secure a sufficient level of validity and reliability.

Also the semi-structured interviews allowed to gain in-depth answers from the lecturers and the observation gave the study an opportunity to verify the lecturers’ responses.

According to Cohen et al (2007, p.149) reliability can be seen as the correlation between the researcher’s recorded data and what actually happens in the natural setting of the research. This was achieved by triangulating the data. After data from the interviews was captured, the correlation between the interview responses and what actually happened in the classroom from the video recordings of the lessons was carried out. This ensured the reliability of the data.

Data generating instruments
Primary data was generated by conducting semi-structured interviews with the two university lecturers and secondary data was obtained by observing the video-taped lessons. The observations allowed me to gain clarity and also to verify what the lecturers said in the interviews, in order to arrive at reliable conclusions. The analysis of the interviews commenced with reading all the data and then dividing it into smaller and more meaningful units. These units were organised into a system that was derived from the data that was generated. The analysis was therefore inductive. The data was allowed to dictate the categories and themes pursued. The themes that emerged from the interviews were: (a) an academic profile of the two university lecturers, (b) the participants’ perceptions of content knowledge, (c) the participants’ view of their classroom practice, and (d) the link between content knowledge and classroom practice. These themes led to the design of questionnaire (see appendix A).

In qualitative research the categories are flexible and may be modified during the analysis process. An important aspect of qualitative analysis is that it should reflect the perceptions of the respondents. This was kept that in mind during the analysis process. There were, however, some gaps in these categories and a second round of interviews was conducted. “In qualitative
studies researchers often find it advisable and necessary to go back……to the participants to collect additional data……(Niewenhuis, 2007, p.100). Data collection in qualitative research is thus an iterative process. Siedel as cited in Niewenhuis (2007, p.100) developed a model to explain this iterative approach of qualitative data analysis quite succinctly. Siedel’s model consists of three essential categories namely: noticing, collecting and reflecting. These categories are intertwined

and interlinked and necessary in the qualitative data analysis process. Sometimes while you are analysing and reflecting on the data that you have collected, you notice gaps in the data. You have to therefore go back to collect additional data in order to fill in the gaps. This study therefore conducted a second round of interviews based on the following interview schedule: (see appendix B).

Activity sheets were given to the students prior to the lessons. The students worked on the questions in class and thereafter the questions were discussed by the lecturers. The activity sheets were based on what research in calculus findings suggested texts should satisfy. It uses scaffolding and is student-centred and is based on self-discovery.

Video-taped lessons of the two university lecturers were scrutinised. Observation “offers an investigator the opportunity to gather ‘live’ data from naturally occurring social situations” (Cohen et al, 2007, p.396). The researcher can thus look directly at what is occurring and this allows for more accurate and valid data. This is the unique strength of observation. Two types of video recordings were used in order to record the lessons that were taught. There was one video recorder that was placed in a fixed position in the lecture room and that recorded the whole class interaction. There was another video recorder that was portable and that followed the lecturers as they engaged with students and also as they conducted the lessons.

Once the categories which merged from the interviews were defined, the observation of the videotaped lessons was a matter of looking for details that further illustrated these categories. The following observation checklist looked out for certain pertinent details that described the various categories: (a) number of students that were present, (b) were students working individually or in groups, (c) the level of student participation, (d) layout of the lecture room (e) delivery of lesson by lecturer, (f) resources that were being used during the lecturer, (g) dialogue between students and lecturer, and (h) was there feedback from the lecturer?

Discussions and findings

Analysis of activity sheets

Using Zhao and Orey’s (as cited in Lipscombe et al, 2008, p.5) six general elements on scaffolded instruction the activity sheets were analysed. Of the six elements the elements of ‘sharing a specific goal’ and ‘whole task approach’ were relevant to written work.
(a) Sharing a specific goal- The two university lecturers, who in this case would be the MKO, established the goal and shared this with their students via the activity sheets (refer to appendix C) that were given to them. The activity sheets made it explicit to the students what was expected of them, for example, in the section entitled ‘Getting started’ the students had to solve the problems and also reflect on their solutions. In the section entitled ‘Key Task 1’ under the ‘Tasks’ section in question 1, the students were asked to use sketch graphs in their discussion of the solution to the question posed. In this way the students were fully aware of what was expected of them. The lecturers therefore fulfilled their responsibility to establish the goal of the topic under discussion and shared this with their students.

(b) Whole task approach- The activity sheets made it clear to the students what the ultimate goal was. The activity sheets were designed in a systematic manner. It starts with a section entitled ‘Getting started’ (refer to appendix C), it then proceeds to a section entitled ‘Rates of change’ where the concepts of ‘average gradient’ and ‘tangent lines’, which are pertinent to the topic of calculus were discussed. The activity sheets then discuss ‘Notation’ relevant to calculus. Thereafter there are ‘Tasks’ that the students have to engage in and this is followed by ‘Consolidation’ and ‘Assessment’. The students therefore had a holistic view of the topic that they were engaging with and they could also see how the various components related to the ultimate end result.

Analysis of observation

The lecturers were observed lecturing to a class of second year undergraduate students. There were seventy eight students in the class of which fifty three were male and twenty five were female. The course module was: Mathematics for Education 310 which dealt with Differential Calculus.

Two video-taped lessons conducted by lecturer 1 and lecturer 2 were observed. The first lesson started with the students working on the solutions to the questions that were given to them in the activity sheet. The students were given time in class to work on the solutions. The students were seated in a lecture room. The desks were all single desks that were arranged in rows facing the front of the lecture room. The students were either working on their own or in groups. The groups the students formed on their own by either turning around and working with students behind them or by working with students that were sitting next to them.

Frame one: the groups that students formed.
This is illustrated in the still photograph above (frame one) that was taken from the video recording of lesson one. As the students worked on their responses both lecturer 1 and lecturer 2 walked around the lecture room to either assist the students or check on what they were doing. Several times both lecturer 1 and lecturer 2 stopped at the desks of students and assisted them with their queries. In this way students were provided with immediate assistance, this in keeping with Zhao and Orey’s (as cited in Lipscombe et al, 2008, p.5) scaffolded instruction. Students also raised their hands to get the attention of either lecturer 1 or lecturer 2 to answer their queries or questions. After about twenty minutes lecturer 1 asked for a volunteer to come to the front of the class and work out question one on the board. The students were initially reluctant but after some persuasion and coaxing a student eventually came to the front of the class and attempted question 1 on the board. Lecturer 1 guided him as he was working out the solution. Thereafter another student worked out question 2 on the board.

Lesson two also began in a similar manner, but this time the students were working on the solution to question three. Only lecturer 2 was present at this lecture. Here again students volunteered to work out the subsections of question 3 on the board. Lecturer 2 encouraged the students to come to the front of the class and also assisted and guided them when they were working out the solutions on the board. Both the lecturers socially interacted with the students to promote learning. Using language and social interaction the lecturers engaged with their students in order to promote learning. This is in keeping with Vygotsky’s learning theory. Vygotsky’s learning theory advocates that learning is enhanced through the social interaction between the student and a teacher. Vygotsky views the teacher as the MKO who is able to lift the student’s achievement level. The lecturers also lifted the performance of the students that they were supervising by providing immediate assistance, this in keeping with the scaffolding approach. The ‘immediate availability of help’ is one of the six general elements of the scaffolding approach which is discussed in detail in the literature review.

**Participants’ views on content knowledge**

**Lecturer 1** defined content knowledge as:

*To me content knowledge is knowledge that is pertinent to a particular topic you are teaching, in other words it does not entail didactic aspects of knowledge. I do not integrate it with pedagogics. It is dealing with a particular topic and the mathematics around it.*

**Lecturer 2** also expressed similar sentiments:

*Content knowledge...knowing the mathematics. The content is about the content, how well you know the content, how it fits in with other topics...about the concepts, having an understanding of how it works, when it works, knowing interrelationships within the content.*

I think what came across very strongly is that content knowledge refers to the actual
mathematics that you are required to teach. These sentiments are echoed by Kilpatrick et al who believe that content “includes knowledge of mathematical facts, concepts, procedures, and the relationships among them; knowledge of the ways that mathematical ideas can be represented; and knowledge of mathematics as a discipline” (2001, p.371). These lecturers responses also agree to Chinnapen’s (2003, p.1) view to content knowledge when he stated that content knowledge refers to the knowing about a subject, the disciplinary knowledge of a subject.

When content knowledge is looked at in quantitative terms then both the lecturers are adequately qualified to teach the course. When asked: “What educational courses or training have you taken or received to teach Calculus?” Lecturer 1 explained:

For this topic is part of the first year, university undergraduate at the B.Sc. level. You do calculus, a whole course in calculus, and then later on you actually study advanced topics in calculus at a higher level like in Measure Theory and Real Analysis.

Lecturer 2 on the other hand refers to the methodology of teaching and comments:
I’m sure we must have done methods in teaching maths at university.

Lecturer 1 also believed that his content knowledge was adequate to teach the particular course since his content knowledge of calculus far exceeded that which he had to teach since Measure Theory is a study of various types of integrals other than those dealing with Riemann Sums. This idea is supported by Long (2003) and Hilton (as cited in Long, 2003) who argued that it was beneficial and advantageous for the teacher to know content that extended beyond the curriculum in order to answer pupils queries. Lecturer 1 had studied calculus up to the honours level and this was reflected by the following comment:

I would say yes because, as I mentioned, the depth of the calculus course. Calculus is not just plain first year differential and integral calculus one sees in textbooks at the classical course given to first year students. In fact calculus has been studied much deeper. As I mentioned if you look at it from an analytical point of view in where you do real analysis in second year and third year courses, where you really have to look at calculus at an advanced level.

This response alludes to the depth of subject matter knowledge that lecturer 1 has on this particular topic. This depth of knowledge contributes to the high level of conceptual thinking experienced by students. The need for in-depth content knowledge “for teaching is of primary importance, for without this, teachers would not be able to engage their learners in high-level conceptual thinking” (Adler et al, p.136).

Lecturer 2 on the other hand did not specialize in calculus, but nevertheless she also believed that her content knowledge was adequate to teach the course.

That class that I was teaching calculus I just went in for a few weeks as part of the project. I didn’t have any hesitation in managing because I knew I would know the calculus, except that I haven’t taught it for a while. No I don’t have any problems in maths with content knowledge.

Also from the observation of their lessons it was quite evident that both lecturer 1 and lecturer 2 were quite comfortable to teach calculus to their classes. They could answer student’s queries and questions adequately. They were also able to guide students’ thinking to bring
them to the correct answer. To demonstrate this reference is made to the activity sheet ‘Key Task 1: Tasks: number 1 (see appendix C). The exchange between lecturer 1 and a student exemplifies this point:

Lecturer 1: Oh, right, so what is your answer then to this question? (referring to question 1). Would you say that the statement is always true, never true or sometimes true? So you say it’s always true. So what do you mean by always true? What is always true?

Student: We said it’s always true according to this function.

Lecturer 1: Very good. He says that according to this function it’s always true.

Student: Ya.

Lecturer 1: So, can there be another graph? There can be another graph.

Student: Yes.

Lecturer 1: For which this will be true?

Student: No it’s not true.

Lecturer 1: So it might not be true. So what will be our choice among our three options? In this way the student arrived at the correct answer. This exchange is also a good example of the scaffolding process. There was an immediate availability of help to the student from lecturer 1. Lecturer 1 also redirected the student’s thought processes to bring him to the correct solution.

In order to keep his knowledge of calculus current and updated Lecturer 1 attends conferences, presents research papers, analyses students’ work and also reads current literature on the topic.

Just to highlight, here’s one copy of a paper I just printed by another academic (points to a research paper on his desk), and I will read this paper obviously and see how this topic is being taught internationally and what successes they have gained so I can implement similar strategies in my teaching.

Lecturer 2 on the other hand had to prepare for the calculus classes as she had not taught this topic recently.

When I was asked to teach that course I looked at three textbooks, I went over them properly. I looked at Dr. X’s notes, I worked out every possible question before I taught.

Participants’ views on classroom practice
“The type of classroom climate generally considered to best facilitate pupil learning is one that is described as being purposeful, task-orientated, relaxed, warm, supportive and has a sense of order” (Kyriacou, 1991, p.65). This was evident from my observation of the lessons and also the activity sheets that the students were provided with. There was an atmosphere of
purpose that pervaded the lecture room. The activity sheets provided the questions that the students were purposefully engaged with. The students were actively working on the solutions to the problems that they were given. The activity sheets also orientated the students to the tasks at hand. The students were also relaxed as they worked in groups that they had formed on their own, yet order prevailed. Both lecturer 1 and lecturer 2 have warm personalities and interacted with the students in a congenial manner. Students were encouraged and assisted where necessary.

Lecturer 1 generally introduces a new topic with a problem or mathematical task.

At the commencement of the lecture I always present them maybe a small mathematical task that they have not done before but they have some idea about how to get along, but they probably would not solve it. But the whole intention would be to say at the end of the lecture is that they can now solve the problem. I don’t know if I’m clear. Ya, a simple example I could give you, for example in the grade eleven class, the child can solve the trinomial using the factor method. So after you do the factor method you will probably throw one that does not factorize, so that at the end of the lesson he will learn how to use the quadratic formula, so at the end of the lesson he has now learned a new technique.

From the video recording it was observed that lecturer 1 demonstrate this. One group of students, when working with question 1 from “getting started” (see appendix C) indicated that they had failed to solve the problem. Lecturer 1 then asked them to explain geometrically what the derivative meant. After a discussion with the students he then asked them to evaluate f(-3) and told them that they should now be able to apply themselves and solve the task.

This relates to Shulman’s ideas on classroom practice and he states that “teaching necessarily begins with a teacher’s understanding of what is to be learned and how it is to be taught” (Shulman, 1987, p.7). Shulman believes that teachers know something that is not understood by others and that they can transform their understanding “into pedagogical representations and actions. These are ways of talking, showing, enacting, or otherwise representing ideas so that the unknowing can come to know, those without understanding can comprehend and discern, and the unskilled can become adept” (Ibid, p.7).

Lecturer 2 would either use a problem to start a new topic or the students would be expected to read their notes, which are given to them before the lesson, in order to prepare for the lesson.

Well if possible I give them a problem to work out beforehand otherwise they always have notes beforehand, they have a breakdown of what’s going to happen. When the maths is quite complicated it really helps if they read beforehand so it helps if they have some sort of idea of some of the new terms.

This was evident in the video recordings where both the lessons began with the students working out problems that they were given in advance to prepare for the lessons.

The activities that lecturer 1 engaged his students in would depend on the topic that he was teaching. In this case since the topic under discussion was ‘calculus for teaching’ the activities that the students were engaged in are reflected in the activity sheets (refer to appendix F).
These activities included questions on gradients, derivatives and tangents, all of which are relevant to the teaching of calculus.

*It would all depend on the situation. On what I wanted to teach within the topic. For instance if I wanted to teach, for example, the derivative concept via first principles, the student has got no notion of the definition at that stage. So from the average gradient I would now lead on to speaking about the approach of one point to another in the classical way where you arrive at the gradient of the tangent at a particular instance on the graph. So what I’m saying is the particular, the concept that I put across determines the activities that I design so as to gain students’ understanding of the concept.*

Lecturer 2 is approaches her teaching in the following manner:

*I will, firstly if I am teaching a course I will look at what I’m supposed to teach. I design the course outlines if I’m teaching it for the first time. Then I go through everything. I work through every possible problem in that text book. Then I’ll go find other books and look at how they approach it.*

Lecturer 1 allows students to discover skills and also lectures in the classical style depending on the context of the learning situation.

*I would say yes, both skills and conceptual understanding…and skills yes. Many of these skills are not self discovered, they are taught to students in a lecture style.*

This was observed in the video recording. This lecturer always provided clues that could (in his mind) assist students in succeeding in the task. He did not provide them with answers.

Lecturer 2 on the other hand

*If I need them to understand something I try to find a motivating question. It could be a maths question, it doesn’t have to be a concrete activity, that will make them think about the need for what I’m going to introduce. Or I present them this whole big idea to them and show them how this little thing fits*

**The link between content knowledge and classroom practice**

In terms of the link between content knowledge of calculus and classroom practice lecturer 1 believed that there was definitely a strong link between content knowledge and classroom practice. He elaborated:

*To me I feel there is a very strong link between my content knowledge and the way I teach. I am able to emphasize on particular aspects of the content*  
Kilpatrick et al (2001, p.372) also argued that the teachers’ content knowledge is important for effective teaching. They argued that the teachers’ content knowledge is important in the development of the students’ proficiency and ability in mathematics.

Lecturer 2 also supported this notion:

*A deeper knowledge of calculus… affects how you teach because the deeper your knowledge is, you have a bigger repertoire of examples to draw upon and you can readily come up with counter examples in order to help learners to see conditions when theorems hold and or*
conditions when rules hold. You are able to, without any problem, come up with relevant examples.

These sentiments expressed by lecturer 2 are supported by Ball and Bass who argued that “knowing content is also crucial to being inventive in creating worthwhile opportunities for learning that takes learners’ experiences, interests, and needs into account” (2000, p.86). Even also endorsed these views when she stated that “acquiring the basic repertoire gives insights into and a deeper understanding of general and more complicated knowledge” (1990, p.525).

In general both lecturer 1 and lecturer 2 saw a link between content knowledge and classroom practice. Lecturer 1 believed:

Certainly there is…my classroom practice, the approach that I use is one that can forsee solutions based on the content knowledge, in other words, the classroom practice, the approach that I use is dictated by content knowledge. I have a whole global picture of where I’m going.

Lecturer 2 added a further dimension:

I don’t think you got a one to one relationship, but definitely a deeper content knowledge results in better classroom practice…it is necessary. To have good classroom practice it is necessary to have good content knowledge but not sufficient.

In terms of her classroom practice lecturer 2 was able to respond to students’ queries on several occasions. The one instance was when she explained the link between the gradient of f(x) with f (x) = g(x) in question 2 of getting started (see appendix C).

Conclusion

Content knowledge is one component of the knowledge that a teacher requires in order to deliver in the classroom context. It is however a very important and crucial component. There has been a lot of research done on this topic, and there is still research being done on this topic currently. Content knowledge is therefore a dynamic field of research. This is echoed by Adler et al who believe that “a great deal of work lies ahead in tackling challenges related to the nature and place of subject knowledge in teacher education” (2002, p.136).

This small-scale study involved two university lecturers and investigated their perception of content knowledge in the context of teaching calculus to an undergraduate second year class. This chapter presents the summary of the findings in the context of the three critical questions raised in chapter one. It also identifies the strengths and limitations of this research and provides issues for further consideration and exploration by other researchers and policy makers.

While researching and reading information on this research topic, there were other topics and subjects encountered, which did not pertain directly to my research topic, but which could be pursued further. Time and the length of this research did not permit me to follow these avenues. Some of these topics were:
(a) teachers’ attitudes towards mathematics- Clemens (as cited in Kennedy, 1997, p.11) argued that even if the mathematics teacher had an acceptable understanding of the nature of knowledge required in his subject, he still needed to have an acceptable attitude towards his
subject. This attitude should be demonstrated by an inquiring mind, an openness to new ideas and concepts and a scepticism that characterises mathematics.

(b) the link between pedagogical knowledge, conceptual knowledge and pedagogical content knowledge and classroom practice. In my research I did look at these other types of knowledge that a teacher requires, but my focus was on content knowledge. There is a lot of information available on the other types of knowledge that a teacher requires for effective classroom practice, however time constraints did not allow me to pursue these other avenues.

The findings of this study has shown that the depth of content knowledge determine the strength of the activities designed for teaching. Kazima and Adler (2006) state that mathematical knowledge for teaching involves the restructuring of knowledge to make it accessible to learners. Much more research is therefore needed on a range of classroom contexts. Also researchers have not yet reached consensus on what exactly comprises mathematical knowledge for teaching and this is therefore something that could be pursued further.

References
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Appendix A
1. What is it about teaching that you enjoy and why?
2. How would you describe your relationship with your colleagues and what impact does this have on your teaching?
3. Please list your qualifications and teaching experience?
4. What educational courses or training have you taken or received to teach Calculus?
5. Do you feel that your content knowledge of Calculus is adequate for teaching the particular class that you are teaching and why?
6. What other type of knowledge, besides content knowledge, do you need for teaching this topic? Could you please explain.
7. Briefly explain what you do to keep your knowledge of Calculus up to date?
8. In your opinion what are some of the most useful strategies you have learned from any conference, workshop or training on teaching Calculus?
9. How do you decide on what activities to engage your students in?
10. Do the activities that you engage your students in allow for the discovery of skills that they require in calculus?
11. How do you prepare your students to get ready for a lesson you are going to present?
12. Have you received any training either formal or informal to assist you in developing successful relationships with students? If yes, please describe.
13. Was there ever a time in your teaching where you felt that your content knowledge was lacking and how did this affect your teaching?

Appendix B
Interview schedule 2
1. How would you define or describe content knowledge?
2. How would you describe the link between your content knowledge of calculus and how this influences your teaching?
3. In general what do you think is the relationship between content knowledge and classroom practice?

Appendix C
Consider the graph of a linear function f(x) and a curve g(x).
1. a) If point C(6, 8) lies on the graph of \( f(x) \), is the gradient of the line \( \frac{4}{3} \)?

b) Can you use point A only to find the gradient of the line \( y = f(x) \)? Explain.

c) Use points A and B to find the gradient of the linear function, and show your workings.

d) Move point B to the right of A and then to the left of A, so that the gradient of the line AB is still the same as it is now.

e) If we keep point A as it is, explain how you could move point B so that

i) the line AB is steeper than it is now

ii) the line AB is less steep than it is now

iii) the line AB has a negative gradient

iv) the y-value of the linear function increases three times as fast as the x-value

v) the y-value of the linear function decreases twice as fast as the x-value

f) Use the gradient of the line to find \( p \) if the point \((12, p)\) lies on the graph of \( f(x) \).

2. Answer these questions for the graphs of \( f \) and \( g \) given above.

a) On the graphs, show these calculations:

i) \( f(5) - f(2) \)

ii) \( \frac{f(5) - f(2)}{5 - 2} \)

iii) \( g(3) - g(1) \)

b) Which is greater: \( f(5) - f(2) \) or \( g(5) - g(2) \)?

c) State whether each of the following is true or false, and explain your answers.

i) \( g(3) - g(7) > 0 \)

ii) \( f(b) - g(a) = 2 \)

iii) \( g(5) - g(7) = \frac{\Delta y}{\Delta x} \)

d) Find two points (a, \( g(a) \)) and (b, \( g(b) \)) so that

i) \( \frac{g(b) - g(a)}{b - a} = 3 \)

ii) \( \frac{g(b) - g(a)}{b - a} = \frac{f(b) - f(a)}{b - a} \)

iii) \( \frac{g(b) - g(a)}{b - a} < 0 \).

e) Find value(s) for \( a \) (where possible) so that

i) \( \frac{g(2) - g(a)}{2 - a} > 0 \)

ii) \( \frac{g(2) - g(a)}{2 - a} = 0 \)

iii) \( \frac{f(3) - f(a)}{3 - a} = 1 \)

f) On the given axes above, draw a linear function \( y = h(x) \) so that \( \frac{h(b) - h(a)}{b - a} = -\frac{3}{2} \).

3. Use the given graphs of \( f(x) \) and \( g(x) \) to answer these questions.

a) Complete (and explain your answer): \( f'(x) = \ldots \).

b) Draw a tangent line to show \( g'(2) \).

c) Find \( a \) so that \( g'(a) = 1 \).

d) Write in order from smallest to largest value: \( g'(2) \), \( g'(4) \), \( g'(5) \).

e) For what value(s) of \( x \) is \( g'(x) > f'(x) \)?

f) For what value(s) of \( x \) is \( g'(x) = 0 \)?

g) Fill in < or >:

i) \( g'(2) \ldots g(2) \)

ii) \( g'(2) \ldots f'(2) \)

iii) \( g(4) \ldots f'(3) \)

h) Find (where possible) values for \( a \) and \( b \) so that

i) \( \frac{g(b) - g(a)}{b - a} = g'(2) \)

ii) \( \frac{g(b) - g(a)}{b - a} = f'(2) \)

iii) \( \frac{g(3) - g(a)}{3 - a} = g'(3) \)

iv) \( \frac{f(3) - f(a)}{3 - a} = g'(2) \)

v) \( g'(a) = f'(a) \)

vi) \( g'(a) > f'(a) \)

vii) \( f'(b) \geq f'(b) \)
Consolidation
Write a short summary about the average gradient between two points on a graph, and the gradient of a graph at one point. Use a graph as part of your explanation, and use correct notation.

Assessment
1. The diagram shows two parallel tangents to the graph of \( f \). The equation of the tangent line at the point \((3, f(3))\) is \( y = 3x - 4 \).
   a) Find \( f(3) \), \( f'(3) \) and \( f'(-1) \).
   b) Find the equation of the parallel tangent through the point \((-1, 2)\).
   c) Find (where possible) values for \( a \) so that:
      i) \( \frac{g(4) - g(a)}{4 - a} = f'(3) \)
      ii) \( \frac{g(4) - g(a)}{4 - a} = 0 \)
      iii) \( f'(a) = -1 \)

2. a) Sketch the graph of the function \( f(x) = 5 \), and hence find \( f'(-1) \).
   b) If \( f(x) = 5x \), use a graph to explain why \( f'(-1) = f'(3) = 5 \). What is \( f'(x) \)?

3. Sketch a possible graph of \( f \) for \( x \) between 0 and 4, if \( f(3) = f(1) = 2 \), \( f'(3) > 0 \)
   and \( f'(1) < 0 \).
   State if each of the following is possible for your graph, giving reasons.
   a) \( f'(c) = 0 \) for \( 1 < c < 3 \)
   b) \( f(2) < 0 \)
   c) \( f(2) > 0 \)
   d) \( f'(3) = -f'(1) \)

4. The point \( A(3, -1) \) lies on the graph of \( g \), and \( g'(3) > 0 \).
   a) Use a graph to show the calculation \( \frac{g(b) + 1}{b - 3} \).
   b) Find the coordinates of a point \( B(b, f(b)) \) so that \( \frac{g(b) + 1}{b - 3} > 0 \).

Solving word problems in a multilingual class

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Abstract

This paper reports on collaborative learning in dealing with word problems that focus on fractions by Grade 8 mathematics learners. For the purposes of this study, the Grade 8 learners were divided into two groups. One group of learners worked collaboratively while learners making the second group worked independently. The participants were 16 girls and 35 boys with ages ranging between 13 years to 16 years (\( M = 13.92; \ SD = 1.97 \)). All learners were from a South African co-educational high school in the province of KwaZulu-Natal. In
the school, classrooms are characterised by multilingual learners coming from varying socio-economic backgrounds. The study was qualitative involving lesson observations, analysis of learner worksheets, questionnaires and interviews. Learners had two tasks to attend to, one on decimal fractions and another on common fractions. The results confirmed assumptions and literature claims. Interesting observations that could have pedagogical implications are denoted.

Key Words: Multilingualism, problem solving, fractions, collaborative learning.

Motivation for the study
South African learners have difficulty grasping key mathematical concepts. This was illustrated in the TIMMS 2003 report, where it was suggested that ninety percent of South African learners do not possess a basic mathematical knowledge as opposed to the international average of less than thirty percent. Only 0.3 percent of grade 8 learners in South Africa could be classified as being able to solve non-routine problems (Reddy, 2006). A major concern in South Africa is that learners will not be competent enough in mathematics to advance to tertiary institutions and pursue careers in the science and technology fields. To ensure a better economy in South Africa, a dramatic improvement must occur in the teaching of mathematics and more specifically, in the development of problem solving skills at school level. Recent studies demonstrate the importance of word problems in school curriculum to develop students’ understanding of how to apply calculation strategies to real-world problems (Ferrucci, et al., 2001).

The lack of problem solving skills in South Africa may perhaps be a result of the way it has been taught in schools. In the past, problem solving tasks were solved individually by learners. Problems presented to learners are frequently abstract and foreign to them, therefore they generally acquire a dislike to problem solving tasks, believing they will be too difficult to solve. This is especially true for learners who are not achievers at mathematics (Barns, 2005) or low attainers, as they are referred to in this paper. We decided therefore to gauge whether learners would achieve success in a group environment. In this regard we raised the following question:

How can problem solving of word problems in a multilingual mathematics class be improved? In this light we facilitated tasks in problem solving in a collaborative manner.

Relevance of study to the South African context
In the past ten years, not many papers reporting on learning in a multilingual classroom have been published locally (Adler, 2001, Botes 2008), Setati & Barwell, 2008,). Brijlall (2008), offered as part of this study, suggestions for further research. In this paper, revisions to these findings and implications for further research are made. We therefore decided to investigate the learning of mathematics by learners whose first language is not necessarily English. In order to encourage mathematical problem solving, we allowed learners to discuss the understanding and solution of the word problems (presented in English) in the language the learner was comfortable with. The basis for this was a report by Dlamini (2008) that second language English learners obtained exceptional results in mathematics but performed poorly in English. We therefore in our investigation motivated us to let learners engage the solution of the problems in their indigenous languages.

Since the teacher is seen as a source of knowledge, learners constantly seek their advice and avoid tackling the problem amongst themselves. For true problem solving skills to develop,
learners need to work independently as well as interdependently with classmates. Problem solving and working together in groups are part of the critical outcomes in the Revised National Curriculum Statement (RNCS) for mathematics grades 1-9 (Department of Education, 2002). Problem solving is continually mentioned in the learning outcomes. However problem solving skills are considered poor in South Africa (Buffer & Leigh, 2005; Arora, 2003). If the approach to problem solving was modified and made less daunting to learners, a change in their attitude towards mathematics in general and more specifically towards problem solving may be achieved.

**Multilingualism**
The diverse nature of multilingualism around the world is reflected in the wide range of multilingual classrooms in which mathematics is taught (Barwell, 2005). We see a classroom as being multilingual if any of the participants (learners or teachers) is potentially able to draw on more than one language as they go through their work. This paper adopts this definition when it refers to a multilingual environment. In essence this refers to classrooms in which learners speaking different languages engage in problem solving activities. Specifically in South Africa learners draw from languages such as English, Afrikaans, isiZulu, Sotho and Swati.

**Realistic mathematics education and real world problems**
Realistic Mathematics Education (RME) is a theory designed by the Hungarian Hans Freudenthal (Barns, 2005). He considered mathematics to be a human activity and thus believed that to learn mathematics one had to do mathematics. It focuses, as Barns (2005) points out, on the need to use learner’s everyday experiences in order for them to unfold mathematics by themselves and that mathematics is rather not a ‘ready-made system with general applicability’ (p. 50). It may be observed that RME articulates with the RNCS which calls for teaching to more learner centred. The RNCS also stresses the importance of interaction between learners. RME allows for such interaction as real world problems are normally solved in a group environment, where all participants work together to solve the problem at hand, rather than solving it individually. This study allowed for problem solving on an individual basis to provide a control mechanism to retain the advantage of a quasi-experimental design. This paper focuses on the rational number system. As The National Research Council (2001), in the USA, notes many learners find the rational number system difficult.

The direct connection between classroom mathematics and real-world mathematics is a tenuous one, because it is often difficult to relate classroom activities to the real world, (Mudaly, 2004). He emphasises that if the word “real” in this instance is not only interpreted as a connection to the real-world, but as a reference to the problem situations which appear real in the learner’s minds, then the relationship between real-world and classroom mathematics become a bearable one. This was kept in mind in the choice of the two word problems which the learners engaged with in this study.

**Problem solving**
Questions used in problem solving tasks must be familiar to the learner. The context of the question must be a reflection of the learners’ socio-economic background in order to make it ‘realistic’ to their personal experience. As Cooper & Dunne (2004) suggest, working-class learners do not experience the same background as middle-class learners, hence will not find the same questions ‘realistic’. By realistic it is meant that the mathematical task has been
designed within a context the learner is familiar with. This is also true regarding learner’s gender, home language and cultural grouping. As a result learners’ mathematical abilities may well be underestimated when related to the context in which the question is asked. For this reason two problem tasks used in the study were related to the learners’ personal knowledge and background. Learners were allowed to query the meanings of words used in the problem statement. They were also allowed to discuss these meanings in their home language when sitting with colleagues who had a similar home language.

The rational number system is represented in a number of ways. The study focused on common fractions and decimal fractions. The National Research Council (2001) believes that the informal knowledge learners possess in ‘sharing and measuring’ is the foundation that rational numbers can be built upon. The National Research Council (2001) also notes that children struggle to link different forms of rational numbers as they battle to see how they are related. The National Research Council (2001) suggested that for effective teaching to take place it would depend on how cognitively demanding the given tasks were. Mathematics should be elaborated through tasks and sufficient time must be allocated to master each task. Learners must also be given the opportunity to link their informal knowledge with the abstract knowledge of mathematics. The National Research Council (2001) believes that there are five strands of mathematical proficiency, namely: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning and productive disposition. Different strategies have been suggested to attempt improving mathematics, one such strategy is collaborative learning (National Research Council, 2001).

Methodology
A qualitative research approach was employed in this research. This was achieved through the collection of data via a) observation of a lesson, b) analysis of learners’ worksheets, c) questionnaires and d) interviews of participants. The selected participants consisted of two grade 8 mathematics classes at a high school in Pietermaritzburg, South Africa. This school is a co-educational, with multilingual classrooms and mixed socio-economic backgrounds. The participants have a mixed ability in mathematics. The participants were 16 girls and 35 boys with ages ranging between 13 years to 16 years (M =13,92; SD = 1,97). Learners were divided into two groups, the control group and the experimental group. The learners in the two classes were ranked in descending order of their average mathematics marks for the first two terms. Every second learner was placed in the experimental group while the remaining learners were placed in the control group. This was to ensure learners with the same academic levels were present in both the control group and experimental group. The control group was given the activity to complete individually. This group completed the activity at the same time as the experimental group and was therefore supervised by a different teacher to that of the experimental group. The experimental group was further divided into seven groups of four and the control group comprised twenty three. Learners were arranged in groups ensuring that the members in each group had an array of mathematical abilities (based on their previous performance). The researcher observed the experimental group.

Problem solving worksheets were used to gather information. The worksheets formed the foundation of the qualitative study and comprised of two tasks: one involved decimal fractions, the other common fractions. Both tasks demanded problem solving skills and both experimental and control groups confronted these problems. In the experimental group learners were asked to initially complete the worksheet on their own and then they were placed in groups where a discussion was held amongst the group members. This was to
promote participation by learners when working in a group. At the end of the discussion, each group was asked to complete a worksheet that expressed the joint views of the group. A fifty minute lesson was provided for learners to solve the problem.

Eight learners were selected to be interviewed. We found it difficult to interview all group members and interviewed four representatives from the experimental group and four from the control group. The representatives from the groups were chosen by the members of the particular groups. The learners belonging to the control group worked individually. One learner was selected from each group to present the responses of his/her group. The linkage was done by choosing the control group interviewees with similar mathematical performance as their counterparts from the experimental groups. The interview was conducted in an informal manner to clarify answers given by learners in the worksheet. The interview focused on the learners understanding of the questions and their personal experience of either working individually or as part of a group. Learners were also asked to comment on how the lesson may have been improved.

Diversity of learners
Fifty one learners completed the questionnaires. The diversity of learners is discussed under the following headings: (1) age, (2) gender, (3) home language, (4) mother tongue language, (5) medium of instruction and (6) racial group. There was an overlap, in general, between the mother tongue and the race of the learners. We regarded home language as the most used language when communicating at home. This to us might be different from the mother tongue which we adopt to refer to language associated to the individual via past generations. For example one child in class was Hindi speaking (as mother tongue) but English speaking (as home language).

Age

<table>
<thead>
<tr>
<th>13 years</th>
<th>14 years</th>
<th>15 years</th>
<th>16 years</th>
<th>No Answer</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>34</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>51</td>
</tr>
</tbody>
</table>

Table 1: Age of learners

The age of the learners ranged from thirteen years to sixteen years old. Two thirds of the learners were fourteen years. Thirteen and fourteen year old learners comprised 86 percent of the participants.

Gender
Sixty nine percent of learners were male and thirty one percent females.

Home language

<table>
<thead>
<tr>
<th>Afrikaans</th>
<th>English</th>
<th>isiZulu</th>
<th>Other</th>
<th>More than 1 response</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17</td>
<td>30</td>
<td>6</td>
<td>3</td>
<td>54 – 3 = 51</td>
</tr>
</tbody>
</table>

Table 2: Home language of learners

Learners were asked to indicate their home language. Home language is the preferred language in which the learners communicate at home. As indicated by table 2 isiZulu is the
dominant language with 58 percent of learners communicating in isiZulu. One learner indicated Afrikaans as home language. English was spoken by only 33 percent of learners. Six learners indicated they spoke a language which was not listed in the questionnaire. These languages were Xhosa (four), Sesotho (one), Sotho (one) and Swati (one). Three learners indicated more than one home language. This demonstrates the diversity of home languages spoken by the learners with the most speaking isiZulu.

<table>
<thead>
<tr>
<th>Mother tongue language</th>
<th>Afrikaans</th>
<th>English</th>
<th>isiZulu</th>
<th>Other</th>
<th>More than 1 response</th>
<th>No Answer</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>14</td>
<td>28</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>52</td>
</tr>
</tbody>
</table>

Table 3: Mother tongue language of learners

Under the category mother tongue, learners were asked to indicate the language that they most identify with. The majority of learners identified with isiZulu although the number decreased slightly compared to home language. English also decreased from 33 percent to 27 percent. One learner did not indicate an answer and one learner indicated two languages. Seven learners selected the category ‘other’. The languages not indicated on the questionnaire and that were mentioned by learners were: Xhosa (four), Sisuthu (one), Sesotho (one) and Swati (one).

Language of Education
All learners indicated that they are educated in English (meaning being taught in the medium of English). Four learners indicated that they had been educated in two languages. The languages they indicated referred to their first additional language. What should be noted is that all learners were taught in English while only twenty-seven percent of learners indicated their mother tongue language as English and only thirty-three percent of learners indicated English as their home language. This means that the majority of learners taking part in the study were second language English speakers.

<table>
<thead>
<tr>
<th>Racial Group</th>
<th>Black</th>
<th>White</th>
<th>Coloured</th>
<th>Indian</th>
<th>Other</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>8</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>51</td>
</tr>
</tbody>
</table>

Table 4: The racial grouping of learners

Table 4 depicts that a variety of racial groups were represented by the learners who participated in the research. One learner selected other and indicated he was Muslim. Two thirds of learners were black, while the other third comprised of white, coloured, Indian and Muslim learners.

The questionnaire showed that all participants received their education in English. This is in contrast to most learners’ mother tongue and home language as the questionnaire reveals that most learners’ home and mother tongue language is isiZulu. Most participants were black males. The questionnaire does however show a diverse multicultural sample group.
Collaborative learning versus individual attempt
For analysis purposes only those seven learners from the control group who were linked to the seven group representatives from the experimental group were used in the comparison. To obtain anonymity and distinguish between learners, the following codes were used. When referring to the group leaders, a ‘G’ is used as opposed to individual learners where an ‘I’ was used. A number was also shown to illustrate the group in which the learners were from or the corresponding individual learner. For example group leader 3 was coded as G3 and individual learner who was linked to group 2 was denoted as I2. G2.2 belonged to group 2 but was not the leader. The data collected from individual learners and the groups of learners was compared and analysed under the following sub-headings: (1) results from problem task 1, (2) results from problem task 2.

Results from problem task 1
The first problem task given to learners was:

A large piece of cardboard paper is 0.01mm thick. It is cut in half and one piece is placed on the other to make a pile. These are cut in half and all four pieces are placed in a pile. These four are cut in half and placed in a pile, and the process is continued. After the pieces have been cut and piled for the tenth time, what is the height of the pile in cm.

The data collected from question one was separated into categories to make it easier to compare. The categories used were: (A) mathematically sound calculation with an accurate answer, (B) accurate answer with no calculation shown, (C) correct solution with incorrect conversion, (D) partially correct solution with calculation shown, (E) no understanding of the question, (F) Incorrect answer with no calculation shown and (G) no answer shown. Learners who obtained the correct answer and displayed a mathematically sound argument including a correct conversion fell into category ‘A’. Category ‘B’ was selected if a learner achieved the right answer but failed to show a method as it is unclear if the learner had a mathematically sound methodology. If a learner was able to achieve a mathematically sound answer before the conversion, and proceeded to either not convert or convert incorrectly, they were placed in group ‘C’. A learner who had an incorrect answer but had initially shown correct methodology was placed in Category ‘D’. Learners were placed in group ‘E’ if their method of solving the problem had no link to the question and hence showed the learner did not have a clear understanding of the question. If only an incorrect answer was shown, they were placed in category ‘F’. If the question was left blank, it was placed in category ‘G’.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>GROUP</td>
<td>2</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>INDIVIDUAL</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5: Categorising learners results for question 1

Table 5 shows the mode (as this displays the high frequency occurrence) of the different categories for both the group leaders and the individual learners. Neither the individual attempts nor the group attempts were left blank. No learner that completed the task individually was able to solve the first problem task. This is in contrast to the seven groups who were all able to solve the first problem before converting to centimetres while two of these groups converted it successfully. Six out of the seven groups were able to give a
mathematically sound explanation for the first question whereas this was not true for individual learners. Most of the individual learners had partially correct answers. By this it is meant that learners had begun answering the question in a mathematically sound manner but had either not completed the task or alternatively had then proceeded with an incorrect procedure. Most learners categorised as ‘D’ had an answer such as learner I4 ‘we said that the thickness of the paper is 0.01 millimetres thick, we timed that by 10 papers which was equal to 0.1’. Here the misconception was that as the paper was folded ten times, the thickness would be equivalent to ten layers of paper. Learners obtaining such an answer did not consider the number of layers increased in each time the paper was divided in half. Most groups had a similar answer to that of learner G3:

‘we changed 0.01mm into cm so it was 0.001. So each time you fold the paper you times by two because it’s two halves. So we times 0.001 by 2 and it becomes 0.002. So if you take the 0.002 and fold it again and you take the answer from the previous answer and times it by two, and then the answer of that you timed it by two until you get to the end. Which the answer is 1.0243cm’

The learner converted to centimetres successfully. A correct understanding of the question was shown by the group as they realized that each time the paper was folded, double the previous answer was obtained. Learners used different methods to solve the problem. G6 said a member of his group had actually done the problem in real life. Diagrams and drawing were used by some learners as confirmed by G2 ‘yes using diagrams actually helps. I never thought so before’.

Group 2 and I2’s calculation of problem task 1 is shown below. As can be seen Group 2’s calculation has been done in logical steps whereas I2’s calculation is not as clear. There is no connection made between his first and second line.

Below, figure 1 and 2 show the calculations of group 2 and individual learner two.

![Figure 1: Group 2’s calculation of Problem task 1](image-url)
Figure 2: Individual learner 2’s calculation of Problem task 1

Group 2 multiplied the answer by two each time for ten times. However their conversion to centimetres was incorrect. Their conversion illustrates a belief that centimetres are smaller than millimetres. I2’s calculation shows that to achieve the answer he multiplied by 10, corresponding to the second line of his calculation. However this does not explain his first line. He initially believed that as the paper was being divided by two so to must the answer.

Figure 3: Group 1’s final answer in problem task 1

Group 1 went a step further in their solution and were able to grasp a connection to exponents. They achieved an answer of $0.01\text{mm} \times 2^{10}$. The group was able to conclude that instead of multiplying ten times by two, one could simply multiply by $2^{10}$. What was also of significance was the fact that this group had three black members who communicated in isiZulu (from observation notes of researcher). So, it seemed that the success of the collaborative work could be due to learners communicating in a common language to create meaning to ideas leading to the solution of the problem.

Results from problem task 2

The following question was given as problem task two:

Four men were shipwrecked on an island. Having no food, they went to work gathering pineapples. After gathering the pineapples, they were tired and all fell asleep. After some time, one of the men woke up and was very hungry so he ate $1/3$ of the pineapples - more than his proper share. He then went back to sleep. The second man awoke and being hungry, ate $1/3$ of the remaining pineapples and went back to sleep. The third man did the same. When the fourth man awoke, he took only his rightful share of the remaining pineapples. Then there were 6 pineapples left. How many pineapples did the men gather?

A similar system that was used in question one was adopted to categorise the data in question two. The categories were: (A) mathematically sound calculation with an accurate answer, (B)
partly correct solution with calculation shown, (C) no understanding of the question, (D) incorrect answer with no solution, and (E) no answer.

Category ‘A’ was selected if both the answer and the calculation were mathematically correct. For category ‘B’, learners did not achieve the correct answer but showed partial understanding in their solution. Where no proper understanding of the question was shown, category ‘C’ was selected. Category ‘D’ was selected only if an incorrect answer was shown. If no answer was present, it fell into category ‘E’. Table 6 illustrates the learners’ results both individually and in groups for the second question.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>GROUP</td>
<td>0</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>INDIVIDUAL</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 6: Categorising learners results from question 2

Neither individual learners nor groups were able to give the correct answer for question two. Two individual learners did not attempt to write an answer and a further individual learner gave only an incorrect answer. All seven groups gave an explanation for their answers, whereas only four individual learners did the same. Most groups had a similar calculation as Group 4,

\[
\begin{align*}
\text{GROUP 4} & \\
\frac{2}{3} \times 6 & = 4 \\
\frac{18}{3} & = 6 \\
\frac{54}{3} & = 18 \\
\frac{162}{3} & = 54 \\
\end{align*}
\]

Figure 4: Group 4’s results for problem task 2.

G4 explains his groups answer:

‘they told us that there were 6 pineapples left and so how many did the man gather? So I started with the 6 and I divided it by 3 because the first guy ate, I mean I divided it by 1/3 because the first guy ate a 1/3 and the answer for that was 18. And the second guy ate 1/3 of that. So I divided that by one third which gave me 54 and the other guy, the third guy which gave me 54. And then the other guy, the third guy, he also ate 1/3 so I divide that by1/3, which gave me 54. And then the fourth guy he got 1/4. So after the third guy I got 162 and then the last guy, I get 162 divide by a ¼. So the men gathered 648 pineapples.’

The group identified that three of the four men ate 1/3 of what was left and the final man ate ¼. They failed to comprehend that in order to get the answer, you had to work backwards from 6 and not start at the beginning. I6 realised this as he explains:

‘Well I didn’t finish my one because I didn’t have time. But what I did, I said 1/3 times 6 because there was six remaining right. And then the last guy, I mean not the last guy but the third guy ate 1/3. That’s correct and then I timed that and I got 8 and then I did it again with the same answer and then I timed it by 1/3
As can be seen, I6 worked backwards from the third ‘guy’ to the ‘second guy’. I6 did not include the pineapples the last man ate in his calculation and failed to mention that the he ate \( \frac{1}{4} \) of what was left. No learner acknowledged that the six pineapples was equal to three quarters and that one needed to find out that one quarter was equal to two pineapples.

Even though the group answers were incorrect, they were better reasoned over the individual learners’ answers. The group’s answers had detailed explanations. This shows that learners had at least attempted to answer the question in their groups. The groups also spent much longer on the two questions as apposed to the individual learners. Individual learners were inclined to read though the question, attempt one answer and leave the question as they thought it was too difficult. Two individual learners received help from each other even though they were instructed not to. As was observed the groups approach to the question was different. At least one member from each group had an initial answer for question two. However, as each learner attempted to explain their answer to the group they would realise that their answer was wrong and would try solving the problem once again. This was particularly evident in group 1 where learners kept arguing with each other.

**Participation in groups**
Initially the learners who worked in groups were extremely teacher dependant. They repeatedly asked the teacher for help. This occurred more frequently with second language English speaking learners. When learners were placed in groups, they became less dependent on the instructor and they communicated in the language they were comfortable with. In many instances, the researcher observed that members in a multilingual group switched between languages when communicating with different members within the group. However not all learners worked effectively in the group environment. Some learners complained of others who, even though present, did not take part in the group discussion. As G2 recalls:

> ‘I remember one person in my group and I don’t remember them giving any ideas. It’s just sometimes when you are working they think, okay I don’t understand and I’m just going to sit down and get the answers.’

This same sentiment was echoed by other learners who were unhappy working in groups. It was observed that mainly the low attaining learners did not participate in group discussions. When asked why, they responded that they either could not contribute to the discussion as they did not know what was going on, or they said that the other members in the group were not including them in the discussion and as a result they could not follow the debate. This would agree with learner G2 who suggested that if learners do not understand the work they do not participate in it. After the researcher explained to learners that to complete the task all members must participate, the low attaining learners still seemed to hold back and listen rather than engaging in the discussion. However towards the end of the lesson, it was observed that in some circumstances the low attaining learners did contribute to their group’s discussion and were able to explain their group’s answers. Learning is evident as in one particular case; a learner was troubled as he was not able to grasp the question. The learner’s group proceeded to explain the question to him. Once he understood it, he was able to contribute to the discussion and became one of the main candidates that solved the problem.
Researcher: I told you that you had to try solve [the question] first on your own. How did you find, or feel trying to solve it on your own first?

G2: I just thought that this was too hard for me

Researcher: Really?

G2: Yes mam.

Researcher: And when you got into a group?

G3: I saw that it was getting easier and I saw that I understood. And I realised that the only reason I thought it was hard was because I didn’t understand.

G2 realised that not understanding what the question asked hindered his problem solving skills. I6, who completed the task individually, initially expressed he preferred working on his own but later he to changed his mind and felt that working in pairs would have been more beneficial. I3 repeatedly uttered throughout the interview that he ‘would have loved to be in a group’. The problem he felt with working individually was that he ‘couldn’t ask anyone for help’. I3 had partially answered the first question and had not attempted to answer the second one.

Composition of groups
Dissatisfaction was raised concerning group members who did not participate in their group discussion. A learner from group 4 was in a different class to those in his group and hence did not know any group members. He was not friendly towards the members in his group even though they tried to include him and he did not participate in the group discussion. G4 commented that ‘he totally ignored [the group] and did the whole thing by himself’. G4 also acknowledged that he received help from members of other groups, as his group had not functioned at all. In the interviews it was confirmed that learners found it difficult working in groups with people they did not know, as G2.2 comments ‘you might not even know that person but it will be hard just to come and talk to them and be friends with them’ and as G2 commented ‘if I start talking to a stranger its all awkward and tense’. This suggested that learners feel more comfortable in groups where they are familiar with each other. Learners may not have the confidence working with the members of the group that they had been placed in, and would have preferred being in different groups.

The above two examples do not reflect badly on collaborative learning as a whole. Learners in groups 1, 2, 5, 6 worked extremely well together. G2 felt that everyone participated and were helpful. He also believed that he ‘wouldn’t have found [the answer] on [his] own.’ Group 1 had two strong willed members who tried to convince each other and the rest of the group that their answer was correct. This is an indication that collaborative learning had taken place as learners were discussing various options and were debating their validity. Also it is possible that such contributions indicate interactions and communication but not necessarily learning. These “strong willed” members might be a disadvantage to collaborative learning as they could convince the quieter peers with the incorrect answer. Hence the facilitator needs to carefully control the activity engagement.
Despite learners dissatisfaction about working in groups, they expressed they do work in informal groups in class. Two learners felt that they did not normally work in groups unless they were unable to understand or complete a problem. At this stage they felt that asking another learner would result in a better understanding and may result in the problem being solved. Collaborative learning did take place in the lesson even though it was not necessarily in the assigned groups. Learners still engaged with each other to find the solution to the problem.

Learners expressed that one of the major problems in the lesson was the dynamics of the group. Most learners believe they achieve a greater knowledge in a group environment as opposed to working individually, but thought that if they were not placed in a good group they would rather work alone. Learners felt that friendship groups would not be the best idea as they would not get any work done. All learners felt that if they were placed in different groups the outcome of the lesson may have been different. Learners felt that making the groups equal with learners possessing similar behavioural problems and academic performance would result in better results.

**Discussion of data**

**Individual problem solving skills versus collaborative learning**

Learners that were placed in groups were found to have a greater ability to solve problems than those that completed the worksheet individually. This would agree with Barkley et al. (2005), and Lyle (1996) who found that learners who worked collaboratively had a greater problem solving ability. Learners working in informal groups felt that it was helpful. Even learners who believed that they did not work in groups acknowledged that they only asked for help when they were not able to achieve the answer on their own. This shows that learners believe that working collaboratively is more successful than working individually when they encounter a difficult problem.

The language of the worksheet was too difficult for learners as they did not initially grasp what the question was asking and hence were not able to solve the problem. The structure of the task is crucial to reduce uncertainty and ensure learners understand what is expected of them (Lyle, 1996). Learners had not been given questions in a similar fashion to this, but had solved problems of a similar nature from their text books. A worksheet however is seen as an important document and not as just another exercise. Learners should be given similar worksheets to obtain more experience of what is expected of them.

**Individual engagement versus collaborative learning**

The data shows that learners working in groups are more relaxed and are able to share valuable information with each other to arrive at the answer which has an advantage over learners who work individually. This does depend on the dynamics of the group. Individual learners were more demanding on the teacher whereas learners working in groups were not as demanding. This would agree with Barkley et al. (2005) who argues that collaborative learning encourages learner centred teaching. Barkley et al further stresses that working in a group can improve the learner holistically. The placement of learners in groups allowed for academically strong learners to help low attaining ones. Both academically strong learners and low attaining ones were advantaged by collaborative learning, as the low attaining learners were able to grasp the meaning of the question, enabling them to contribute towards the group discussion. The academically stronger learners’ would have gained conceptual understanding while explaining the question to low attaining learners, as indicated by Barkley
et al. More research may be done to verify this assumption. Allowing learners to choose their groups may have curbed learners’ anxiety of working with those they do not know. The results show that learners found it difficult working in the groups they had been placed in especially when learners were not familiar to each other. Previously learners worked more effectively in non official groups that they developed on their own. As Lyle (1996) shows, familiarity with each learner in a group influences how the learners will interact, hence learners who are friends work better together.

Botes & Mji (2010) have found that learners performed better in the mathematics class if learners utilise learner companions. This, they found to be true, since the learners would subsequently understand what certain mathematical terms meant in their own language. This concurs with our findings as respondent I3 who said “I would ask again for help” and so a learner companion (in the terminology of Botes & Mji (2010), could simplify the words in the problems engaged.

**Implications for collaborative learning in multilingual classrooms**
The use of two or more languages, usually English and other indigenous languages, has become a frequent observation in multilingual classes in South Africa (Vorster, 2008). The study has shown that collaborative learning (allowing learners to switch between languages) has a significantly greater success rate than individual engagement, although it is advised that further research be conducted to clarify this point. Learners within groups explained mathematical terminology (like the fraction concept) in preferred languages other than English. The role of language for conceptualisation and for mathematical problem solving skills has long been acknowledged in other researches (Genter & Goldin-Meadow, 2003; Pimm, 1987, 1991; Usiskin, 1996; Vygotsky, 1962). This would indicate that mathematical teachers must make use of collaborative learning in the classroom not only specifically for fractions and decimals but for all aspects of mathematics. This study has shown that collaborative learning was a factor which promoted the interaction between low attaining learners and academically stronger learners, which enabled the stronger learners to help the low attaining ones improve their understanding of word problems involving fractions. This invariably gives the teacher more free time to ensure that learning is taking place by ensuring learners are on task and assisting where necessary. Collaborative learning also allowed the lesson word problems involving fractions to be more learner centred in line with the RNCS (Department of Education, 2002). Caution once again must be taken in the placement of learners in groups. A suggested method may include placing learners in the same group for a long period of time to allow learners to gain confidence in their group members.

**Implications for further research**
Further research should be conducted to verify the findings of this study. Other possible research would be:
1. to determine if group dynamics improve problem solving skills,
2. to determine if placement in a group for extended periods of time improves the group dynamics,
3. learners’ difficulties in fractions and decimals and
4. collaborative learning in multilingual classes improves both the low attaining learner and the academically strong learners simultaneously

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**Learning to engage with learners’ mathematical errors: an uneven trajectory**

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This paper presents initial results from a project where mathematics teachers work together in professional learning communities to understand and engage with their learners’ errors. From a social practice perspective, the paper argues that particular kinds of engagement with learner errors on the part of teachers are crucial for giving access to the practice of mathematics. Through analyzing three teaching episodes of one teacher, the paper shows that learning to engage with errors in ways that give access to the practice of mathematics is itself a practice and requires ongoing commitment to the learning, with successes and challenges along the way.

**Introduction**

This paper is part of a larger mathematics teacher development project conducted over the past three years at our University. In the project we have worked with teachers to support them in understanding and engaging with learner errors in the classroom. In this paper, I present an analysis of one teacher’s trajectory in becoming more aware of learner errors, both in his teaching and in his reflection on his teaching with a group of colleagues in the project. I argue that there are subtle shifts in both his practice and his reflections and that attempting an analysis without either of these would be problematic. In particular, the fact that he needs to account for his practices to other teachers fundamentally influences his learning.
I begin the paper with an account of the theoretical framework that informs the project and the importance of errors in this framework. I then review some of the literature on errors, briefly describe the project and the methodology and then present the analysis and main argument of the paper.

**Theoretical framework: the notion of practice**

Social practice theory has been gaining ground over the past twenty years as a way to understand learning both in and out of schools (Lave, 1996; Wenger, 1998). Practices are patterned, coordinated regularities of action directed towards particular goals, and develop knowledge, skills and technologies to achieve the goals (Scribner & Cole, 1981). Practices are always located in historical and social contexts that give structure and meaning to the practice and situate the goals and technologies of the practice. Thus “practice is always social practice” and involve social and power relations among people and interests (Wenger, 1998, p. 47). Learning is central to a practice, because as social goods and goals shift, so do the means to achieve them. According to Wenger (1998) practice entails community, meaning and learning; practices learn and people learn in practice.

There are two key elements in any practice: the criteria for what count as appropriate acts within that practice, and how the community that constitutes the practice defines what counts in the practice and holds people to account to the criteria of the practice. As Ford and Forman argue (2006) “in any academic discipline, the aim of the practice is to build knowledge, in other words, to decide what claims “count” as knowledge, distinguishing them from those that do not” (p.3). The same holds for professional practices such as teaching, which rests on a knowledge base and which is concerned with the enculturation of learners into knowledge-saturated practices (Darling-Hammond, 1989; Shulman, 1987). So practices always have content and are always socially situated. Explicitly articulating what counts as knowledge means that boundaries are delineated (Bernstein, 2000), within which people can learn to act and hence begin to gain access to the practice. By communicating to each other what counts as that practice, members discursively constitute the practice in an ongoing way and hold each other to account for participation in the practice. The criteria of a practice are never fixed and unchanging, rather a key characteristic of a practice is that criteria change and develop as the practice learns and grows.

Both mathematics and mathematics teaching constitute practices in relation to the above description. The goals of mathematics are to produce new mathematical knowledge, shaped by communities of mathematicians while the goals of mathematics teaching are to produce new generations of mathematicians and “doers” of mathematics (Ball, 2003) in other fields. The two practices of mathematics and mathematics teaching intersect through the use of the artefacts and technologies of mathematics, which include: symbolising, generalising, solving problems, justifying, explaining, and communicating mathematical ideas and concepts (Ball, 2003). The artefacts and technologies of the practice of mathematics teaching further include: the mathematics curriculum; understandings of learning mathematics and learners; mathematics teaching approaches; and assessment strategies. A key task for teachers is to work across these two practices to give access to the practice of mathematics to their learners (Ball & Bass, 2003; Brown, Collins, & Duguid, 1989). Teacher learning in professional

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1 This can be seen as a more situated version of Shulman’s (1986, 1987) distinctions between subject matter knowledge and pedagogical content knowledge.
communities can also be seen as a practice, which brings the practices of mathematics and mathematics teaching together. The notion of social practice has two important implications for mathematics teachers’ learning: first, successful teacher learning requires sustained, coordinated patterns of activity focused on the artefacts and technologies of mathematics and mathematics teaching; and second, teacher learning is strongly connected to the goals of the practice of teaching mathematics and what counts for this practice.

The importance of learner errors

In our project we define errors to be systematic, persistent and pervasive mistakes performed by learners across a range of contexts (Nesher, 1987). We distinguish errors from slips (Olivier, 1996), which are mistakes that are easily corrected when pointed out. 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).

In a social practice theory of learning mathematics, labeling something an error invokes the criteria of the mathematical practice by delineating what is not acceptable, and by implication, what is acceptable in relation to a particular statement. So errors are boundary markers for a practice. In this way, errors illuminate what mechanisms need to be put in place to give access to the practice and to develop the practice further. Errors point to the demands of the practice and are the point of leverage for opening access to the practice. This is why errors are a key area of evaluation for mathematics teachers, who need to give learners access to the practice of mathematics by showing them the boundaries of what is acceptable and what is not.

Teachers can evaluate errors in different ways. One way is to correct errors, which makes the correct knowledge publicly available but not necessarily accessible to learners. A second way is to avoid errors, which may arise from teacher concerns about judging or shaming learners or a fear that bringing errors into the public realm will support a “spread” of errors among learners and create more obstacles and stumbling blocks. This approach does not support accessibility to the practice. A third way is to embrace errors (Swan, 2001) as a point of contact with learners’ thinking and as points of conversation, which can generate discussions about mathematical ideas and the boundaries of the practice. In this way learners’ thinking and the practice are brought into contact with each other.

A key theoretical consequence of our notion of practice, which supports the third option above, is that errors are a normal part of the learning process, for both old-timers and newcomers to a practice (Smith, et al., 1993). Even experienced mathematicians make errors and in so doing create new knowledge and practices in mathematics, thus recreating and shifting the boundaries of the practice (Borasi, 1994). A key point here is that errors are reasonable and make sense to the person who makes the error and are part of gaining access to the practice and developing it further. So errors also make for points of engagement with learners’ current knowledge. This notion of errors gives us a way to help teachers to see learners as reasoning and reasonable thinkers and the practice of mathematics as reasoned and reasonable (Ball & Bass, 2003). If teachers search for ways to understand why learners may have made errors, they may come to value learners’ thinking and find ways to engage their current knowledge in order to create new knowledge. Borasi (1994) takes this a step further, arguing that there is a difference between diagnosing and remediating errors, with the aim of
eliminating them, and using them as “springboards for inquiry” where errors become part and parcel of mathematical development and knowledge creation (see also Lakatos, 1976).

An important issue for teachers’ thinking about errors relates to the role and responsibility of teachers in producing errors. Errors are seldom taught directly by teachers and yet all learners, even “strong” learners, develop them at some point. However, teachers sometimes exacerbate errors through “thoughtless”, i.e. taken-for-granted use of language and concepts, and, at another level, through not making them public and dealing with them. At yet another level of complexity, a deeper understanding of errors suggests that teachers cannot deal with errors quickly or easily because they are firmly held by learners, are widespread across learners and contexts and may be resistant to instruction (Smith, et al., 1993). This is because errors arise in the interactions between the features of mathematics, of learning, and of social practice. So a focus on errors allows teachers to develop nuanced understandings of the nature of mathematics, teaching and learning and the relationships between them.

The literature on teachers’ work with learner errors suggests that 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. Peng and Luo (2009) identify four kinds of error analysis that teachers can use to engage with students’ written texts: identify, interpret, evaluate and remediate. In two case studies they report on, the teachers were able to identify the students’ errors but struggled to interpret them appropriately. They were therefore not able to appropriately evaluate or remediate the errors. In a study with 45 pre-service teachers, Prediger (2009) asked them to analyse a student’s error and in analyzing their analyses suggests four characteristics necessary for diagnostic competence of student errors: interest in student thinking; interpretative attitude of understanding the student’s thinking from her/his perspective; general knowledge of learning processes; and domain specific mathematical knowledge. The two different kinds of knowledge support teachers to make appropriate interpretations of learners’ errors, once they have the interest and interpretative attitude. Most of the students in Prediger’s study showed an interest in understanding the student’s error but those who did not have an interpretative attitude were likely to make suggestions for remediation that were confusing or that re-taught what the student already knew, rather than pinpointed the source of the error. Students who showed an interpretative attitude with some general knowledge of learning were able to partially understand how the learners might be thinking but were not able to activate the mathematical knowledge that they needed to fully understand and work with the error. Only students who activated all four levels of competence were able to make appropriate interventions.

In a study with 25 in-service teachers, Wallach and Even (2005) asked the teachers to analyse videotaped episodes of their students’ problem solving. They identified different ways in which teachers hear their students’ mathematical thinking. Teachers under-hear their students when they ignore some of the important mathematical points that students make; they over-hear their students when they argue that their students have made certain mathematical moves even though there is not sufficient evidence for these claims; non-hearing of students’ ideas occurs when teachers ignore all of what students say; biased hearing occurs when the teachers make claims about the students’ work based on characteristics other than the evidence in the episode; and compatible hearing is where the teachers takes full account of the evidence in the episode and only the evidence in the episode. The ways in which teachers hear learners is important in supporting how they are able to identify, interpret, understand and embrace their errors, and the ways in which they activate their knowledge in order to engage with learner
errors. If their hearing is not compatible with what learners say, then they are less likely to be able to engage appropriately with learner errors.

The project

The data-informed practice improvement project (DIPIP) is a three-year professional development program that works with teachers to design and reflect on lessons, tasks and instructional practices, and builds professional learning communities. The project focuses on building teachers’ understandings of learner errors, both more 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.

The project consists of the following activities:
1. Analyses of learner results on an international standardized, multiple-choice test, with a particular focus on the reasoned errors implied by the distractors for each test item;
2. Mapping of the test in relation to the South African mathematics curriculum;
3. Reading and discussions of texts in relation to learner errors on two mathematical concepts – the equal sign and visualisation;
4. Drawing on the above three analyses to develop lesson plans for between three to five lessons, which aimed to engage with learner errors in relation to the concepts;
5. Reflections on videotaped lessons of some teachers teaching from the lesson plans.

The first two activities - test analysis and curriculum mapping\(^2\) - aimed to develop teacher interest in learners’ thinking and their knowledge about and sensitivity to learner errors in relation to the curriculum, i.e. an interpretive attitude. These two activities formed the basis of the program and were carried through to two cycles of the next three activities - readings and discussions on learner errors in a particular concept, and developing and reflecting on lessons on the concepts.

At any one time there have been between 45 and 50 teachers from Grades 3-9 involved in project.\(^3\) They work in small grade-level groups of 3-4 teachers, with two groups per grade (14 groups), engaging in the activities above. Each group meets weekly during school terms, and has a member of staff or post-graduate student at the university as a team-leader. All team leaders are experienced classroom mathematics teachers and many have experience in initial teacher education and in-service teacher development.\(^4\) The team-leaders were trained before each activity by the author of this paper. They were trained to keep a focus on the key aim of the activity\(^5\), and to support patterns of constructive critique and rigorous enquiry by acknowledging and working with the strengths of teachers’ ideas and at the same time pushing teachers to move beyond their taken-for-granted assumptions and into uncharted territory.

\(^2\) See author ref for a discussion of the second activity
\(^3\) 80% of the teachers who joined the project in 2008 are still in the project. Those who have left usually do so for personal (illness, pregnancy) or work-related reasons. The teachers are paid for the time spent in meetings.
\(^4\) At any one time there are 14 team-leaders in the project, one per group. Over the three years, 23 team leaders have worked in the project.
\(^5\) For example in the test item analysis activity team-leaders were trained to keep a focus on the reasons underlying particular errors and in the video analysis activity they were trained to keep the focus on the teachers’ interaction with learner errors rather than focusing on where the learners had done well.
The program introduced an important design feature whereby the grade-level groups (henceforth the small groups) came together into three larger groups (henceforth the large groups), each consisting of four to six small groups and reported on activities 4 and 5 to each other. The first set of large group meetings took place after activity 4, where each small group presented to the large group an overview of their lesson plans, the tasks for one lesson in detail, and discussed difficulties they anticipated among the learners. We call these the pre-lesson presentations. The second set of large group meetings, called the post-lesson presentations, took place after activity 5, and each small group presented two episodes from the classroom videotapes, one where the group thought the teacher had dealt well with learner errors and one where the group thought the teacher had not dealt so well with learner errors. The presentation included a brief background to the episodes to contextualise them within the set of lessons and a justification for why the group had chosen each episode. Each group gave a 10-minute presentation and about 50 minutes were given for discussion where other groups could comment, question, challenge and give feedback. The facilitator of the large group discussion, in this case the author of this paper, worked to hear the teachers’ accounts, put them into conversation with each other both within and across sessions, challenged the teachers to think more deeply about their practices, sustained a focus on learner errors and learner thinking, drew together the teachers’ contributions into summaries of what had been said, re-articulated program goals in relation to teacher contributions and reminded the group of previous discussions that could be taken as shared knowledge.

Data collection and analysis

In this paper, I report on one Grade 8 teacher’s trajectory in engaging with and reflecting on his learners’ errors. Data was collected through the project activities – as the chosen teacher for his group, his lesson were videotaped, and the larger sessions where he presented the four episodes chosen by him and his group were also videotaped.

Four lessons were analysed, three on the equal sign in round 1 of activities 4 and 5 (119 minutes), and one on visualization in round 2 of activities 4 and 5 (60 minutes). The lesson analysis identified all the learner errors made in the lessons and the teacher’s responses to these. On the basis of this analysis, it could be determined that the episodes chosen for presentation to the larger group did in fact illuminate important issues relating to the teacher’s engagement with learner errors that came up throughout the lessons.

All the larger group sessions where this teacher’s group presented their lesson plans (pre-lesson presentation) and their episodes (post lesson presentations) were analysed, amounting to four hour-long sessions. I wrote detailed summaries of each of the four sessions and analysed each summary, looking for how the teachers spoke about learners’ errors in general and in the particular cases under consideration. This meant looking for who said what and when, presences and absences in what they said, and tracing comments back to previous comments and forward to subsequent ones. In this paper I focus only on the two post-presentation sessions where this teacher presented two episodes of his teaching for each of the two concepts, the equal sign and visualisation. In each case he presented one episode where his group thought he had dealt well with a learner’s error and one episode where his group thought he had not dealt so well with a learner’s error.

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6 In total there were 14 pre-lesson and 14 post-lesson presentations for each concept. The teacher who taught the lessons presented the post-lesson presentation, while another member of the group (not the teacher) presented the pre-lesson presentation. Sometimes two group members presented together for support.
**A good start: embracing an error**

The first episode that this teacher presented was an example of where the teacher dealt well with a learner error. A discussion arose in his classroom when learners solved the equation $5 = x + 3$, and one learner said the answer was $2 = x$. A number of learners insisted that this was incorrect, it should be $x = 2$. The teacher revoiced the two possibilities and asked the learners for their reasons why it should be $x=2$ or $2=x$. After a few minutes of discussion, the teacher explained that these two expressions are the same. In the reflection session, the teacher explained to the larger group that this was an error because:

> They thought that $x$ was the main thing, everything was based on $x$ so $x$ had to be written first, so that was the misconception

When asked why it was a good episode, another group member argued:

> I thought that it was quite good that he emphasized that and said lets discuss this, because he was the one that asked the class is two equal to $x$ or is $x$ equal to two, who agrees that they the same thing or different, and I thought it was quite good to bring about that discussion, because if you not aware of the misconception of the equal sign a lot of people would have just continued and moved onto the next question.

In the discussion on this episodes a number of other teachers said that while they know that $2=x$ and $x=2$ are the same, they would most likely have agreed with the learners that they should write $x=2$ and not $2=x$. In the readings on the equal sign that these teachers had discussed in activity 3, it was argued that a left-right reading (only $x=2$ is correct) is common among learners with operational understandings of the equal sign, while a relational understanding permits readings both ways (Baroody & Ginsburg, 1983; Kieran, 1981).

In reflecting on the episode, the teacher told us that ordinarily he also would have evaluated the answer $2=x$ as incorrect, and merely told the learners that they should write $x=2$ and not $2=x$. Given the work he had done in the project, he realised firstly that the learner was in fact correct, and secondly, that the learners who disagreed and made the error, did so because they were working with an operational notion of the equal sign. So he was working with a more textured understanding of learner errors and how they might be evaluated.

In this case the teacher was able to identify and interpret the learners’ error, and could draw on his general knowledge about learners’ errors and misconceptions and his specific mathematical knowledge about the equal sign to respond appropriately, through giving learners an opportunity to justify their positions and then explaining himself the reasons why $2=x$ and $x=2$ are the same. His hearing of both the correct and incorrect response was compatible and it was supported by what he had learned in the project. He was able to interpret the error appropriately and make a useful intervention. Although he was not yet using the error as a springboard into inquiry, he did understand it, embrace it, and use it to give access to mathematical knowledge.

**The first challenge: becoming patient**

This teacher’s second episode on the equal sign occurred three days after the first and was one
where he and his small group argued that he had not dealt well with a learner’s error. The learner’s error was:

\[ p - 28 = 4 + 1 \]
\[ = p - 28 = 5 \]
\[ = p = 33 \]

In presenting the episode to the larger group, the teacher explained what happened in class:

> So we were now solving those equations, and I moved around in the groups and realised that some of the children were, were repeating a misconception that I had dealt with, they were writing something, which I had dealt with, even some of the best students were doing that, and one of the students actually justified why he was doing that

The teacher reported that in class he was irritated with the learner because he had already taught them why they should not write equal signs in that way. However, during the small group reflections, he had come to see that the learner was not entirely incorrect, in fact the first two statements were mathematically valid, even though the learner was working with an operational understanding of the equal sign, using it to mean “and the next thing is” (Kieran, 1981). It was only the final line that was not valid in relation to the first two. The teacher had come to see that he could have validated part of the learner’s work, in order to explain why the other part was incorrect but he had not done so, because:

> I actually found it annoying because I had actually worked out a question, you can hear from my tone of voice, that I was now annoyed because I explained it to great depth and I had actually showed them the layout and I had actually told them, do not put the equal sign there

He had also realized in discussion with his group that he had not explained adequately to the learner what the problem with his thinking was.

> I don’t think I explained to the satisfaction of the child, he just said okay yes sir because you said so, but it was not one of those where he actually speaks the reason, what’s wrong with it ... I didn’t quite explain to him, I didn’t use more examples to show that it doesn’t work in all cases, the fact that he was writing the equal sign to mean that the next thing is, the next thing is, the next thing is, so I felt that that wasn’t very well articulated

Here we see that in the classroom the teacher was able to identify and interpret the learner’s error based on the knowledge he had gained in the project. However, he wasn’t able to move beyond seeing the error as problematic and he could not hear the validity in part of the learner’s response, an example of under-hearing. So he was not in a position to intervene appropriately to give access to the mathematical practice.

Other teachers in the large group responded as follows:

> The kids are so used to writing, they get taught that every step they must write, when they in the younger grades, equals and then whatever and then in the next step equals, so that’s exactly what that child was doing, he was writing, which you just wanted to get rid of because you didn’t want two equal signs
I find that because in junior school they’ve been told that on pain of death they don’t put equal signs on every line, they now put equal signs on every line regardless of whether the lines are actually equal or not.

Here we see the other teachers accounting for the learner’s error as well as indentifying with the teacher’s difficulty. They acknowledge the constraints on their practice, even as they try to shift that practice to take account of learners’ thinking. Such shifts require resources that they and learners might not always have, especially time, patience and the capacity to hold their own emotions somewhat at bay to engage with learners’ reasoning.

The teacher himself suggested that he was angry with the learner, and if he had been able to hold off his anger he might have been able to hear his reasoning more appropriately. Other teachers spoke about the fact that such errors are “ingrained” and take time to challenge, supporting the teacher’s suggestion that patience is important. One teacher explained how she writes down the common errors like this in her notebook and prepares in advance ways to explain them to learners.

The second challenge: learning to hear

This episode comes from the teacher’s lesson on space and shape, which was the second concept that the teachers worked with, so this occurred about six months after the first two episodes. The teacher had given a task where learners had to cut up a rectangle into two smaller rectangles and compare the area and perimeter of the smaller rectangles with the larger one. They had actual measurements on the board, were generalising from those and had established that the areas of the two shapes added together were the same as the original shape. The teacher then asked about the change in perimeter and there was the following interchange:

L1: The perimeter of shape 2 and 3 is either the length or the width of the area of shape 1
L2: Sir, it just increased
T: What
L2: It just increased
T: It increased, okay lets address his problem first, L1, what are you saying?
L1: The perimeter of shape 2 and 3 is either the length and breadth of shape 1’s area
Learners mutter
T: So, the length of this is 18, the perimeter of shape 2 is 46, that is not correct, that is not the correct deduction isn’t it, what is the correct deduction
L3: The perimeter is the measurement around the shape, so if the shape is going to be cut into two, there’s going to be more sides around the shape so there’s going to be more sides to calculate
T: So it means what, what happens to the perimeter
L3: It increases

Learner1’s response was difficult for the teacher and for other learners to understand. However the teacher remained patient and asked the learner to repeat his explanation even though there was another, correct response (“it increases”) in the public space. The teacher tried to make sense of the learner’s thinking by pointing to numbers on the board (18 and 46) but could not do so. Unfortunately he did not ask the learner himself which numbers he was
using. The rest of the class was getting irritated and so the teacher moved onto another learner who gave a correct answer and a good explanation for the answer.

In reflecting on the episode, one of the teachers in the larger group suggested that learner I did not have a conceptual understanding of area and perimeter, that he merely knew the formulae. It would be quite easy to accept this as an explanation but the teacher argued against it, saying that he thought that the learner had a relational understanding and was working towards some sort of numeric relationship between the original and new perimeters. He then acknowledged that:

*Although he was speaking perfect English, I couldn’t really see what he was talking about*

Later he said

*That was a tricky one, I couldn’t react to it initially, there was something about it, he was talking about things and he was looking at them and I also wanted to see what he was looking at, but I couldn’t see it ... I had a strong feeling of trying to find out what he was talking about but when he asked him after the lesson he just said, I’ve changed my thinking*

Here we see that the teacher could not interpret the learner’s error in class, nor in reflection with his group afterwards. This is because the learner’s response was poorly articulated. This is an example of “non-hearing”, because although the teacher heard the actual words, he could not understand them or make use of them in any way. However the teacher had a strong sense that the learner was saying something sensible and in fact was looking for a more complex relationship than the one eventually sanctioned as correct in the classroom. He suggested that he had this sense in the classroom, and his actions in trying, even briefly, to use the numbers to make sense of the generalization, confirm this. However his subsequent actions in ignoring the error and moving quickly to the correct answer means that the error was not explored or used as a possible entry point into understanding a more complex relationship. As the facilitator I suggested that the learner may have meant that in finding the perimeter of the cut up shapes you have to add (twice) the length or breadth of the original shape. The teachers could see sense in this interpretation and we discussed ways in which the teacher could have worked in class to make sense of the learner’s thinking.

**Discussion: the teacher’s trajectory**

What did this teacher learn about working with learner errors? After an initial successful episode in identifying, interpreting and intervening appropriately when learners made an error, the next two episodes suggest that he struggled to work with learners’ errors in class. However, a deeper analysis shows that the teacher has learned, and it is important that this learning be seen in relation to the resources that were available to the teacher in his practice of learning in the project. Given that the first two episodes occurred in the first round of activities 4 and 5 and the third was in the second round, the question about his learning can be asked as follows: what did the teacher learn from the first two episodes that influenced his teaching in the third and what resources was he able to draw on in his learning.

In the first episode, the teacher drew directly on the project resources, knowledge of operational and relational understandings of the equal sign, and was able to understand and embrace an error and intervene appropriately. A key element in this episode is that in fact
both answers were correct, the error was in the learners’ claim that 2=x was not correct. The way the task was constructed – to solve the equation \(5 = x + 3\)\(^7\), which gave rise to both possibilities (x=2 and 2=x), made a usually submerged error public and provided a resource for working with the learners’ error.

In the second episode, the teacher identified the learner’s error but did not acknowledge the validity of part of his response. The teacher was angry that such an error was still being made, and did not distance himself from his emotions. Dealing with this error required additional resources than dealing with the previous one, which he was not able to muster. In fact, at this point the teacher lost sight of the fact that errors are difficult to eradicate, they are ingrained and need a lot of time and patience on the part of the teacher to be able to engage and work with them. The reflection on this episode made two points clear to all the teachers – the fact that errors arise from the mathematics as much as from the learner – there is a reason for them, and therefore patience is required to work against them.

In the final episode, the teaching was subtly different from the second episode. A superficial analysis might suggest that the teacher ignored the error and moved quickly to the correct answer. However a deeper analysis, in conjunction with the teacher’s and the other teachers’ reflections, shows that in fact the teacher had become more patient and tried to give the learner the opportunity to explain his thinking. The learner could not do so, and his articulation was very difficult to understand. However, the teacher could sense some meaning in the learner’s error, although he was not able to pinpoint it and make use of it. When another teacher suggested that the learner did not understand perimeter and area, he defended the learner and argued for the complexity of the learner’s thinking in relation to the other learners. In this case, the teacher had fewer resources to draw on – none of the learners actually helped him to understand the error and yet he made a serious attempt to do so. That he was not successful speaks to the difficulty of the task, rather than to a lack of learning on his part.

**Conclusion**

It is clear from this analysis that learning to engage with learner errors is a difficult task, which requires a range of resources and ongoing commitment to the practice of engaging with learner errors. This teacher’s trajectory, so far, suggests that there will be successes and challenges along the way, and the learning is certainly not linear, although it requires sustained opportunities to engage and reflect on the engagement with learner errors. Further analysis of the next round of teaching of this teacher may illuminate next steps in his learning.

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\(^7\) This formulation was suggested by the readings and by feedback in the pre-lesson presentation of this group.
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The changing character of a number in rational number learning

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This paper reports on an exploratory research project into the teaching and learning of rational numbers. A possible organizing principle that arose from this project, is that the character of a number changes as a child develops rational number understanding. This paper develops the idea of the character of a number and then presents an argument based on the research, to justify this principle. It is shown how the developing character of a rational number provides a unifying perspective on rational number understanding that could greatly facilitate the child’s learning of rational numbers. In conclusion, some of the implications of this principle for the teaching of rational numbers are briefly discussed.

Introduction

Although much is known about the learning and teaching of rational numbers, effective learning of this topic remains an area of concern for many children (Lamon, 2007). It thus remains an important area for research in mathematics education. According to De Corte (2004), we require both theories of learning and theories of teaching for particular content domains. In developing theories of learning we need to consider the particular mathematical content; ways of understanding this mathematical content; and how this may impact on the learning of the mathematical content. This was originally theorized as pedagogical content knowledge by Schulman (1986) and recent developments have specialized this further to form the research area of content knowledge for teaching (Ball, Thames & Phelps, 2008).

This paper reports on an ongoing research project to investigate the content knowledge for teaching of rational numbers. Currently, this is a qualitative, exploratory research project whose aim is to develop frameworks for understanding rational number learning. One result of the research has been the development of a unifying perspective on this learning, based on the idea of the character of a number. This paper will develop the idea of the character of a number and then argue for the position that the character of a number changes as a child’s experience and understanding of numbers develops from an initial understanding of whole numbers, to an understanding of rational numbers. A number of examples drawn from the research project will be used to flesh out this development and to indicate the unfolding process of conceptualization that arose in the research. Finally, the possibility of focussing on the character of rational numbers to enhance the teaching and learning of rational numbers, will be discussed.

The character of a number

Character will not relate to the mathematical characteristics of a number; or to the symbolic representation of a number; or even to the graphical, concrete or situated models of a number, that are commonly used by teachers and children. Rather, character will be taken to incorporate the fundamental perspectives that children may take on numbers, and that enables them to view numbers as objective (even though abstract) entities. And it is the character of the number that forms a unifying framework for the vast array of mathematical characteristics; symbolic representations; and graphical, concrete and situated models; that exist in the child’s experience of the number.

This idea is fleshed out in the following brief discussion of the character of a whole number in the early years of schooling. That is, after the child has consolidated their pre-school experience of informal protoquantitative situations with their experience of formal number sense development in the
initial years of schooling. This learning is reviewed and discussed in Resnick (1989). A child’s protoquantitative experience with numbers includes the schemas of numerosity, comparison and simple subdivision. While their more formal learning includes learning the counting sequence; counting objects; then adding and subtracting objects; and comparing through finding the difference; and finally extending to multiplication and division.

These consolidated mathematical experiences may be organized and given coherence, as different ways of relating to the activity of counting. For example:

- Addition may be seen as combining and counting, or as counting on.
- Subtraction would involve removal and counting or counting down.
- Difference comparisons relates to counting up (or down) from one to another.
- Multiplication is often modelled by repeated addition or counting in multiples.
- Division is modelled by counting the number of multiples constituting the number.

That is, as a mental entity with an objective character, a number may be seen as a count — a way of precisely describing the numerosity of a collection of objects. It is the view of a number as a count that forms the character of a whole number.

Note that the character does not link directly to precisely how the technical operations are carried out, but rather to a way of conceptualizing, or making sense of these operations, as objectified through fundamental experience. That is, the character of a number is different from a number schema, which relates directly to the precise operations carried out with the number.

The research project

The complexity of rational number learning is generally acknowledged in mathematics education research (Lamon, 2007). The research project which is reported in this paper, involved working with the teachers of mathematics from grade four to grade seven in an English medium primary school in the Eastern Cape. Eight teachers were involved in the project, teaching two grade four classes and three classes from each of the grades five, six and seven.

In previous research, the early learning of rational numbers was explored in order to develop an understanding of the full extent of this process. A preliminary framework was then developed to incorporate the important elements of this process as evident in the research. The complexity of the resulting framework motivated the search for principles that would serve to organize and clarify the framework and provide a clear orientation to the teaching process. A second exploratory research project was designed with this aim in mind and it is this research that forms the basis for this paper.

Two introductory workshops were held to discuss the teaching and learning of mathematics in general and the teaching and learning of rational numbers in particular. Then regular weekly meetings with teachers were held for the duration of the second and third terms. In these meetings, we discussed the rational number teaching and learning occurring in the classroom as well as any specific issues that arose in the process. Also, teaching materials and samples of learners’ work were collected for analysis. In the third term, weekly grade 4 classes were attended and teachers were individually interviewed.

This qualitative data was analysed for themes relevant to the orientation of rational number teaching in ways that could organize and clarify the learning process. Themes such as teaching for stable knowledge, and teaching rational numbers as objective entities emerged, and building on these, the idea of the changing character of a number in the process of rational number learning was developed. It is this development that is discussed in this paper.
Developments emerging from the research data

Counting or quantifying size?

Rational numbers introduce a range of complexity into the idea of a number that makes it difficult to reconcile with the character of a number as a simple count. As was the case with each of the seven teachers interviewed in the research project, a number may be seen as a means that allows the precise quantification of much of our everyday experience. This extends the idea of a count by introducing the principle that wholes may be subdivided. The teachers interviewed, particularly those in earlier grades saw this principle as one of the most important things that they wanted their learners to take away from their rational number teaching.

Even this extension from simple count to quantification with subdivision, results in a change of character, from ‘count’, to ‘quantification of size’. This becomes evident when we ask the question “What are we quantifying?”. Are we quantifying the number of discrete objects, or are we quantifying the size of some composite conglomeration? As an example to consider, Figure 1 shows a task that is similar to many presented to children to develop their understanding of fractions.

![Figure 1: Example fraction task. What is being quantified?](image)

In this example, comparing counts of the number of blocks shaded, will result in the conclusion that A > B. However, comparing the fraction quantities will lead to the opposite conclusion: A \( \frac{5}{8} < \frac{4}{6} \) B. This is the desired result and it stems from a simple visual comparison of the size of the composite shaded regions. From this we see that fractions allow us to precisely quantify the sizes of these regions, as opposed to the number of constituent objects.

But the link between the symbolic fraction notation and the comparison of sizes is not straightforward. In fact, a child that compares either of the counts used for the fraction notation (shaded blocks for numerator with numerator, or the total number of blocks for denominator with denominator), would obtain an incorrect fraction comparison. Instead the fraction comparison is expected to proceed through a visual comparison of the sizes of the shaded objects. The teaching objective of this task could thus be seen as developing the understanding that the naming fractions correspond to the size of the composite object, and so judgements about the fractions could be made using the sizes of the objects. In terms of the use of symbols, the child is learning to use counts to describe the sizes of the composite objects, but not to use counts (or the symbolic fraction quantities) to compare the sizes.
The extension from a number as a count to a number as quantifying size, is evident in the work of a class of grade 4 children on a worksheet containing tasks similar to that shown above. A number of children initially counted pieces and wrote responses such as $\frac{5}{8} > \frac{4}{6}$. But this was not because they were not able to make the size comparison. Because, when the teacher mentioned that the question was asking them to compare the size of the regions, they quickly and confidently changed their response to read $\frac{5}{8} > \frac{4}{6}$. Furthermore, many of these children had written $\frac{1}{8} > \frac{1}{6}$ in a following question when the comparison was between two shaded single pieces, and hence they chose to count the total number of pieces in the subdivision to get a counting comparison. But after the teachers brief input to focus the previous question, they immediately went on to also change this response to the desired $\frac{1}{8} < \frac{1}{6}$. It appeared as if these children were quite capable of both responses, and the difficulty experienced in answering these questions is that they were not sure what the question required. Here the wording of the question did not explicitly request a (visual) comparison of size, or state that a count of parts was not required. The fact that they knew that they were learning mathematics and that the question required a simple visual comparison, rather than a more technical (mathematical) count, possibly contributed to their choice of the more technical, counting response. The nature of their response to this ambiguous task, indicates that the children were in transition between the two different perspectives — developing the, not yet stable link between fractions as quantifying size.

Another view of this transition occurred in a different grade 4 class a few lessons after this. In this class the children were drawing and marking subdivisions on number lines, and then using fractions to label the marks. These children confidently used equivalent fractions to confidently generated multiple representations for their marks. The interaction of interest occurred after the children had divided a line from 0 to 2 into four and correctly labelled the marks. This included a discussion in which many different alternatives for the 1½ mark were developed by the children, including mixed numbers and improper fraction such as $\frac{3}{2}$ and $\frac{6}{4}$. After this, the children were asked to make a line from 0 to 4 and halve it repeatedly to form 8 equal parts. They readily identified each part as a half unit, calling out that this was an “easy question”. The teacher then asked them to label the marks by counting in half units, and showed the first two counts: $\frac{1}{2}$ and $\frac{2}{2}$ on her line. Most of the children found this a very difficult task and worked on it with teacher facilitation for an extended time. After this, the teacher labelled all the marks on her demonstration board. But many of the learners appeared uncertain even then. The teacher then went on to write sums of repeated eighths for calculation on the board (such as $\frac{1}{8} + \frac{1}{8} = \_\_\_$, or $\frac{1}{8} + \frac{1}{8} + \frac{1}{8} = \_\_\_$). In their responses, the children much more readily gave equivalent responses such as $\frac{1}{8} + \frac{1}{8} = \frac{1}{4}$, than counting responses such as $\frac{1}{8} + \frac{1}{8} = 2/8$. Here it appeared as if the learners may have over generalized the rule of quantifying sizes rather than counting, to the point that they found it difficult to count using fraction units, even when explicitly asked to do this. Such an over generalization of informal rules is another indicator of the possible occurrence of a transition of representations in thinking (Karmiloff-Smith, 1992).

The influence of the whole

It is important to note that the first example and the corresponding discussion depends critically on the fact that the ‘whole’ objects for A and B are the same sizes. This allows us to greatly simplify the learning task by disregarding the size of the containing region. But it does result in a restricted understanding of rational numbers and thus a restricted perspective on the character of rational numbers. To further flesh this out, we will discuss two examples in which the whole, or the reference unit is an important feature.

The first example occurred in a grade 4 class. In the first two lessons of a teaching sequence on fractions, the teacher grouped the children into groups of 2, 3 or 4, provided some food items to each group and then asked them to share this fairly among the group. They then drew and discussed the results. In the first lesson, they shared they shared three hot dogs and in the next, one cookie. The care that the children took to ensure that all the shares were equal was noticeable. It was also evident that the children had some experience of fractions because they confidently used fraction names and notation to describe their shares. In the third lesson, the teacher grouped the class into pairs and gave
each group an apple to share. Again great care was taken by each pair to ensure that the apple was equally divided into halves and the children readily reported that each child in a pair received the same share — half of their apple. The teacher then asked the children if every child had the same amount of apple. In preparing for the lesson, she had selected some apples of quite different sizes and she was expecting a lively discussion from the class, of who had more or less. As a result, she was rather surprised with their initial response that they all had the same amount — a half apple. On getting the children to compare half apples of different sizes, they acknowledged that they did see the difference in size, but they found this confusing, given that they each had half an apple. An explanation that the whole apples were of different sizes and so the halves would also have different sizes, did not appear to offer much clarity.

It appeared that in their previous learning, the children had not been asked to compare fractions of different sized wholes. As a result, they had developed little appreciation of the fact that the size of the whole was an important factor in determining the size of the fractions obtained by subdividing the whole. Thus, to use a fraction properly to quantify the size of an object, it is also necessary to consider the size of the whole.

The second example shows the opposite effect, where quite different responses by children are turn out to be consistent once the size of the whole, or reference unit is taken into consideration. In this case, children were responding to the following question in a grade 5 class test:

“Use drawings to show how you would share 5 slices of bread among 2 people. What fraction would each person get?”

Three answers to this question are shown in Figure 2.

Figure 2: Responses to sharing five loaves of bread between two.

The teacher expected either of the first or the second responses, in which fractions were used to describe the number of slices of bread received. To investigate the logic of the third answer, the child was asked to explain the answer of 5/10, in a lesson following the test. The response was that each slice was cut into two equal parts and this gave ten pieces of bread. Then five pieces of the ten were given to each person. So each person got 5/10 of the bread. This response, though different, was also correct and the apparent contradiction between the fraction quantities was resolved as soon as the reference unit used by the child was incorporated. In the first two cases, the reference unit was one slice of bread and in the third case, it was the original five slices of bread.

The reference unit thus has a profound effect on the way in which the numerical symbol is related to the size of whatever is being quantified. Accounting for this has an equally profound influence on the character of the rational number. For the quantification of size changes from a global quantification of
absolute size (where all halves are the same size) to a quantification of size relative to some chosen whole, or reference unit. From this perspective, a rational number becomes seen as a relative quantity, in effect a measurement relative to the chosen unit.

The argument in this and the previous sections, shows how possibly the most common teaching approach to rational numbers, will, when effective mastery of rational numbers is achieved, result in a rational number being seen as a ‘relative measurement’ rather than as a simple count.

Further developments

Relative measure or comparison?

The extension of the character of a rational number that of a relative measure emphasizes the fundamental relationship between rational numbers and the process of measurement. This relationship is developed in the measurement sub-construct of the rational number field (Marshall, 1993). But this is not the only rational number sub-construct that has been identified in the literature, raising the question of whether further extensions can be made to allow the incorporation of all the different sub-constructs.

Five rational number sub-constructs were identified by Kieren (1976, 1988, 1993) and by Behr, Lesh, Post, Silver and Harel (1983, 1992, 1993). They were developed through “a logical analysis of mathematical interpretations of rational numbers” (Kieren, 1976, pg 103). These sub-constructs are: part-whole, measure, quotient, operator and ratio.

Measure: Relating to the use of rational numbers to measure quantities relative to some chosen reference unit, this is the character currently being considered.

Part-whole: This involves the use of rational numbers to quantify some distinguished part of a whole. According to Kieren (1988), this sub-construct formed the foundation for the classical introduction to fractions, and hence rational numbers. Thus it is unsurprising that a high proportion of the teaching evidenced at the school involved in the research, including the example shown in Figure 1, relates to this sub-construct. The argument up to this point has taken into account both the quantification of the part and the effect of the whole, thus incorporating this sub-construct.

Quotient: This sub-construct relates to the mathematical operation of division, with the resulting quotient giving the rational number. Division has two very different interpretations in terms of everyday activities, as discussed by Behr et. al. (1992) and Neuman (1999): partitive and quotitive division. Partitive division corresponds to sharing, which led to the view of a rational number as a relative measurement. Quotitive division corresponds to grouping of objects to form composite units, with rational numbers arising through the comparison of the original number of objects, or the number of remaining objects, with the number of objects in a group. Such tasks were commonly assigned in the teaching observed with responses often expressed in a form such as ‘5 out of 8’. Grouping may be seen as a relative measurement, where both the quantity to be measured and the reference unit are comprised of discrete objects.

Operator: Deals with the conversion of a quantity into a different quantity by proportional means. Rational numbers arise as the proportional multipliers in the conversion.

Ratio: This involves the use of ratio to compare two quantities. The ratio is a multiplicative comparison of the values of the two quantities and may be expressed as a rational number.

Rational numbers arise in the operator and ratio sub-constructs, through the comparison of two quantities that have equal status. In these cases, there is no distinguished reference unit. The character of a relative measurement does incorporate a distinguished reference unit and so will impose additional structure on these two sub-constructs. To fit these sub-constructs, the structure thus needs to be weakened, while retaining the element of a quantification through relative comparison, required in
the previous analysis. In fact, simplifying the character to essentially this element will give a suitable view of a rational number as a relative comparison.

**Unifying the number system: Tangling the hierarchy**

As they work with rational numbers, children will have the repeated experience of whole numbers occurring naturally in this rational domain. Through this experience, they will come to appropriate whole numbers as rational numbers, rather than as separate from rational numbers — simplifying their work with numbers by unifying the number system. The technical development of the rational number system is such that nothing technical is lost in this unification, and the child will gain a great deal of power and flexibility in their technical work with whole numbers.

But this unification will have important consequences for the child’s view of the character of numbers. For, if this is to be a proper unification, the character of the numbers in the system needs also to be unified. The preceding discussion shows that the view of a number as a count is not consistent with the system of rational numbers, and for this reason, unification of character will allow a changed perception of the character of whole numbers, from whole numbers as counts, to whole numbers as comparisons.

The result of such a unification will thus be a tangled hierarchy, where whole numbers form the foundation for the development of a superstructure of rational numbers. But then the foundational whole numbers themselves become incorporated into the superstructure. The result is a complex, tangled, system, which allows the owner to use the best of both worlds. It increases both the technical and interpretive power of the system, allowing the expanded technical facility of rational numbers and the use of whole number objects as either counts or as comparisons.

**Possible implications for teaching**

Explicitly adopting the view of a rational number as a relative comparison of size, could have a profound effect on the teaching and learning of rational numbers. For this would encourage children to develop their understanding of the character of a number from a count to a comparison and thus enable them to overcome many of the problems of learning rational numbers that occur as a result of viewing numbers as counts. It also acknowledges the complexity of the transition in understanding that is required by the learning of rationals.

This would also encourage the engagement with all the different aspects of rational numbers and so discourage the premature fixing of the concept in an impoverished form. In particular, this relational approach would encourage the development of multiplicative reasoning and multiplicative skills, through an experience of this multiplicative character of rational numbers. It would also provide rich experience of measurement in multiple contexts. In this way it would provide a unifying focus not only for rational numbers, but also for a large proportion of the mathematical learning in primary school.

The proper development of this character will require more time than is currently spent in the initial stages of learning the concept, because of the complex, relational nature of this character. But this requirement of more time to provide a more comprehensive and stable initial experience of rational numbers before the teaching emphasis shifts to more symbolic and technical work, could also be important for improving learning through current approaches.

An effective change of the teaching perspective will thus require more time and the principled acknowledgement of and exposure to the complexity of rational number understanding. It is important to note that this will involve deepening and extending current initial teaching tasks and activities, and delaying some of the more technical development. But this does not imply that current approaches should be seen as ‘bad’. These would retain an important place in a more rounded and comprehensive approach to teaching incorporating an altered perspective. But such a change would require careful
and deliberate planning of rational number teaching over a number of years, thus making it important for teachers work together over a number of grades in order to coordinate such a teaching programme.

References


Towards a description of the constitution of mathematics and learner identity in pedagogic contexts

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In this paper, we discuss the constitution of school mathematics and learner identity through an analysis of the pedagogic operational activity in a grade 9 lesson. We make use of theoretical and analytical resources in order to begin to describe the way in which mathematical knowledge and learner identity are constructed through pedagogy.

Introduction

This paper is a contribution towards the development of analytical resources for the description and analysis of mathematics pedagogy, emerging from research in five Western Cape schools. The general problematic within which the paper is located is the constitution of school mathematics. The specific aim of this paper is to begin to develop an analytical framework to describe the co-production of school mathematics and learner identity in pedagogic contexts using an example from a lesson in one of the five schools. The paper focuses specifically on the constitution of mathematics through the pedagogy in this example, and the learner identity which this constitution produces. The analytical resources of Davis (2009b, 2010a, 2010b) are used in conjunction with Lacan’s psychoanalytic categories of the Real, the Imaginary and the Symbolic (in Jameson, 1988) and Eco’s (1979) notion of a model reader, as tools in describing the co-production of school mathematics and learner identity.

At first glance: Apples and Oranges

The example comes from a grade 9 lesson in which the teacher states that he will be teaching the addition and subtraction of terms. In a previous lesson he has discussed algebraic expressions, focusing on the degree of a polynomial, index of terms, constant terms and coefficients. He starts the lesson by briefly reminding the learners of these concepts, before turning to the topic for the lesson and starting with addition.

He explains that in order to add terms the powers must be alike, writing on the board “if they are alike (the same power/index)”. He then works through the example (“−2a² −3a + 5 − 5a + 2 + 3 − a + 5a² “, see Figure 1), which he describes as a problem requiring the addition of “like terms”. It seems that he requires the learners to simplify the given expression with respect to common multipliers, in order to obtain an expression with fewer terms.

The notion of a “like term” is central to his procedure, which consists of these general steps: identify terms having unknowns with the same power as “like terms”; rearrange the expression by grouping the “like terms”; add the “like terms”.

At first, his explanation is focused largely on the powers, the sameness/difference of which he uses as a criterion to identify and rearrange what he refers to as “like terms”. When rearranging the terms he draws brackets beneath the sums of “like terms”, as seen in Figure 1, and he repeats his explanation about how to identify “like terms” based on their powers. When adding the “like terms”, he now focuses on the coefficients, at first ignoring the variables with their powers, and asks the learners to add the coefficients. Once they have given him the correct answer, he attaches it to the variable. He refers to the $a^2$ terms as apples and the $a$ terms as oranges in his explanation.
He moves on to a second example, in which he distinguishes between what he refers to as two methods for adding terms – the “horizontal method” and the “vertical method”:

![Figure 2. The teacher’s two methods](image)

He starts with his horizontal method and as he writes up the examples, he says that he will be “adding them all horizontally...in a straight line”. He does the calculation by first rearranging the terms horizontally, see Figure 2, and then computing.

He writes the heading “vertical method” as he states that “the vertical method is going to add them in rows downwards”, after which he rearranges the terms vertically and computes. The only explanation he offers for his rearrangement of terms is that the xs “go together” and the numbers “go together”. Both explanations are more focused on the rearrangement of terms (horizontally or vertically) and not on the actual adding of terms, which was his topic for the lesson.

In summary, the key features of the procedure used by this teacher in his explanation are:

- Identification of “like terms” based on sameness of powers, as seen in his repetition of the need for terms to be “of the same power” before they can be added.
- Emphasis on spatial rearrangement of terms, as seen in his two methods (Figure 2).
- Addition of terms as objects to be counted rather than symbols representing numbers, as seen in his separation of coefficients from unknowns and use of “apples” and “oranges” to distinguish and separate terms from each other.

Before further analysis of the teacher’s procedure and the way in which four learners carry out this procedure, we turn to some of the relevant literature on the use of symbols and procedures in school mathematics in order to re-describe these features of this teacher’s explanation.

**A brief survey of the literature**

Tall discusses what he refers to as the “degeneration of algebra into apples and bananas” (1992: 7), an approach to explaining algebraic notation to learners first encountering it. He believes that although it may help with manipulation of symbols, the meaning it gives is inflexible and fails when, for example, negative numbers are involved (in our example, can you have “minus two apples”?). He believes, as we do, that this use of symbolism is flawed. He explains the way in which algebraic notation functions as both process and concept, which he refers to as the notion of a procept – “the ambiguous use of notation to stand either for a process or the object produced by that process” (Tall, 1992: 2). Learners who tend towards procedural thinking will struggle to understand this particularly when there are unknowns present. But those for whom notation is more flexible, it can represent a potential process but is also more likely to be conceived as an object that can be manipulated mentally. He thus suggests that those learners who can work with notation more flexibly are more likely to be successful in algebra, whereas others will be confused by the multiple meanings of the symbolism. Gray and Tall (1994) contend that the range of interpretation of proceptual symbolism – from procedure to be carried out, to flexible procept representing either process or resultant object – leads to a range of success and failure in mathematics. Through their analysis of the nature of the procedures used in arithmetic, they
often found that the procedures were far harder than what they refer to as “flexible proceptual methods” (1992: 16). In light of this they believe that those who find mathematics difficult are often forced into even more difficult procedures for solving specific problems. They refer to the “ever-widening gulf” between successful proceptual thinkers and less successful procedural thinkers, as the “proceptual divide” (1992: 16).

The development of an inflexible conception of symbols is discussed further by Lima and Tall (2010: 2), who described operations involving the movement of symbols as “procedural embodiments”, which they explain as “the embodied movement of symbols as mental entities being moved around, with additional rules to get the right answer”. They discuss the cognitive and sensori-motor shifting of symbols as objects in the context of solving linear equations, with rules such as “change sides change signs”. They give examples of learners misremembering the rules and making mistakes, revealing the fragility of procedural methods. In the lesson under discussion, terms are shifted around mentally and physically with the rule being to group and then add terms with the same power together, which is suggestive of the procedural embodiment described by Lima and Tall.

But although this explanation of the way in which symbols can be understood by learners is helpful in understanding the problem with procedural thinking it does not explain the role of pedagogy in the facilitation or prevention of this way of thinking. The work of Harel, Fuller and Rabin (2008) focused on teaching practices that could lead to the non-attendance of learners to mathematical meanings. Such practices create what Brousseau (1997) calls didactical obstacles (as opposed to epistemological obstacles – which involve the innate difficulty individuals have in developing new conceptions.) One of the ways in which teachers do not emphasize mathematical meaning is to accept or make use of non-referential symbolic thinking, which Harel et al suggest results in the adoption by learners of such reasoning practices. They refer to non-referential symbolic thinking as the behavior of operating on symbols as if they are objects in their own right, rather than treating them as representations of entities in a coherent reality. This lack of attention to the meanings of symbols used to solve problems results in learners viewing symbols as “having a life of their own” and manipulating them based on arbitrary rules (Harel et al, 2008: 125). They give examples from pedagogic contexts where learners were led to focus only on what procedure to use. Their concern is that “when the meaning of symbols and operations is not considered, practice problems become procedure drills rather than opportunities to reason repeatedly, a critical step for students to internalize their knowledge” (Harel et al, 2008: 125).

The work of Harel et al, although acknowledging the role of pedagogy in creating such didactical obstacles, does not give us a framework for understanding how this takes place.

The next section of the paper outlines a methodology for describing what is happening in the given example through analysing the operational activity of the pedagogy more closely.

**Methodological resources**

Davis and Johnson (2008) suggest that in order for learners to develop conceptual understanding, the mathematical objects need to be present as the fundamental ground on which the procedures and examples used are based, rather than being the end goal of a pedagogy which is based on a procedural ground. They propose that this fundamental ground, which they renamed propositional ground (2009b), underpins any procedural understanding of mathematics, and that the mathematical objects are always present, but not always accessible to learners due to the pedagogic strategies used. In research carried out in five Western Cape schools, they observed a widespread use of iconic and procedural resources which did not give learners access to the propositional mathematical ground.

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8 The work of Ma (1999) with elementary school mathematics teachers in the USA and in China led to her description of conceptual and procedural understanding. She describes procedural understanding as consisting mostly of procedural knowledge of mathematical topics underpinned by what she refers to as a “pseudo-conceptual understanding” (1999: 23) of the mathematical concept. In contrast, the knowledge of teachers (and learners) with a conceptual understanding contains procedural knowledge, conceptual knowledge and basic principles of mathematics.
This work in five Western Cape schools, consisting predominantly of learners from working class backgrounds (discussed in detail in Davis & Johnson, 2008 and Davis, 2009b), has taken place over three years, involving the collection of data in grades 8, 9 and 10. The data collected for each school includes observation notes, video records and transcripts of three consecutive lessons in each of these three grades. Two cameras were used to record the lessons – one focusing on the teacher and the other on the activity of the learners. The example under discussion comes from a grade 9 lesson, the second in the three which were recorded. For this paper, the teacher’s operational activity and the work of four learners have been analysed in terms of the theoretical resources introduced below in order to begin to describe the co-production of school mathematics and learner identity in a pedagogic context. We will now introduce these descriptive and analytic resources.

**Model learners**

Eco (1979) refers to a model reader as a model of a possible reader anticipated by the author of a particular text “supposedly able to deal interpretatively with the expressions in the same way as the author deals generatively with them.” (1979: 7). He discusses the way in which texts explicitly select a model reader through the choice of linguistic code, literary style and specialisation indices. Some texts give explicit information about the model reader they presuppose through direct appeals, others through implicitly presupposing a “specific encyclopaedic competence” (1979: 7). Eco thus suggests that a well-organised text not only presupposes a model of competence coming from outside the text (in the model reader) but also constructs this competence (he refers to Riffaterre, 1973).

We have used Eco’s discussion of a model reader and applied it to pedagogic situations to fashion the concept of a model learner, as a way of describing how pedagogy both presupposes and structures the mathematical competence of the learner. The teacher anticipates or presupposes a certain kind of learner competence, and we suggest that this shapes the evaluative criteria generated in pedagogic contexts, which in turn structure the ways in which learners do mathematics. Thus any pedagogic activity implies a model learner, not to be confused with the actual learner, as highlighted by Davis (2010). We have used the Lacanian psychoanalytic registers of the Imaginary and the Symbolic to differentiate between two levels of model learners implied by pedagogy.

**The Imaginary, the Symbolic and the Real**

Lacan described three registers – the Imaginary, the Symbolic and the Real, referred to by Jameson (1988: 82) as “sectors of experience”. The Imaginary refers to engagement with the Other in terms of an image, while the Symbolic refers to engagement with the Other in terms of the way in which the other functions within a particular structure. The focus is on the internal constituents of the structure, rather than the image, external appearance, or spatial configuration, as in the Imaginary (Jameson, 1988).

In terms of the teaching and learning of Mathematics, we take the Imaginary as representative of the image held by the teacher of the learner. The kind of learner anticipated by the teacher is thus the Imaginary model learner, which represents the image or identity of the learner constructed through pedagogic discourse, a particular moralizing of the learner. The analysis of regulative, moralistic statements by the teacher would yield data about the implied Imaginary model learner (such as “our learners struggle with mathematics”, or instructions to learners about which methods to use). This is the level of Bernstein’s regulative discourse, which he describes as a “moral discourse which creates order, relations and identity” (1996: 32).

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9 **Evaluative criteria** are the rules for regulating an activity and reveal what is realised as legitimate in particular pedagogic contexts, as discussed by Bernstein (1996). We focus on the criteria for the production of mathematical statements in pedagogic contexts, which may have their origin in the complete body of mathematical knowledge, which we refer to as the encyclopaedia, or they may emerge in response to the pedagogic context, as discussed by Davis (2010b).
We take the Symbolic to represent what the learner needs to acquire in terms of the symbolic aspects of mathematics. The way in which the teacher performs mathematical activity can either facilitate or disrupt this symbolic acquisition. The Symbolic model learner is thus implied at an operational level of pedagogy, which can be likened to Bernstein’s instructional discourse, which “creates specialised skills and their relationship to each other” (1996: 32). In our discussion the operational activity of the teacher is inferred through analyzing his procedure in terms of the mathematical objects which he manipulates and the manipulations themselves, which could be mathematical operations or non-mathematical, pseudo-operations. Davis (2009b) discusses the nature of mathematical objects and operations and their inter-relations. This paper is based on his analytical framework, which is used to analyse the operational activity of the pedagogy in this example. Davis (2010: 21) describes an operation as:

\[ f : X_1 \times \ldots \times X_k \rightarrow Y \]

a function of the form \( f : X_1 \times \ldots \times X_k \rightarrow Y \). The sets \( X_j \) are called the domains of the operation, the set \( Y \) is called the codomain of the operation, and the fixed non-negative integer \( k \) (the number of arguments) is called the type or arity of the operation.

He refers to pseudo-operations as the production and manipulations of objects that cannot be covered by the above definition.

The unit of analysis is an evaluative event (discussed by Davis, 2010b: 5), which is “composed of a sequence of pedagogic activity, starting with the presentation of specific content in some initial form, and concluding with the presentation of the realization of the content in a final form”.

We now turn to a brief discussion of the Real. Lacan introduced the Real register in response to that which cannot be or has not been symbolized – the Real “resists symbolization absolutely” (in Jameson, 1988: 104) and refers to existence outside of the Symbolic. The Symbolic cannot capture everything and will at some point fail, and it is at this point of breakdown that the Real, according to Lacan, emerges.

In terms of education, the learner represents the potential point at which knowledge breaks down. The learner can be described as Janus-faced - having either a sacred face (facilitating the reproduction of knowledge) or a profane face (disrupting the reproduction of knowledge). The profane learner thus represents a point of breakdown, and the potential intrusion of the Real. In order to deal with the learner as Real, schools and teachers respond by trying to construct the learner as facilitative rather than disruptive, using either Imaginary or Symbolic responses, or a combination of the two, at the two levels described in the above discussion of the Imaginary and the Symbolic in an educational context. We suggest that these two categories, the Imaginary and the Symbolic, are useful analytical tools for describing the co-production of mathematics and learner identity in pedagogic situations. For the purposes of this paper, we do not discuss the Imaginary model learner, implied at the regulative level but we propose the possibility of an Imaginary, regulative level at which a particular learner identity is produced as an area for further exploration. The focus of this paper is the Symbolic, operational level of pedagogy, which we analyse below by comparing the mathematics produced by the teacher and the learners with mathematics in the encyclopaedia, in order to discuss the model learner implied at the level of the Symbolic.

Let us now return to our example in order to analyse the combinatorial resources used in terms of objects and operations and their inter-relations.

**A closer look: analysing the operational activity**

The first part of the teacher’s procedure involves what he refers to as identifying and then rearranging the like terms spatially, as seen in this section of the transcript:

Teacher: Addition and subtraction of terms. The first one we’re going to deal with it’s addition. How can you add terms? You are only allowed terms if they are alike. You can only add terms if they are alike or the same [writes on board “if they are alike (the same power/index)”]. So before we can add we need to identify terms that are alike. Now I’m just going to give you
some few terms and I would like us to identify. [Writes “–2a^2 –3a + 5 – 5a + 2 + 3 – a + 5a^2” on the board]

Teacher: I’ve just given a long expression of a number of terms. I’d like us to identify first the terms that are alike. How do you know that terms are alike? We said you look at the powers to find like and unlike terms. Which ones have the same power here? [points at “–2a^2 ”]. Minus two a squared is of the same power as …

Learner: Five a squared

Teacher: Five a squared. Let us put them together. Minus two a squared let us put it together with a plus five a squared. Why do we say they are alike? Because they are having the same power.

Learner: Same power.

Teacher: They are having the same index. The index is 2. The same power.

(Transcript, School P1, Grade 9 Lesson 2)

The topic announced by the teacher is the addition of terms. He presents the learners with the first example and then begins to outline a procedure for dealing with it. He introduces the identification of “like” or “unlike” terms, and states that terms can only be added if they are alike. But the expression “–2a^2 –3a + 5 – 5a + 2 + 3 – a + 5a^2” is a sum which, by definition, requires the operation of addition over the reals. Thus the statement “you can only add terms if they are alike or the same” must have a different meaning. It seems that the purpose of this task is to produce a simplification of the expression by reducing the number of operations that need to be performed on representations of real numbers, but in a particular way. The distributive property is used, along with the associativity and commutativity of multiplication and addition, with respect to common multipliers (a^2, a, a^0) to produce a simpler expression. Let’s describe the mathematical activity involved in this simplification in terms of the operations used:

The starting point is –2a^2 –3a + 5 – 5a + 2 + 3 – a + 5a^2 (expression 1). In order to simplify this expression, we know that addition over the reals is commutative and associative, and multiplication distributes over addition, so we can write:

\[ a^2(-2 + 5) - a(3 + 5 + 1) + 10 \]

\[ = 3a^2 - 9a + 10 \] (expression 2, an alternative expression of the sum in expression 1).

Expression 2 can be rewritten as \( 3a^2 - 9a + 10 \) (expression 3). If we rewrite expression 3 in terms of the operations being used, we get:

\[ + (3a^2, +(-9a,10)) \]

\[ = + (\times(3,a^2),+((-9,a),10)) \]

\[ = + (\times(3,SQU(a)),+((-9,a),10)) \]

Expression 3 is computationally simpler than expression 1 – the number of computations that should be performed has been reduced to five operations. Note that expression 3 is not an absolute reduction of expression 1. If we were to apply the distributive rule to completely reduce expression 1, we would do so as follows:

\[ a(-2a + -3 + -5 + -1 + 5a) + 10 \]

\[ = a(3a - 9) + 10 \]

\[ = + (a(3a - 9),10) \]
= + (\times(a,3a - 9), 10)
= + (\times(a,+(3a, -9)), 10)
= + (\times(a,+(\times(3, a), -9)), 10)

This results in a simplification that has even fewer computations than expression 3 (four operations) and consists of combinations of addition and multiplication only. But this simplification does not involve the use of common multipliers, which seems to be the purpose of the given task.

From the above analysis, we can see that the operational resources needed for this simplification are addition, multiplication and squaring over the domain of the reals. The properties of reals drawn on are the associativity and commutativity of addition and multiplication, and the distributivity of multiplication over addition. The ground on which this problem rests is the field of the reals, with its axioms (see Table 1).

Table 1. Axioms of the field of reals

<table>
<thead>
<tr>
<th>Field axioms</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \forall a, b, c \in R, a + (b + c) = (a + b) + c )</td>
<td>Associativity of addition</td>
</tr>
<tr>
<td>( \forall a, b, c \in R, a \times (b \times c) = (a \times b) \times c )</td>
<td>Associativity of multiplication</td>
</tr>
<tr>
<td>( \forall a, b \in R, a + b = b + a )</td>
<td>Commutativity of addition</td>
</tr>
<tr>
<td>( \forall a, b \in R, a \times b = b \times a )</td>
<td>Commutativity of multiplication</td>
</tr>
<tr>
<td>( \forall a, b, c \in R, a \times (b + c) = (a \times b) + (a \times c) )</td>
<td>Distributivity of multiplication over addition</td>
</tr>
<tr>
<td>( 0 \in R, \text{ and for } \forall a \in R, a + 0 = a = 0 + a )</td>
<td>Existence of additive identity</td>
</tr>
<tr>
<td>( 0 \neq 1 ) and for ( \forall a \in R, a \times 1 = a = 1 \times a )</td>
<td>Existence of multiplicative identity</td>
</tr>
<tr>
<td>( \forall a \in R, \exists (-a) \in R \text{ such that } a + (-a) = 0 )</td>
<td>Existence of additive inverses</td>
</tr>
<tr>
<td>( \forall a \neq 0 \in R, \exists (a^{-1}) \in R \text{ such that } a \times a^{-1} = 1 )</td>
<td>Existence of multiplicative inverses</td>
</tr>
</tbody>
</table>

But instead of drawing on the ground of the reals, the teacher recontextualises “simplification by reducing the number of operations to be performed” to “adding like terms” so that a procedure for “adding like terms” can be produced. The behaviours of operations over the reals are thereby removed from explicit consideration, as the following analysis will reveal.

Recontextualisation: the teacher’s procedure

Let’s return to the transcript to examine this recontextualisation more closely:

Teacher: Now this is what we do. Because we are speaking of apples we normally add apples to apples, oranges to oranges, which means like terms together. Now whatever answer you’re going to get here it should be the answer of apples alone. I’ve got minus two apples and plus five apples. What should be the answer of minus two and plus five?

Learner: Plus three.

Teacher: Plus three. Therefore plus three apples. That’s why I’m still having \( a \) squared. Alright. Now let us come to the next one. What is a minus three a minus five and a minus one?

Learner: A minus

Learner: Minus nine.

Teacher: Ok how do we get minus nine? Minus three and minus five is?

Learner: Eight.
The computations in this extract rely on the use of the distributive rule, but this is not mentioned by the teacher. In his instructions, he does not explicitly make use of the properties of reals, but uses different resources in order to get to the particular simplification required. In order to analyse the operational activity of the teacher, we break his procedure down into a series of steps. We rewrite each step in terms of the operations and their inputs and outputs to reveal the predominance of pseudo-operations in this procedure:

Step one: Sunder\(^{10}\) the powers from the bases

Step two: Identify or select terms with the same powers

Step three: Concatenate\(^1\) the powers with the bases

Step four: Rearrange/group the terms selected according to their powers

Step five: Represent terms with the same powers as physical objects distinct from terms with a different power.

Step six: Sunder the coefficients from the multipliers (repeated twice for the \(a^2\) and \(a\) multipliers in this example)

Step seven: Add the coefficients as integers (repeated twice in this example)

Step eight: Concatenate the sum of the coefficients with the multiplier (repeated twice for the \(a^2\) and \(a\) multipliers in this example)

Step nine: Add the constant terms (containing the multiplier \(a^0\)) as natural numbers

From this operational description of the teacher’s procedure it is evident that the mathematical operations of addition over the reals, multiplication and squaring are implicit, as well as the distributive, associative and commutative properties of multiplication and addition. Thus the operational resources of the mathematics encyclopaedia needed to compute the given example are not referred to by the teacher and the major resource, knowledge of the behaviour of operations over the reals, is not dealt with in his procedure, which is thus incomplete. His procedure consists predominantly of pseudo-operations. He attempts to achieve the same effect as the operations outlined previously (simplification by reducing the number of operations), but using different, non-mathematical resources, which are iconic and procedural in nature.

Davis and Johnson (2008) describe the use of iconic resources in pedagogy as iconic ground (which functions as the regulation of the production of knowledge statements by way of reference to iconic similarity of expression). They also describe procedural ground (2009b) – use of a “standard form” and rules, which appeals to more than just iconic similarity as it involves the selection of operations from a cluster that are commonly used in working through the particular type of procedure being dealt with. They found that these two types of ground function as the dominant supports for the evaluative

\(^{10}\) Sundering and concatenation are described by Jaffer (2009) and Davis (2009b) as pseudo-operations, and they occur in the criteria of many of the lessons we have recorded and analysed. Sundering involves a decoupling or separation of characters (e.g. \(2a^2l\) to \(2l, a^2l\)) and concatenation an attaching of characters (e.g. \(2l, la^2\) to \(2a^2l\)). These are pseudo-operations because the objects being operated on are not mathematical objects, but are merely character strings.
criteria operating in the teaching and learning of mathematics in these schools. Both of these types of ground are Imaginary in nature as they are based on imagistic and visually-detectable features of the teacher’s solutions and procedures.

In this example, the teacher uses both iconic and procedural ground in his pedagogy, and at a Symbolic level the constitution of mathematics which emerges from his activity is an Imaginary mathematics - the focus is on imagistic or iconic features of mathematical content and activity. His focus on the similarity of powers in identifying what he calls “like terms” as well as his strong emphasis on spatial rearrangement of terms and his reference to terms as apples and oranges reveal the imagistic focus of his pedagogy. The way in which the terms are worked with as objects themselves, rather than as symbols representing real numbers; the absence of equal signs in his first example; the implicit use of the distributive, associative and commutative properties of addition and multiplication; and the separation of powers from bases, coefficients from unknowns suggest that the Symbolic nature of mathematics is rendered as subject to the Imaginary.

His operational activity not only produces an Imaginary constitution of mathematics, but also presupposes a particular kind of learner. The implied model learner at the level of the Symbolic is ignorant of the distributive, associative and commutative properties of addition and multiplication over the reals, except in an empirical way. Thus despite the intention of the teacher to produce learners who are competently able to carry out the simplification of the given expression, recontextualised as a procedure for the addition of “like terms”, his operational activity tells a different story.

Let us now turn to the written attempts of four learners of example (b) \((x^2 + 4x; -2x + 5)\), which the teacher instructed them to do using both the horizontal and vertical methods.

**Reproduction: the attempts of four learners**

**Learner 1**

![Learner 1's attempt](image)

**Figure 3. Learner 1’s attempt**

The first learner whose work is shown (see Figure 3) uses only the horizontal method for the two examples he attempts. But in the margin next to example (b) he has written “vertical”. He does both examples by first rearranging and then computing, arriving at the correct answer in both cases. He crossed out his first attempt at rearranging the terms for example (b) in his second attempt, as well as in example (c), he arranges the terms by taking the first term of each followed by the second term of each, just as the teacher did, which suggests that he used the teacher’s procedure as an iconic resource, using the same order for selecting terms despite it being unnecessary in this particular example. This could suggest that the criteria he uses to group the terms are based on their position in the original expressions.
Learner 2

Figure 4. Learner 2’s attempt

Learner 2 (Figure 4) uses both methods, but does not complete the computation using the horizontal method. He merely rearranges the terms twice. The first time he groups the $x^2$ term (first term of the first expression) with the 5 (second term of the second expression), then the second time he changes the order – he takes the $x^2$ term first followed by the $-2x$ (which is the first term of the second expression) and then goes to the second term of each expression. It seems that the first time he grouped the “non-$x$” terms together, followed by the two terms with coefficients of $x$, but for some reason he chose to change his grouping. The second time he rearranged as the teacher had done in the example – first terms then second terms of each expression, again suggesting a use of iconic and procedural similarity. He does not compute the answer when using this method. Alongside he used the vertical method (see Figure 4). He used his first rearrangement of terms and aligned them vertically, with the $x^2$ and constant term in one row and the two $x$ terms in the other.

Learner 3

Figure 5. Learner 3’s attempt

The third learner (Figure 5) uses only the horizontal method. He attempts to rearrange the terms but in the process separates the 4 from the $x$ in the $4x$ term, which reflects the separation of coefficients and variables in the speech of the teacher during his explanation. He then goes wrong in his calculation of the answer – he correctly adds 4 and 5, but it is not clear how he gets $-2x^2$. It appears that he then adds the $-2x^2$ and the 9 to get $7x$. This addition reveals an ability to add integers, but not variables, which is consistent with the teacher’s separation of coefficients and variables, and his differential treatment of variable and constant terms.
The fourth learner (Figure 6) completes both methods. In his use of the horizontal method, he does not rearrange the terms as the others have done, but simply rewrites them as they are given, but then goes wrong in his computation of the $x^2$ and $x$ terms. In his attempt at the vertical method, he aligns the $x^2$ and both $x$ terms vertically and the 5 in another column. His answer here is the closest to correct – he keeps the $x^2$ term separately despite his arrangement, but makes an error with the addition of the two $x$ terms.

Discussion: mathematical knowledge and learner identity

When we compare the attempts of these four learners to the teacher’s procedure, we see a reproduction of Imaginary mathematics in response to the teacher’s recontextualisation. The attempts of Learners 1 and 2 show confusion about the criteria used by the teacher for rearrangement of terms, both horizontally and vertically. The attempts of Learners 2, 3 and 4 reveal difficulty with adding terms with the same powers. The work of Learners 2 and 3 highlight this particularly, as they both attempt to add terms which are “unlike”, according to the teacher’s discussion, whereas Learner 4 chooses the correct terms to add to each other when using the vertical method, but makes an error with the sign of the $x$ term in his answer. The separation of 4 from $x$ by Learner 3 reflects the separation of coefficients from unknowns by the teacher. Thus the attempts of all four of these learners reveal the same imagistic focus and rendering of the Symbolic under the aspect of the Imaginary, as seen in the teacher’s procedure.

The recontextualisation of mathematical operations and resultant production of Imaginary mathematical knowledge by the teacher led to the reproduction of this Imaginary knowledge by four students, shaping their Symbolic identity as learners who produce Imaginary mathematical discourse.

This illustrates the co-production of mathematical knowledge and learner identity as Imaginary, instead of Symbolic, at the level of the operational activity.

Concluding remarks

This discussion has drawn on the analytical resources of the Imaginary and Symbolic in describing the teaching (with its recontextualisation) and learning (with its reproduction) of mathematics, and has distinguished between two different levels at which these categories can be used – the level of operational activity and the level of moral or regulative discourse. These two levels of analysis can be used to describe the way in which pedagogy shapes the mathematical knowledge and the identity of the learner. We focused only on the operational activity of the teacher in order to identify the mathematical knowledge produced by him and his learners, and from there to infer the Symbolic model learner – the learner identity presupposed at the level of the operational activity, or instructional discourse. We highlighted the potential for a parallel discussion of the moral discourse in a mathematics classroom in order to ascertain the Imaginary model learner – the learner identity presupposed at this, the level of the regulative. Further analysis is needed in order to ascertain whether this way of talking about what happens in mathematics classrooms is useful in understanding why it is that the mathematics produced by learners is so often different from that which the teacher intends them to be able to produce.
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Aspects of a method for the description and analysis of the constitution of mathematics in pedagogic situations

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We map out aspects of a method for describing the operational activity that emerges in the pedagogic situations for the teaching and learning of school mathematics. We start by describing the unit of analysis—called an evaluative event—and then move on to marshalling theoretical resources that enable us to describe operational activity. Describing operational activity requires us to define the operations and operation-like manipulations that emerge in a pedagogic situation as well as the collections of objects operated over. In that way we produce primary data about each evaluative event as well as the complete pedagogic situation under scrutiny. Such data can then be analysed further to produce more complex data about the situation and enable us to comment on the constitution of mathematics in the pedagogic situations of school mathematics.

Introduction

The general problem engaged with in this paper is that of the constitution of mathematics in pedagogic contexts; specifically, what is constituted as mathematics and how, in the pedagogic situations of school mathematics teaching and learning. The purpose of the paper is to introduce a few of the methodological resources that have developed out of an engagement with the problem. We have chosen to introduce the work by way of an extended discussion of an empirical instance of a grade 8 teacher and her learners engaging with the topic of prime factorisation. Our analysis of the teaching of prime factorisation is not the main purpose of the paper; it is merely a way of opening up a space for the elaboration of the methodological resources we wish to introduce. A number of the foundational ideas of the work have been discussed previously and will not be rehearsed here due to constraints on space (see Basbozkurt (2010a, 2010b), Davis (2010a, 2010b, 2010c), Jaffer (2009, 2010a, 2010b), Johnson & Davis (2010), Mackay (2009, 2010), and Roberts (2009, 2010)).

We start immediately with a discussion of the segmentation of records of teaching into units of analysis and then develop aspects of the methodology as we discuss the teaching of prime factorisation. Background ideas and other material will be discussed briefly as the need to do so arises.

The unit of analysis: the evaluative event

The unit of analysis is referred to as an evaluative event. We shall use a simplified version of the idea here. An evaluative event is composed of a sequence of pedagogic activity, starting with a presentation of specific content in some initial form, and concluding with the presentation of the realisation of the content in a (provisionally) final form. Such finality might be only temporary, as in cases where content requires elaboration over several lessons (or even over several grades). The idea of the
evaluative event is used to partition records of pedagogic situations (video and transcripts of the speech of teachers and their learners) into segments that are homogeneous with respect to the mathematical topic and the particular type of activity that participants in the pedagogic situation are engaged in. Different events can, therefore, be concerned with identical topics but have participants engaged in different activities. For example, a teacher expositing on prime factorisation while her learners take notes and the learners independently working on a set of practice problems dealing with prime factorisation are considered to be different events. The transcription of the video record of a class working on prime factorisation that we will use later is a typical example of a segment of pedagogic activity construed as an evaluative event. Occasionally we find that teachers and learners hit a snag in the elaboration of the mathematics content, or need to address an off-topic question introduced into the situation by a participant, thus prompting a discussion of content not central to the main ideas. In such cases we can think of the detour thus produced as generating a sub-event. Table 1 summarises a segmentation of a grade 8 lesson we observed into six evaluative events, showing the topics, type of activity, and the duration of each event measured in minutes and seconds. Evaluative events 03 and 04 deal with the same content but two events are listed because the teacher and her learners tend to treat the content as an accumulation of discrete procedures, even in cases where the mathematics content might be considered the same. Events 05 and 06 also deal with the same mathematics content but the participants are differently engaged in the two events.

Table 1. A brief description of the evaluative events spanning a grade 8 lesson

<table>
<thead>
<tr>
<th>Evaluative Event</th>
<th>Type</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>01 Prime factorisation of natural numbers [00:00 – 01:26]</td>
<td>Expository</td>
<td>01:26</td>
</tr>
<tr>
<td>02 Multiples of natural numbers [01:26 – 02:50]</td>
<td>Expository</td>
<td>01:24</td>
</tr>
<tr>
<td>03 Addition of fractions with same denominators [02:50 – 04:50]</td>
<td>Expository</td>
<td>02:00</td>
</tr>
<tr>
<td>04 Addition of fractions with different denominators [04:50 – 07:35]</td>
<td>Expository</td>
<td>02:45</td>
</tr>
<tr>
<td>05 How to calculate lowest common multiples [07:35 – 14:08]</td>
<td>Expository</td>
<td>06:33</td>
</tr>
<tr>
<td>06 Calculating lowest common multiples [14:08 – 19:46]</td>
<td>Exercise</td>
<td>05:38</td>
</tr>
</tbody>
</table>

Once a lesson has been segmented into a series of evaluative events the latter are subjected to more detailed description and analysis. In many instances a productive approach to the analysis of an evaluative event is that of considering the manner in which the procedures for the production of solutions to problems are constituted because the effects of the pedagogic structuring of content are registered in the particular realisations of engagements with problems. Procedures can be understood as sequences of transformations, the initial and terminal points of which are expressions of one or other kind, and where each transformation is constituted by one or more operations over some domain, or domains, of objects.

**Objects, operations, pseudo-operations and the arbitrariness of the sign**

We start by drawing attention to a fundamental methodological feature of mathematics that is of the first order of importance, despite its painful obviousness: the operations that populate mathematics are functions. The insistence on operations being functions invests mathematics with great stability at the level of its operations since functions have unique outputs for given inputs. In other words, addition, multiplication, and so forth, all behave in a stable, predictable way because they are restricted to behaving as functions, and that stability is part of the bedrock upon which various mathematical edifices are constructed. The great consequence of the fundamental requirement that mathematical activity be functional at its base—for pedagogy, for curriculum, for policy and for research—is that all processes that are to be deployed as operations in mathematical work in pedagogic situations must be functions. If they are not functions then an essential mathematical property is absent, and what remains cannot be mathematics, whatever other apparent contact with mathematics is enjoyed by such
processes. In other words, if mathematics is fundamentally constituted as the composition of functions at the level of its operations, as we are arguing here, and operations are the stuff that actually enable mathematical processing, then removing the requirement that operations be functions (even if only implicitly) removes the stability enjoyed by the operations; consequently, the “operations” become unstable and, thereby, unusable. No operations, no mathematics.

If we accept that an essential property of mathematics is that its operations are functions, then that property is context independent, precisely because it is essential; that is, it can’t change, or be changed, as mathematics is moved across contexts—like, say, from the field of production to the classroom, or to textbooks, or to the curriculum, or to policy, or to educational research. Any claim that a particular activity is an instance of mathematics, or realises mathematics, is simultaneously a claim that the essential features of mathematics are intact, one of which is that the operations it employs are functions. The presence or absence of the latter property is amenable to testing; we can produce the necessary data for the test by describing the computational criteria used in operational terms.

So, when we refer to the objects of operations we are referring to whatever is taken to be the elements of the domains and codomains of operational activity. An operation, *, is defined in general terms as a function of the form $*:D_1 \times \cdots \times D_k \to C$, where the sets $D_i$ are the domains of the operation, the set $C$ is the codomain of the operation; the fixed non-negative integer $k$, which indicates the number of arguments, is the arity of the operation. For any operation, described as a function, its elements are of the form $(d_1, d_2, \ldots, d_k, c)$ and, gathered together, constitute a subset of the cross product $(D_1 \times \cdots \times D_k) \times C$. In other words, the operation qua function might be considered a particular subset of $(D_1 \times D_2 \times \cdots \times D_k) \times C$, consisting in a set of elements of the form $(d_1, d_2, \ldots, d_k, c)$. Since there is no essential difference between $(d_1, d_2, \ldots, d_k, c)$ and $(d_1, d_2, \ldots, d_k, c)$ we can use the latter, simpler, expression to indicate an element of an operation. The usual basic arithmetic operations—addition, multiplication, division and subtraction—are binary, and are usually defined as functions (or partial functions, when necessary) of the form $*:A \times A \to A$. However, since we are interested in operations and operation-like manipulations including, but also those additional to the basic arithmetic operations, we will use the more general definition of an operation.

The set theoretic description of a function—and hence, of an operation—remains silent on the rule, or process, that generates its elements, telling us only that a function (and so an operation) is what the rule, or process, accomplishes. Stewart (1981: 327), for example, has this to say of the rule associated with a function:

In other words, any ‘rule’ is tantamount to a set of ordered pairs. This is not immediately obvious (it would be tragic if everything in the world was) but, in the words of a well-known politician, ‘You know it works.’

Further, Stewart & Tall (1977: 84-88), remaining with the set theoretic notion of a function, $f$, struggle with the idea of the ‘rule’ associated with a function and end up referring to the ‘troublesome rule’ (p.86) as the set of ordered pairs $(x, f(x))$, just as Stewart (1981; originally published in 1975) did. Differently, however, those adopting category or topos theoretic approaches to functions often experience the set theoretic descriptions of functions as unsatisfactory, not least because such descriptions tend to be silent on the specifics of the rule associated with a function. (See Goldblatt (2006: 17-20) for an illuminating example of a topos theorist’s dissatisfaction with the set theoretic account of functions.) Lawvere & Schanuel, for example, argue that a particular rule for a function—the rule being that which describes the process by means of which each element of the domain is uniquely associated with an element of its codomain—is itself not unique with respect to the function. They discuss an example that clarifies their point: the rule, $f$, ‘add 1 to the input value and then square’, and the rule, $g$, ‘square the input value, double the input value, add the two results and then add 1’, are different even though they can be equated at the level of value:
What the equation \((x + 1)^2 = x^2 + 2x + 1\) says is precisely that \(f = g\), not that the two rules are the same rule (which they obviously are not; in particular, one of them takes more steps than the other) (Lawvere & Schanuel, 1997: 22-23).

Now, just as with functions in general, it is possible to replace an operation—which is the process by means of which domain and codomain elements are associated—by a rule that is composed of more than one operation but which, nevertheless, produces the same \(c \in C\) for a given \((d_1, d_2, \ldots, d_k) \in D_1 \times D_2 \times \ldots \times D_k\) as the original operation. In fact, that is precisely what often happens in the pedagogic situations of schooling. It is also not unusual to find alternate operations, or even pseudo-operations, replacing the operations indicated by mathematical statements in the pedagogic situations of schooling. However, it is not always the case that the manipulations introduced by teachers and/or their learners are operations in a mathematical sense because the structure of a manipulation would have to conform to that of a function to be considered an operation. See Ma (1999), Sfard (2007, 2008), Lima & Tall (2008), Jaffer (2009, 2010a, 2010b), Basbozkurt (2010a, 2010b), and Davis (2010a, 2010b) for examples of instances where teachers and/or learners use alternative and sometimes pseudo-operations.

We therefore believe that it is productive to adopt an extensional stance when analysing pedagogic situations—which simply means that one accepts whatever emerges in the operational unfolding of school mathematics as participating in the constitution of mathematics in the local pedagogic situation.

Now for the arbitrariness of the sign. Saussure describes the sign as follows:

The link between signal [signifier] and signification [signified] is arbitrary. Since we are treating a sign as the combination in which a signal [signifier] is associated with a signification [signified], we can express this more simply as: the linguistic sign is arbitrary.

There is no internal connexion, for example, between the idea ‘sister’ and the French sequence of sounds s-ö-r which acts as its signal [signifier]; the same idea might as well be represented by any other sequence of sounds. This is demonstrated by differences between languages, and even by the existence of different languages. The signification [signified] ‘ox’ has as its signal [signifier] b-ö-f on one side of the frontier, but o-k-s (Ochs) on the other side.” (Saussure, 1983: 67-68; italics in the original.)

When we examine the operational responses of teachers and their learners to the familiar signifiers of mathematics we often find operations, or manipulations, that suggest domains of objects different from those we conventionally associate with those signifiers. For example, Davis (2010a, 2010b) discusses examples of teachers and learners employing procedures for computations on integers that require them to really perform operations over the natural numbers, so that it is some idea of natural number rather than of integer that teachers and their learners use to regulate their operational activity. What we, therefore, often encounter in pedagogic situations is an operationally induced polysemy in response to the signifiers of school mathematics, even when the specific type of object of concern—like integers, say—is explicitly announced. Accepting the Saussurian proposition on the arbitrariness of the sign enables us to argue that the correlation of a mathematical symbol, term or statement with a meaning in a pedagogic situation is a matter for empirical investigation rather than simply to be taken as that which is set out in the mathematics encyclopaedia. In other words, Saussure’s proposition clears the way for us to describe the objects and operations of operational activity in the pedagogic treatment of mathematics in ways that are not bound to what is usually recognised, or expected, as mathematics.

**Describing an evaluative event in terms of objects, operations and pseudo-operations**

Consider the following pedagogic situation. Learners in a grade 8 mathematics class are being taught to generate prime factorisations of natural numbers. Their teacher reminds them of recent work on two methods for generating prime factorisations of natural numbers as they focus on a series of four written solutions to the problem of generating the prime factorisation of 36.
Figure 1. Teacher’s factor tree and ladder methods for generating prime factorisations of natural numbers.

Teacher: So we said there were two methods. There was the .. factor tree .. which was this method [referring to the solutions marked (a), (b) and (c) in Figure 1].

Learners: [Various learners call out.] And the ladder. The ladder. Ladder.

Teacher: Or it was that ladder one [referring to the solution marked (d) in Figure 1].

Learner: The ladder.

Teacher: And then .. But we gave you .. There were four different options on the board, .. And each option gave the same answer. … So for the learners that said the factors of thirty-six was six times six .. ’cause they broke it up further into two times three .. they got the .. same answer .. as the learners who said the factors of thirty-six are nine times four. And then .. nine was broken up into three times three. Four was broken up further into two times two. Again .. the factors were .. two squared times three squared.

We should note that the implicit general domain and codomain of computations for the teacher and her learners is the natural numbers. The teacher’s description of the production of factor trees for prime factorisation is a bit unusual. When factor trees are used to represent prime factorisation the arithmetic operations performed are usually close to those used by the teacher in her ladder method: divide the given number by the smallest prime by which it is divisible, and continue doing so for each subsequent resulting composite factor, until no further composite factors remain (see Figure 2).

The teacher’s factor tree method is, however, a method that differs from her ladder method, and we might describe her procedure, perhaps inaccurately, as follows: starting with any divisor of a given composite number—the divisor being either composite or prime—generate factors until only prime factors remain. The teacher’s procedure does not require her learners to start by selecting prime divisors, even though the textbook she uses (Bull & Hepworth, 2008: 24) implicitly does so (see Figure 3).
That said, the description of prime factorisation in the textbook does seem to emphasise knowledge of multiplication and products rather than the use of prime divisors. That the smallest positive proper divisor$^{11}$ of a natural number is necessarily prime was not made explicit in the teacher’s elaboration of the procedures,$^{12}$ and its absence requires that learners know, or have access to, a list of primes, or are able to decide whether or not a particular natural number is prime when using her ladder method. Now, it appears to be knowledge of multiplication tables for small non-zero natural numbers that is used as the primary resource in the teacher’s procedure, so that her learners are encouraged to start the required series of computations by relying on the knowledge of a given natural number being the product of two other natural numbers rather than by selecting a number explicitly conceived of as a divisor. Further, it is not clear that knowledge of primes is to be used to recognise the terminal points of the procedure since terminal values can be recognised by merely noting that the computations cannot continue other than in the trivial case of attaching to a number branches for 1 and the number itself. Yes, the possibility of having to draw a pair of related branches for 1 and the number itself can be read as indicating that the number is prime, but our point is that it need not be read in that way; it can be read as an indication to terminate the computation without the concept of prime number even being present to the learner. In other words, the explicit use of the notion of prime number is not a necessary regulative resource for the learner; having a sense of “can’t continue” will do just as well to indicate termination of the procedure.

Let’s return to the transcript, where a learner is concerned to know which of the two methods would be privileged in examinations and asks the teacher to indicate her preference.

Learner: Miss, when we do that part in the .. the exams miss, that we can either write that or that method.

$^{11}$ In this paper we take positive proper divisors to exclude 1.

$^{12}$ Suppose that the smallest positive proper divisor, $p$, of $n \in \mathbb{N}$ is not prime, then there must exist a natural number, $s \leq n$, such that $1 < s < p$, where $sp$, since $p$ is composite. So, $s|p \Rightarrow s|n$ because $p|n$, contradicting the definition of $p$ as the smallest positive proper divisor of $n$. Therefore, $p$ must be prime.
Teacher: No! You .. Yes! You will be told .. Factorise. .. Write the number as a product of its prime factors. .. And then you must choose whichever method you .. suits you. Now the .. exercise we did in the Khanya lab .. none of the examples look like this [points at her ladder method solution, displayed in Figure 1]. Hey?

Learners: Yes, miss.

Teacher: All the examples were like this [referring to her factor tree solutions, displayed in Figure 1].

Learners: Yes. Yes, miss.

Teacher: So .. But in the exam we won’t .. specify .. We won’t say you must use this method [referring to the factor tree solutions] or that [referring to the ladder method solution]. It will simply say .. write it as .. a product of its prime factors .. and then you choose the method that you find easiest.

The teacher’s response to the learner suggests that her two methods for prime factorisation are equivalent, but we read her as, ultimately, prioritising the factor tree method: none of the previous problems the class worked on in the computer lab, using the Cami Maths software package, involved her ladder method procedure, for example. The interesting thing is that Cami Maths does have a module on prime factorisation that uses a procedure identical to the teacher’s ladder method, but she chose to use the module on factor trees to teach prime factorisation. The Cami Maths procedure that is equivalent to the teacher’s ladder method requires the user/learner to enter only prime numbers in response to a given composite number, and only the smallest prime divisor in each instance, as is clear from Figure 4. We will now describe the teacher’s procedures in more formal terms. We remain close to the teacher’s description of the procedures. First, her factor tree method. We note that it is the products of natural numbers that are emphasised in the procedure. We also observe that the teacher does not explicitly indicate that the positive integral factors of a natural number are also divisors of the number.

**Procedure 1, “factor tree method”**: given a natural number \( n \), select a pair of natural numbers which, when multiplied, produce \( n \) as their product. In more formal terms, for a given \( n \in \mathbb{N} \), we select a pair \((n_i, n_j)\) of natural numbers \((n_i, n_j) \in \{(n_x, n_y) \mid n_x, n_y \in \mathbb{N}, n_x \times n_y = n, n_x, n_y \neq 1 \text{ and } n_x, n_y \neq n\} \), if such a pair exists. The pairs \((n_i, n_j)\) are, of course, cofactors of \( n \). If there is such a pair of natural numbers, \((n_i, n_j)\), then we repeat the selection of a \((n_i, n_j)\) for each \( n_p \); otherwise we terminate selection of a \((n_i, n_j)\) for the \( n_p \). If no further \((n_i, n_j)\) can be selected for any of the \( n_q \), then we take the product of the \( n_q \) to be the desired result. Finally, we express that product as \( n \) as powers of the terminal \( n_q \): \( n = \prod_{i=1}^{k} n_i^{m} \), where \( n_i, m \in \mathbb{N} \).

![Figure 4. Cami Maths interface for prime factorisation, showing that the user is obliged to use the smallest prime divisor at each point in the computation and to write the solution](image-url)
starting with the smallest prime divisor.

As we noted previously, multiplication over the natural numbers—i.e., \( \times(n,m) \rightarrow n \), where \( n,m \in \mathbb{N} \)—is an operation central to the procedure. Here, \( \times: \mathbb{N} \times \mathbb{N} \rightarrow \mathbb{N} \). More importantly, however, a demand is made on the learner to select an appropriate pair of natural numbers in response to a given natural number. Now selection is usually thought of as a nullary operation—i.e., an operation of arity 0—but we find it helpful to think of selection in terms of what it is that is to be selected in this context because the selections we make are rarely unmotivated or unbounded. We indicate selection by \( \text{SEL}(c,T) \rightarrow t \), where \( c \) indicates a specific object-type and \( T \) is the particular set of objects from which a selection of the object, \( t \), is to be made. Here \( c \) is taken to be a pair of natural numbers while \( T \) is the particular set of pairs of natural numbers that are proper factors of a given natural number. In this specific instance, \( \text{SEL} \) has \( \mathbb{N}^2 \times \{(n,n) | n \times n_1 = n, \text{ where } n,n_1 \neq 1 \text{ and } n,n_1 \neq n, \text{ and } n,n_1,n \in \mathbb{N} \} \) as its domain and \( \mathbb{N}^2 \) as its codomain. That is,

\[
\text{SEL}: \mathbb{N}^2 \times \{(n,n) | n \times n_1 = n, \text{ where } n,n_1 \neq 1 \text{ and } n,n_1 \neq n, \text{ and } n,n_1,n \in \mathbb{N} \} \rightarrow \mathbb{N}^2.
\]

(1)

The learner is to select an element of the set \( \{(2,18),(3,12),(4,9),(6,6),(9,4),(12,3),(18,2)\} \) initially. Since multiplication over the reals is commutative we might consider reducing the set to a set of pairs like, say, \( \{(2,18),(3,12),(4,9),(6,6)\} \). The procedure works adequately provided the learner is required to factorise a series of familiar natural numbers; that is, natural numbers for which s/he knows at least one pair of factors. We can think of the procedure as requiring factors to be selected from a notionally extended multiplication table available to the learner, like that displayed in Figure 5. However, where the learner has no direct access to the factors of a number that arises in the computation s/he has to amend the procedure to produce the required factorisation. Now for the teacher’s ladder method. We shall indicate the set of prime numbers by the symbol \( \mathbb{P} \). Of course, \( \mathbb{P} \subseteq \mathbb{N} \).

Procedure 2, “ladder method”: given a natural number \( n \), divide \( n \) by its smallest prime divisor, \( p_1 \). If the result, \( n_1 \), is greater than 1, then divide \( n_1 \) by the smallest prime number by which it is divisible, \( p_2 \). If the result, \( n_2 \), is greater than 1, continue with the procedure, dividing each subsequent \( n_i \neq 1 \) by the minimal prime by which it is divisible, \( p_i \), until we get \( n = 1 \). We take the prime factorisation of \( n \) to be the product of the powers of the \( p_i \) since the \( p_i \in \mathbb{P} \) are the prime factors we seek: \( n = \prod_{i=1}^{m} p_i^m \) where \( m \in \mathbb{N} \).

The central focus of the procedure is division, i.e., \( \div(n,p) \rightarrow n_{i+1} \), where the \( n,p \in \mathbb{N} \) and the \( p_i \) are the smallest prime divisors of each of the \( n_i \). So, \( \div: \mathbb{N} \times \mathbb{P} \rightarrow \mathbb{N} \). \( \text{SEL}(c,T) \rightarrow t \) makes an appearance once again because the learner has to select the smallest prime divisor of a given natural number, \( n \), from the set of primes. In this instance \( c \) indicates an element of the set of primes, \( \mathbb{P} \), and \( T \) is the set consisting of a single element, \( \{t \in \mathbb{P} \text{ s.t. } \forall p \neq t \text{ where } p \mid n \Rightarrow t < p, p \in \mathbb{P} \} \). \( \text{SEL} \) has as its domain \( \mathbb{P} \times \{t \in \mathbb{P} \text{ s.t. } \forall p \neq t \text{ where } p \mid n \Rightarrow t < p, p \in \mathbb{P} \} \) and, as its codomain, \( \mathbb{P} \). That is, \( \text{SEL}: \mathbb{P} \times \{t \in \mathbb{P} \text{ s.t. } \forall p \neq t \text{ where } p \mid n \Rightarrow t < p, p \in \mathbb{P} \} \rightarrow \mathbb{P} \).

(2)
The demands made on the learner by the two procedures are very different: (2) requires a bit more than multiplication facts about familiar numbers, as is demanded by (1). Both procedures require the learner to construct part of the domain of SEL. In (1) the part of the domain that needs to be constructed is the set \( \{(n_i,n_j)|n_i \times n_j = n, \text{ where } n_i,n_j \neq 1 \text{ and } n_i,n_j \neq n, \text{ and } n,n_i,n_j \in \mathbb{N} \} \), or some subset of it, and it is clear from the teacher’s procedure that any element of the set will do as an output value, if it exists. In (2) there is only one output value implied by the part of the domain the learner has to construct, indicated as the set \( \{t \in \mathbb{P} \text{ s.t. } \forall p \neq t \text{ where } p|n \Rightarrow t \prec p, p \in \mathbb{P} \} \), if it exists.

Both procedures are variations on **direct search factorisation**, which is the simplest of the procedures available for generating prime factorisations of natural numbers: for any natural number, \( n \), test the natural numbers between 1 and \( n \) for proper divisors of \( n \), starting from 2; every divisor of \( n \) is a factor of \( n \). Only the divisors between 1 and \( \lfloor \sqrt{n} \rfloor \) need be tested since, if all the natural numbers less than \( \lfloor \sqrt{n} \rfloor \) have been tested, then all possible factors and their cofactors have been tested. As soon as a proper divisor for a given \( n \) is found the process is repeated, until no further proper divisors can be found. The product of the proper divisors is the sought after prime factorisation. Recall that the smallest proper divisor of a natural number is necessarily prime. This procedure does not depend on selection in the way the teacher’s two procedures do. Here we simply start from 2 in our search for a divisor and continue until we find one by increasing our potential divisor by one each time, repeating the whole process as many times as required, up to \( \lfloor \sqrt{n} \rfloor \).

### Concluding remarks

We can now strip off all the discussion and argument we used to arrive at the data produced in the previous section. What we need to generate an initial description of the mathematics constituted in a pedagogic situation is, first, a segmentation of records of pedagogic activity into evaluative events. Next we describe the operational activity that emerges in each event by defining the operations and operation-like manipulations empirically encountered in each event, as well as the collections of objects operated over. For any mathematics topic announced in an event we also consider the cluster of inter-related definitions, propositions and procedures that are indexed by the topic in the encyclopaedia. The extent of the latter is, of course, to be realised in a manner constrained by the demands of the grade-specificity of the particular pedagogic situation.

The extended space of objects over which operations and operation-like manipulations unfold can now be described, giving us a picture of the kind of stuff that emerges within and across events. The list of operations and operation-like manipulations that we describe shows us how the stuff is processed at the level of individual manipulations as well as in sequences of manipulations. Armed with reasonably precise descriptions of the stuff and processes of pedagogic situations we can compare what we find there with the mathematics content we would expect to find and, if we so desire, begin to map the deviations of that which is constituted as mathematics in the pedagogic situation from what is expected as content and explore the reasons for and effects of such deviations.

For example, let’s return briefly to the direct search factorisation procedure, which may well appear simple-minded and mechanical, but the automaton-like features of the procedure are precisely what is mathematically interesting. The absence of selection from the direct search factorisation procedure indicates that it is mathematically complete without needing to refer to its user. The teacher’s procedures, on the other hand, depend on processes of selection (SEL) undertaken by the learner and are, in that sense, mathematically incomplete. This is somewhat surprising because the teacher’s procedures appear to be motivated by a desire to regulate the learner to produce the required
computations despite the state of their knowledge of the primes and of prime factorisation. That is, the teacher hopes that the success of whichever procedure they choose to use depends on what they (can be expected to) know prior to an engagement with the current content, so that it doesn’t matter whether any particular learner’s knowledge of the content is robust or lacking. The teacher’s strategy for dealing with content absences in her learners is not one that attempts to work with them on eradicating those lacks but, instead, one that attempts to sidestep the effects of lacks by rendering them irrelevant. The problem with the strategy in this specific instance is that the presence of a lack that the teacher attempts to foreclose with her procedures returns at the operational level in the form of a demand for learner input into the procedure. What is, perhaps, truly foreclosed is a more nuanced and mathematically principled appreciation of prime factorisation.

References


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What Teacher Educators consider as best practices in how to prepare pre-service teachers for teaching mathematics in multilingual classrooms

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This paper reports on an investigation into what Teacher Educators consider to be best practices in how to prepare pre-service teachers to effectively deal with the challenges of teaching mathematics in multilingual contexts; and how what they (teacher educators) consider as best practices inform their own classroom practice. 12 Teacher Educators (TEs) from 4 universities in a Province in South Africa participated in the study. Through a qualitative analysis of the interviews, 5 practices emerged as best practices for these teacher educators: the use of code switching, the creation of an environment of trust in the classroom; the use of one (rather than two) medium of instruction – English; the use of linguistic metaphors that the languages present in the class potentially provide for use in mathematics; and finally, the creation of awareness of the multilingual context in which pre-service teachers would teach at the end of their qualification. Given that most teacher in South Africa teach in multilingual classrooms and teacher education research on mathematics education has not, thus far, focused on multilingual mathematics education, it is hoped that these five practices would serve as a provocation for both teacher educators and researchers alike. The author also cautions against the adoption of imported practices from other countries and argues that bearing in mind the distinctive nature of multilingualism in South Africa is the key to delineating practices that are more likely to work in the South African context.

Introduction

Concerns on improving the quality of teacher education have followed quite an interesting trajectory over the past centuries. It can be argued that the paradigm shifts in what constitutes quality mathematics teaching have aligned themselves very intricately to the shift in the
perception of the nature of mathematics, what constitutes mathematical knowledge and what it means to engage with mathematical activity (Wood, 1996). Over the years, from the notion of mathematics as “a set of rules and formalisms invented by experts, in which everyone else is to memorize and use to obtain unique correct answers” (Romberg, 1992: 453), most psychologists and educationists now conceptualise mathematics as involving the understanding of mathematical concepts as well as the ability to communicate mathematically. Moschkovich (2002), for example, holds that in addition to algorithmic competence, solving word problems and using mathematical reasoning, interaction/communication in the mathematics class is also important in the teaching and learning of mathematics. Hence, the argument by both research (Pimm, 1987, 1991; Adler, 2001; Setati 2005; Sfard, Nesher, Streefland, Cobb & Mason, 1998; Moschkovich, 1999, 2002) and curriculum (DoE, 1997, 2002) is that learning to communicate mathematically is a central aspect of what it means to learn school mathematics. From this new understanding arise not only questions regarding mathematics knowledge for teaching and pedagogic content knowledge, but fundamentally, questions concerning teachers’ knowledge of the use of language(s) to create epistemological access to the mathematics content. The situation takes on an added complexity in multilingual classrooms. In multilingual classrooms of learners whose home language is not the language of learning and teacher (LoLT) and who are not yet proficient in the LoLT, teachers are faced with the dual challenge of striking a balance between attention to mathematics, attention to English (LoLT) and attention to mathematical language (Barwell, 2009). It can be argued that it is not a given that pre-service teachers would acquire the skills involved in dealing with this challenge by the mere experience of being in a multilingual environment, but rather through some form of formal teaching or induction. Teacher educators need, therefore, to enculturated pre-service teachers into the dynamics involved in teaching mathematics in multilingual classrooms.

The question is: How are teachers trained to deal with teaching mathematics to multilingual learners whose first language is not the language of instruction? This paper reports on the first of two phases of a wider research study which investigated the pedagogic/discursive practices of teacher educators who are preparing pre-service teachers to deal with the complexities of teaching in multilingual classrooms where learners learn mathematics in a language which is not their home language.

The study is informed by the anthropological perspective of situativity which holds that, in context, different discourses give rise to different kinds or forms of knowing (Putnam & Borko, 2000) and that the pattern of language used by teachers and students within and about a particular content area (mathematics in the case of this study) would determine the nature of enculturation into the discipline and invariably, would lead to the internalisation of the ability to engage in discursive mathematical practices in particular kinds of ways (Brilliant-Mills, 1994). The knowledge, skills, and practices of the teacher educator in bringing this to bear, – of creating an enabling environment for the learning of mathematics, cannot be undermined. In a multilingual pre-service class, therefore, the practices used by the teacher educators, therefore, make teaching a central focus of professional learning experiences for the pre-service teachers. Using the anthropological perspective of situativity, the main aim of this first phase of the study reported in this paper was to describe, interpret, and interrogate teacher educators’ practices in pre-service multilingual mathematics classrooms and what, given their context, they consider as the best practices in creating opportunities for epistemological access in multilingual mathematics classrooms. Hence, in this paper, the following specific question is of interest: What do teacher educators consider to be the best practices in how to prepare pre-service teachers for teaching mathematics in multilingual classrooms and how
does what they consider as ideal inform their practice? In this paper, the term “practice” is taken to incorporate the mathematics-related activities that teacher educators engage in deliberately with the aim of developing mathematical proficiency and/or with the aim of enculturating pre-service teachers into the dynamics of teaching mathematics (in multilingual contexts).

One size fits all?

As Broeder, Extra & Maartens (2002) rightly pointed out, South Africa presents a complex and interesting picture of multilingualism. This is due not only to its political history of apartheid, but also to its very distinct nature of multilingualism. Of the 11 (official) languages in South Africa, nine are indigenous African languages. These African languages can be grouped into two major groups based on their linguistic distance: The Sotho languages and the Nguni languages (Linguistic distance is taken as the extent to which two or more languages differ from each other/one another with regards to, amongst myriad other characteristics, vocabulary, grammar, written form, structure and semantic aspects of the language and their status). The languages in each of these groups are mutually intelligible (this is not the case with the remaining two African languages: Tshivenda and Tsonga) and are linguistically very ‘close’. Because of this mutual intelligibility of languages, it becomes easy for one to learn the other indigenous languages. It must be noted that this is not the case with most multilingual settings in other African countries. The example of Nigeria is a case in point. Even though there are over 250 indigenous languages in Nigeria, most of them are very autonomous in the sense that they share very little (if at all) common vocabularies. In most classrooms in most cities in Nigeria, there might be about 10 completely different languages present in the classroom, so much so that if the teacher uses his/her home language to teach, a good number of learners would not understand and would be thus, disadvantaged.

Elsewhere (Essien, 2010), I have argued that in her comparison of the South African linguistic context to that of Nigeria, Cele (2001) ignores both the fact that the Nigerian indigenous languages are mostly autonomous and mostly linguistically very distant from one another. She also ignores the fact of the existence of the Pidgin language. This has serious implications for her recommendation that “the South African education language policy should be modeled after countries like Nigeria that in spite of many indigenous languages existing in their cultural fabric, English is used as an official unifying factor” (Cele, 2001: 192). I argue that not only are the colonial legacies or the historical contexts of language development in a country important in determining what the best practices are in teaching and learning, but also important is the nature of the languages (indigenous and otherwise) present in the country in question. Hence, practices that have been proven to work in multilingual classrooms elsewhere may not necessarily be the best practices in the context of South Africa.

Research design

In order to address the critical questions which this research sought to explore, a qualitative case study approach was adopted. Semi-structured interviews focusing mainly on teacher educators’ practices in multilingual classrooms were conducted with teacher educators and tape-recorded. These interviews were then fully transcribed to enable analysis.

Sample
This first phase involved the interviewing of 12 teacher educators at four universities in a province in South Africa. Because of the distinct nature of multilingualism in South Africa as argued above, in the selection of participants for the study, all the teacher educators who were newly employed in the participating universities, but who had experience in teacher education from other countries were systematically excluded from the study. Teacher educators who were newly employed and had no previous experience in teacher education were also excluded from the study since the interviews took place at the beginning of the academic year. Those who were newly employed in the participating universities, but had experience in teacher education in other teacher education higher institutions were, however, considered for interviews in this phase. Furthermore, teacher educators teaching either of (or both of) mathematics methods and mathematics content courses were included in the study. Permission from the relevant departments of each of the universities was granted to the researcher for the purpose of this research. All 12 teachers selected for the study were involved in teaching multilingual mathematics pre-service teachers. Amongst other questions, TEs were asked what, for them, constitutes the best practices with regards to preparing pre-service teachers for teaching mathematics in multilingual contexts; whether or not TEs think pre-service teachers need to be apprenticed into particular ways of teaching mathematics in multilingual contexts and what TEs think needed to be done to accomplish this. The pronoun, ‘she’ would be used for all the teacher educators in this study to protect the anonymity of the TEs.

**Data analysis and discussions**

In what follows, I discuss the five practices that emerged as best practices in preparing pre-service teachers for teaching mathematics in multilingual classroom.

**The use of Code switching**

Ayeomoni (2006, p. 91) defines code as “a verbal component that can be as small as a morpheme or as comprehensive and complex as the entire system of language”. Given this definition, a single morpheme in the Zulu language, for example, can be regarded as a code, so also is Zulu language itself. Code switching has been defined by many researchers and scholars. In this paper, I take code switching as a term which covers the phenomena of alternating between two or more languages within the same conversation.

A noteworthy finding in this study was that all 12 teacher educators were in a position where they could not code switch in their classrooms (for various reasons such as the language infrastructure of the classes they were teaching or their inability to speak the African languages). The context depicted in Excerpt 1 was typical to most of the teacher educators in the study.

**Excerpt 1**

R Do you sometimes code switch?

T.E Elm, for me, it is difficult because of the background. Because the students we have here are from all over South Africa. You find students as far as Venda. In fact, even in the class, we have Vendas, Spedis, Shangans, we’ve got Zulus who are in the majority, we’ve got Xhosa and Ndebele. So, for me as a lecturer, when to code switch is going to be a problem, because some would not understand. It would
disadvantage others when I try to…like even myself, I don’t know all those languages. But what I realise is that, when I give them something to discuss, they switch to their language. You see, they don’t discuss it in English…

Even though as teacher educators they did not code switch in class, they all agreed that code switching is a good practice which could have added value to their teaching. All 12 teacher educators, therefore, said they encourage code switching by the pre-service teachers in their classes. They do so by asking learners for mathematical expressions in their home languages; asking learners to interpret/translate to the teacher Educators when a student asks questions in another language not familiar to the TE; by encouraging learners to do group discussions in a language they are comfortable in; and/or by using metaphors that the different languages in the class potentially provide for use in mathematics (I will return to this last point in a later section). Excerpt 2 is reminiscent of the sentiments of other teacher educators with regards to what they do in class and the advice the teacher educators give to their students when they go for practical teaching:

**Excerpt 2**

R  Ok, do you notice any linguistic challenge when you visit them during teaching practice?

TE1  ...My usual resolve is that if you see that your learners are grappling with the language, break the concept in as many parts as possible. Let the learners bring in some input, maybe *call a learner and say, how would you explain it in Xhosa*. Then the learner would explain in Xhosa and you ask: have you understood? Yes. ...That's what I mean by a square, or that's what I mean by a triangle ...3 sided.

TE2  Ok, What I realise is that they use code switching a lot, because they are in places, let’s say for instant, in Nelspruit, they speak Swati there, so they are able to code switch. It’s not a problem. I don’t have a problem because the learners would benefit. And I always encourage them that they can only code switch if they realise that the learners have a problem with understanding something. It should not be a matter of making things easy for them [pre-service teachers]. It should be to the advantage of the learners. That’s what I always encourage them to do. The medium is English, and from there, they can only code switch where there is a need.

TE1 uses the practice of asking students to explain concepts in their home language with the hope that this would enable epistemological access to concepts which the students are struggling to understand. What is interesting is that TE2 also does encourage code switching as a strategy of teaching, but on one condition – that it is for the benefit of the learners in the class and not as a strategy for making the pre-service teacher able to switch to a more comfortable language for him/her in order to communicate his/her message. In this teacher educator’s practice, she tries to get learners who are not proficient in English to ask questions in English and only employs the services of a translator as a last resort. This strategy of persuading pre-service teachers to communicate mathematically in English resonates with the
strategy used by other TEs who persuade their pre-service teachers to present lessons/tasks in English so that by so doing, they can enrich themselves linguistically in the LoLT and become better at communicating mathematically in the language of learning and teaching. In this regard, Kasule & Mapolelo (2005, p. 611) notes this concerning the dilemma of being an African teacher:

African teachers know that they must enhance learners’ exposure to the English language, must overcome their own sense of inadequacy in that language, and must ensure that learners are prepared for higher education and that outside world, so they must not code switch; but they must ensure that learners understand and participate in classroom talk even if the teacher speaks a home language his learners do not speak.

This is exactly what TE2 envisages when she discourages her students from code switching to make up for their English language deficiencies, and when he and the other TEs encourage their students to communicate in English despite their students’ low proficiency in the English. In a study by Setati (2008), it was also found that both teachers and learners who position themselves in relation to English are concerned with access to social goods (higher education, jobs, etc). The conclusion that can be drawn from the above discussion is that even though code switching is an important strategy for access to mathematics in multilingual classrooms, sometimes, the deliberate use of English is essential for enculturating students into the mathematics English register.

Creating an environment of trust

Trust is also important for teaching in a multilingual context according to the TEs. It is important that the students do not feel the TE looks down on them because of their language deficiencies or/and that the TE are not negatively critical of their culture as evident in excerpts 3 and 4:

Excerpt 3

TE: I got my degree in Afrikaans and later on, had to study in English for my honours degree… So, I can identify with my students in many ways. It is difficult and they are scared and it is intimidating and overwhelming, and we need to create that environment where they can comfortably risk things, risk making mistakes, risk talking English and learning the language while they are learning the subject specific discourse.

From the TE’s utterances in excerpt 3 (above), it can be deduced that what constitutes the best practice for this TE is the creation of an environment where students can risk making mistakes when they speak English, that is, where students are not shy to express their mathematical thinking in the language they are still learning even as they speak; where students see their linguistic inadequacies as an opportunity for becoming linguistically enriched. This sentiment is also echoed by the TE in excerpt 4:

Excerpt 4
Given your vast experience of teaching both in-service and pre-service teachers, what can we learn from you in terms of what it means to teach in multilingual pre-service classrooms of pre-service teachers preparing also to teach in multilingual classrooms?

I think, elm, ... I had in the past researched into the multilingual situations, so I am very sensitised to the whole importance of the total human being’s immersion in his world... In short, what I am trying to say is that it is important that we acknowledge the fact that our students are coming to our classrooms with a multitude of background information that we are not familiar with given the multicultural and multilingual situation of our country. And not only acknowledging it, but making it apparent from the one go, that you respect them, and that you think that they can make a contribution; that the learning process is a 2-way street. For me, that has worked over the years, because that also sets the tone for respect and for trust. Because of trust, the student knows he/she would not be ridiculed if he/she makes a mathematically incorrect statement. I look at this whole thing as some kind of immersion in the context of South Africa, and we must be very careful not to take another country’s model of multilingual situation as model for South Africa.

It can be argued that some form of teacher-learner trust is required in any classroom (including a monolingual context where the students and the TE share the same language). In a multilingual context such as that of South Africa, the issue of trust takes on an added importance in the creation of an environment conducive for learning. The nature of multilingualism and therefore, any attempt at suggesting what the best practices for teaching and learning are for a country, as I have argued previously, depends not only on the nature of the languages (indigenous and otherwise) present in the country in question but also on the colonial legacies or the historical contexts of language development in a country. In South Africa where mother-tongue education was used as a tool for suppression and where English was synonymous with superiority, power and whiteness and fluency in English was perceived as an “emblem of educatedness”, the issue of creating or building trust (especially between monolingual/bilingual TEs and students) – of creating an environment where students feel comfortable to speak English without fear of ridicule or criticism, becomes essential in multilingual classrooms. To go back to Cele’s (2001) recommendations, the issue of the creation of an atmosphere of trust is a typical example of where the colonial history plays an important part in what is perceived as a best practice for a particular context. The remark, therefore, by the TE (in excerpt 4) that South Africa ‘must be careful not to take another country’s model of multilingual situation as model’ is of critical importance.

The use of Afrikaans and/or English as media of instruction

In the preceding section of this paper where I engaged with the distinctive nature of multilingualism in the South African context, it must be noted that at the micro-level of the individual universities, what teacher educators considered as best practices to some extent was a function of the educational university contexts in which they find themselves. It is, therefore, not surprising that some of the practices mentioned by teacher educators from historically black universities were not a concern for teacher educators in historically Afrikaans medium universities and vice versa. In excerpt 5 below, the teacher educator from a historically Afrikaans university was responding to the question about what he considers as best practices given her (multilingual) context of teaching and given the fact that her students would most likely teach mathematics in multilingual classrooms:
Excerpt 5

TE You know at the beginning, I had Afrikaans and English in two separate classes. Then I said no, no, in one class. At the beginning, they didn’t like it, but now they are actually fine with that. And I think it is a good way to do this because, if they are going to be teachers, they’ll get all kinds of learners in one class. And so at university, it’s not gonna help if you are going to sit in only Afrikaans class. So, I think this is a way of learning how to cope when you are out there as a teacher. That is why I also advice my students that they go to a school that they are not used to. So if you attended a rural school, you try to go to a different kind of school. Or if you attended some kind of a modern school, try to do your school practice in a different school. Otherwise, you are not going to learn anything because you were there for 12 years and you will only gain experience from standing from the other side of the desk, but you have to gain experience in other cultures as well.

What comes out forcefully in this excerpt is that for the TE, the best practice for preparing pre-service teachers to deal with the challenges of teaching in multilingual contexts is not to have separate classes for students according to their language background at the university or teacher training level. Her consideration for this conviction of this as a good practice is foregrounded by her advice to students to go to a different school to what they are familiar with during their teaching practice. In the TE’s own practice, even though her university allows for a course in the first year to be taught both in English and in Afrikaans and for the students to choose which of these classes to attend, she merged the Afrikaans and the English class together in order to give all students the opportunity to acquaint themselves with the cultures of others. Her reason for this is because when they (students) become qualified teachers, “they’ll get all kinds of learners in one class”.

The use of linguistic metaphors

Three of the teacher educators interviewed identified the use of linguistic metaphors that the different languages that are present in the class potentially provide for use in mathematics as evident in excerpt 6 from one TE:

Excerpt 6

R … Your students would eventually go to teach in multilingual classrooms. So, what for you would be the best practices in teaching such students? That is, what would you regard as best practices given your context and not necessarily minding what the constraints you as a person might have?

T.E1 …for me the best practice would be if I know the languages to such an extent that I can use the metaphor of the languages. If I knew these languages, I would still teach in, say, a shared language, English for instance. But if I were aware of imageries evoked by the different languages [present in the class], I would make a point of bringing that in. I am talking about something like, if you think of the concept of multiplication. There is a lovely Zulu word for multiplication called phinda phinda, right? I have heard it in adult education and in school, when they don’t understand and you say ‘it’s like phinda phinda’, …they say ohhhhh, repeat repeatedly. And they understand it. So if I know more of those, I would use them and make explicit in teaching. In Geometry for instance, we have picked up that there
are subtle differences in positional language in different languages. For instance, in some of the African languages, there is a difference between ‘behind’ with regards to if you can see the object that is behind or if you can’t see it at all. Now, I don’t know all those differences. If I knew them, I would bring them in to enrich positional language. And I think it can help English speaking people to, I would say, generate more interesting cases of mathematical applications.

For the Teacher Educator in excerpt 6, a good practice would be to be able to use multiple languages to engage with students using different metaphors and imageries around a mathematical register in the different languages present in her class to enable epistemological access.

Another related best practice for teaching in multilingual class for this TE is the ability to use subtle differences for expressing a mathematical idea/word that exist in one language to enrich discussions around the mathematical concept under consideration. She cites an expression in the Zulu language that expresses the concept of multiplication – *phinda phinda* – ‘repeat repeatedly’ and how she uses the few words she knows in some of the students’ home languages to teach in class. Studies (see for example, Arzarello et al, 2005) have shown that the use of analogical representations (metaphors) can help in the development of mathematical concepts. This, in my opinion, is much more so if in a multilingual class, the metaphors are in the home languages of the learners and are used to enrich classroom discussion around a particular mathematical concept.

**The creation of awareness of the multilingual context pre-service teachers would be teaching after their qualification**

The TE in excerpt 7 cites an example with White students who do not know the African linguistic structures and do not think there is a big problem in the class since they believe that once the students are proficient in English, that is all they need.

T.E  Let me give an example; many white students that are here, are not aware of the complexity of the African language structures. And I see it and I talk to them about it. They don’t think there is a big problem in the class. “If I can speak English and the teacher speaks English, that’s fine” – that’s what they think. Whereas, my black students, …I was once in a class where the students were trying to understand the mathematical term for the spacial term, ‘behind’ in 4 dialects in Shangan. They couldn’t agree on the meaning of the term in their language. And the white kids were surprised because they couldn’t understand why that was a problem. Of course, for them they only have one word for it. What I’m saying is that depending on your background, your understanding of the problematic situation of language is sometimes very limited. The white kids are not familiar with this, the white teachers are not familiar with this – *the whole thing of double language, kafasi fasi – double language to show steps of big, bigger biggest* – different terms for showing your degree of comparisons. So, in this country, I think there is definitely a need for people to be aware of the complexity of language imbedded in culture. The language structure of the African languages is different from English

**Excerpt 7**
Excerpt 7 foregrounds the fact that TE is awareness of her context of teaching and the students’ lack of awareness of the important role language plays in multilingual contexts of teaching. As Wagner (2007) argues, students need to be able to problematize language in such a way that they (students) come to the realization that language problems are inherent in mathematics classroom discourse.

Besides the issue of linguistic structures which both teachers and students need to be aware of, 5 teacher educators strongly think that creating an awareness of the complexity of teaching mathematics in multilingual contexts (starting with teacher educators themselves) is important in dealing with the teaching and learning of mathematics in the South African context. This, according to them, can be done by introducing materials and reading (that deal with this issue) to students (and lecturers). These TEs also argue that the ideal situations would have been if students knew basic concepts in mathematics in their home language, but since this is not the case, a multitude of media of communications – reading, writing, talking, etc, needs to be employed to support students in the teaching and learning of mathematics.

Some TEs suggested that one of the things universities and colleges of Education needs to do is to enculturate pre-service teachers into teaching strategies and approaches that specifically deal with and aim at creating awareness of the relationship between mathematics and language, especially with regards to multilingual students. They urge anyone teaching mathematics in multilingual class to consult with more experienced teacher(s) (educators) and literature which deals with teaching mathematics in multilingual contexts in order for them (teachers) to acquaint themselves with the intricacies of teaching mathematics in multilingual contexts. They also indicated that at the undergraduate level, a module or a course which focuses on language issues in the teaching and learning of mathematics in multilingual classroom needs to be introduced. As I have argued elsewhere (Essien 2010), even though a course at the university level that attends to teaching and learning in multilingual classrooms is essential, creating awareness of the multilingual context of teaching and learning and what it entails should be a thread that runs through the entire teacher education (mathematics) curriculum.

**Conclusion**

The findings from this study clearly indicate a strong awareness on the part of the teacher educators about i) the context of their classroom practice and ii) the prospective context in which the pre-service teachers would be teaching at the end of their qualification. This awareness runs through what these TEs consider as best practices in enculturating pre-service teachers into the complexity of teaching and learning mathematics in multilingual classrooms.

At the micro level of the universities, it can be argued that the delineation of what constitutes the best practice for the TEs in this study was, to some extent, dependent on the immediate educational context in which teaching and learning occurs (at the universities). Such contexts included the context of teacher education; the context of the individual universities involved in the study; the language infrastructure of the classroom; and who the teacher educator is (that is, whether the TE is monolingual, bilingual/multilingual). But as Barwell (2009) argues, these different contexts (at the micro-level in universities) have something of a wider value to contribute to teaching and learning in the (the South African) multilingual contexts.

The question that remains to be answered is: to what extent should teacher training institutions adopt some or all of the 5 practices delineated by the TEs in this study? In South Africa where most of the classes are multilingual and where most learners, despite their low English language proficiency choose to do mathematics in English (Setati, 2008), one of the
challenges for teacher education institutions, teacher educators and researchers alike is to legitimate practices that would equip pre-service teachers to deal with the complexity of teaching effectively in multilingual mathematics classrooms. Investigating what teacher educators themselves consider as best practices is an integral part of that process.

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University students’ experiences of a mathematics service module:
Numerical Skills for Nursing

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Abstract

Universities offer a variety of Mathematics service modules. These modules service a wide range of fields such as the Sciences, Health Sciences, Business Sciences, Education and Engineering. This study focuses on the students’ experiences of a mathematics service module in the Health Sciences. This module, called Numerical Skills for Nursing, is compulsory for students doing an extended Nursing Degree at an Eastern Cape University. Both qualitative and quantitative methods were used in this study. The findings reveal that there are key principles which characterise the teaching and learning of this module and these are discussed. These principles may also have relevance for other Mathematics service modules.

Introduction and background

Mathematics departments at universities tend to offer a variety of modules or courses which service a wide range of academic departments and faculties (Howson, 1988). One area where mathematics plays an important service role is in the health sciences. As far back as 1939, there has been concern about nurses’ ability to do mathematical calculations (Faddis, 1939 cited in Weeks KW, McWhirter G and Woolley N, 2003) There is evidence from international nursing literature and the department of health (in the UK) that medication dosage calculation errors continue to be committed by health care professionals in clinical practice. This concern has led to nursing training institutions examining their curricula and
looking for ways in which essential mathematical calculations can be incorporated into courses for nurses (Sabin, 2001).

Sabin (2001) also reports on the work done by Hilton (1999) and others who identified some key components of nursing calculations. These include the following:

- Addition of three digit integers
- Subtraction involving three digit integers
- Multiplication involving two digit integers
- Division of an integer by a number between 1 and 9.
- Multiplication of two decimal numbers
- Multiplication of two fractions
- Division of two fractions
- Conversion of fractions to decimals
- Conversion of decimals to percentages
- Calculating percentages of integers
- Conversion between SI units
- Multiplication of integers and decimals by 10, 100 and 1000.
- Evaluation of expressions of the form \((A \times B) \div (C \times D)\).  

(Sabin, 2001)

It would appear from the components identified above that numerical calculations should form an integral part of any nursing curriculum. This study was undertaken at a university where service modules are offered in both mainstream and extended programmes. Included in these offerings is a six month module to prospective nurses. This module, aptly named “Numerical Skills for Nursing” is included in its nursing degree programme for extended studies students. This module comprises most of the above components, with additional topics, relevant to a nursing context, also included. Although this module is not offered to mainstream students at present, there are plans in place to do so in the near future.

**Research question**

This study examines the experiences and reflections of nursing students who have completed the “Numerical Skills for Nursing” service module at an Eastern Cape University. The following research question formed the basis of this study.

“What are the experiences and reflections of nursing students who completed the mathematics service module, “Numerical Skills for Nursing”, at this university?”

The following subsidiary questions were also developed in an attempt to answer the research question.

- Does mathematical background influence the experiences and reflections?
- How did students experience the module?
- What did they learn from the module?
- How did the students perform in the module?
What do statistical analyses of the numerical data say about the students’ performance?

The conceptual framework for this study

As mentioned earlier, this module was intended for students doing an extended degree in nursing studies. This means that they did not fulfill the requirements for direct admission into the degree programme and had to do an extra year of studies as opposed to students who had direct admission into the programme. An important assumption is made here: students who do the extended degree in nursing need additional support with numerical calculations. An interrogation of the experiences, reflections and performances of these students may reveal whether the support given achieved its objectives.

There are two key words in the research question, experiences and reflections. These two key words are crucial when locating a conceptual framework for this study. The first learning theory to consider when examining students’ experiences of this service module, is the experiential learning theory. (Kolb & Fry, 1975). David A. Kolb, with associate Roger Fry, created his famous experiential learning model out of four elements: concrete experience, observation and reflection, the formation of abstract concepts and testing in new situations.

The second stage of the Kolb model, observation and reflection, is analysed further. The importance of reflecting on what one is doing as part of the learning process has been emphasised by many researchers. Schön (1983) suggested that the capacity to reflect on action so as to engage in a process of continuous learning was one of the defining characteristics of professional practice. The cultivation of the capacity to reflect in action (while doing something) and on action (after you have done it) has become an important feature of professional training programmes in many disciplines.

In the light of the discussion on experiential and reflective learning, it is fair to say that both these learning theories have relevance for this study and form the basis of its conceptual framework.

Selection of participants

The 52 participants in this study area are doing the extended Nursing degree, where the first year of study is extended over two years. They participated voluntarily in this study and the sampling used in this study could be classified as “convenience sampling” (Cohen and Manion 1994:88).

Research methodology

This study involved the collection of both quantitative and qualitative data and thus methods suitable to the collection of both types of data were used. Quantitative methods involve the use of numerical variables while qualitative variables are more conceptual and lead to data that are expressed in words and sentences rather than numbers (McKnight, Magid, Murphy & McKnight 2000: 17).

The use of a multi-method approach in the collection of data subjects the data to triangulation with the triangulation “between methods” being appropriate to this study (Cohen and Manion, 1985: 260). More clarity on the use of these methods in this study will emerge in the data
collection section that follows.

Data Collection

The data in this study was collected through various data collection instruments, namely, an initial survey, classroom observation and a follow-up survey. Class assessments (including the class marks and overall semester marks) as well as each student’s overall rating in the chapters of the module were compared.

Initial survey

At the beginning of the semester, the students were surveyed by means of a questionnaire. This survey sought to establish the following information from the students:

- Their personal contact details
- Details of their schooling and the level of mathematics done at school
- Description of their experiences of mathematics at school
- Their views of doing numeracy in their degree programme
- How they learn numeracy
- Which method/s of teaching best fit their learning style for numeracy

Classroom observation

Classroom observation was important in this study. It gave the researcher an insight into the way the students operated in the classroom. The students were placed into two class groups for lecturing purposes. The lecturer had access to both classes. Special attention was given to the following issues.

- Their interaction with the learning materials
- How they responded in the classroom
- Their interaction with their colleagues
- Their interaction with the lecturer
- Their attitude to the work done

Follow up survey

Once the students had completed the module (in the first semester), a follow-up survey was conducted with the students which sought to obtain the following information:

- How they experienced this module
- What they learnt from the module
- What they found challenging
- How they experienced the assessment tasks
In this survey, students also had to rank themselves for each of the chapters of the module, on a 1-5 scale as shown in the table below:

**Table 1: Ranking of performance in chapters of the module**

1 – poor (need lots of help); 2 – weak (need some help); 3 – competent (capable of improvement); 4 – very competent; 5 – excellent (exceptional performance)

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 1: Basic Operations with whole numbers</td>
<td></td>
</tr>
<tr>
<td>Chapter 2: Common &amp; Decimal fractions</td>
<td></td>
</tr>
<tr>
<td>Chapter 3: Rounding off &amp; approximations</td>
<td></td>
</tr>
<tr>
<td>Chapter 4: Basic Calculator Skills</td>
<td></td>
</tr>
<tr>
<td>Chapter 5: Percentages</td>
<td></td>
</tr>
<tr>
<td>Chapter 6: Ratio, rate &amp; proportion</td>
<td></td>
</tr>
<tr>
<td>Chapter 7: Measurement &amp; units of measure</td>
<td></td>
</tr>
<tr>
<td>Chapter 8: Reading scales</td>
<td></td>
</tr>
<tr>
<td>Chapter 9: Changing the subject of the formula and substitution into formulae</td>
<td></td>
</tr>
<tr>
<td>Chapter 10: Plotting Graphs; reading and interpretation of graphs</td>
<td></td>
</tr>
</tbody>
</table>

The rankings were added up to get a total out of 50 and then doubled to 100 so it could be compared to the class mark and final mark. The class mark was also compared to the final mark.

**Assessments**

After teaching selected chapters of the module, students were given tutorial tests followed by more comprehensive tests. Their performances in these tests and in the examination that followed were analysed with a view to discovering key trends and features.

**The data**

In reporting on the data from the various data collection procedures, the emphasis is on detecting the emergent trends and patterns of coherence.

**Initial survey**

*Background of the students*

The sample consisted of different race, cultural and ethnic groups. This diversity, although not requested in the initial survey, was self-evident. More diversity, especially with regard to schooling, emerged from this survey.
This diversity is shown in the statements below.

- Students came from all over Southern Africa, with the majority from the Eastern Cape.
- They completed their Grade 12 in different years. Some worked after Grade 12 and then decided to study while others came to study immediately after their schooling.
- The students in the sample also had very different mathematical backgrounds.

**Mathematical background of the students**

The breakdown of the mathematical background of the students is shown below in Table 2.

**Table 2: Mathematical Background**

<table>
<thead>
<tr>
<th>Classification Category</th>
<th>Number of students</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCS mathematics (2008)</td>
<td>20</td>
</tr>
<tr>
<td>Old curriculum mathematics (before 2008)</td>
<td>20</td>
</tr>
<tr>
<td>NCS Mathematical Literacy</td>
<td>8</td>
</tr>
<tr>
<td>No mathematics (after Grade 9)</td>
<td>2</td>
</tr>
<tr>
<td>International mathematics (O levels)</td>
<td>2</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>52</strong></td>
</tr>
</tbody>
</table>

It would appear that the entry requirements for the extended nursing degree at the institution in question, is more inclusive than other extended degree programmes. While this is very noble practice, it means that the lecturer must be aware of the differing levels of knowledge and skills that the students bring to the class.

**Mathematical experiences of the students (at school)**

Most of the students indicated that they enjoyed Mathematics in their junior grades but struggled with it in Grades 11 and 12, especially in sections like geometry and trigonometry. Although the majority persevered with Mathematics up to Grade 12, some did Mathematical Literacy from Grade 10 or 11. Those who had done Mathematical Literacy found the subject mostly very easy. The students who did Mathematics up to Grade 9 commented that mathematics was “good” but did not give any further comment.

**What do they feel about doing Numeracy in their Nursing Studies?**

Most of the students had very favourable comments about doing Numeracy in their nursing degree programme. They relished the opportunity of doing
mathematics which was relevant for their chosen careers. They believed that exposure to a wide range of mathematical calculations in context would be useful preparation for their nursing careers. Although they thought that the mathematics would be easy, some stated that doing computations without the use of a calculator would severely handicap them.

How they would learn numeracy

The students responded that it was important to pay attention in class when the work was being taught. Once the work had been done in class, they would go over the work again and then work through the exercise in the workbook, thereby giving them much needed practice to master the concepts addressed in class.

Which method of teaching would best suit their learning styles?

No one method was favoured by the students. Instead, they favoured a combination of teaching methods in the classroom. The most popular combination was the lecture-type method with group and pair discussions. They believed that it was important to get the lecturer’s perspective on the content being taught as the lecturer was the “expert”. Thereafter, they could learn more from discussing the work with their classmates. Other methods favoured were the question-and-answer method and the problem-based method.

Classroom observation

Due to the diverse backgrounds of the students, interaction with the study material occurred at different levels, with some finding the work easy and others having difficulty, especially when they had to do basic computations without using a calculator.

The study material consisted of a study guide and a separate workbook of exercises. Thus, after a chapter or portions of a chapter were taught, students had to complete the relevant exercises in their workbooks. This enabled them to practice the mathematical skills learnt in class and also do additional calculations. The “weaker” students improved their numerical skills, while the “top” students used this as an opportunity to achieve even higher marks in the module.

Students built up a good camaraderie in each of the classes. Although they tended to sit next to people with whom they felt “comfortable”, this did not stop them from interacting positively and constructively in class. They were encouraged to discuss ideas and solutions with their neighbours. Whenever possible, students were encouraged to share these ideas and solutions with the whole class.

There was also a very good rapport between the lecturer and the students. A
combination of teaching methods was used. Although the lecture method was dominant, class and pair discussions, question-and-answer and problem-based approaches were also used. This mixed-method approach found favour with the students and ensured that class attendance remained high. The lecturer encouraged healthy competition amongst the students to build confidence and raise achievement levels. At the same time, “struggling” students were appreciative of the additional support given by the lecturer.

At first some students, especially those with a very good mathematics background, were very skeptical about the need to do this module. Those with poor or no mathematical background also shared this view, but for different reasons. As the weeks went by, students’ views changed as they began to see the value of this module. They adopted a more positive attitude, became confident, and their performance in the module improved. It would appear that the module had become very popular with all of the students.

Follow up survey

How they experienced this module

On the whole, students had very favourable views on the module. They saw the relevance of Numeracy, which they classified as some of the mathematics they did in primary school and early high school, for their future nursing careers. They found it exciting as they would be able to use mathematics in a nursing context, something they had not done before. They had also learnt new skills such as measuring and estimation, skills which were also useful in their everyday lives.

What they learnt from the module

In a follow up to the previous section, students had to indicate what they had learnt from the module. It would appear, judging from the students’ responses, that students learnt a lot from this module, with some giving general comments and others being more specific.

Some of the more general comments included: how to work without a calculator; using shorter methods in calculating and estimating; and making sense of calculated answers. Comments on the more specific aspects of the module tended to be linked to applications of mathematics to the nursing context. These included: working out medicine doses; taking temperature and pressure readings; plotting these readings on an appropriate chart; reading and interpreting graphs; working with percentages in different scenarios; and calculating drip rate.

What they found challenging

Due to the diverse mathematical backgrounds of the students, it was always likely that some students would experiences challenges with sections of the work. These sections included: changing the subject of the formula (some stated that they could not see the relevance of this section of the work); working without a calculator; working with fractions, decimals, ratio and percentages; word sums; and
compiling a table of equivalent ratios.

Other interesting comments were also noted. The two students with no mathematics background mentioned their struggles with the work, one commenting “The work is very difficult as I have not done mathematics for a long time”. The students with a mathematical literacy background were very comfortable with the methods used in Numeracy. When working through the various problems, students were encouraged to use methods with which they were comfortable. They were exposed to both numerical and algebraic methods. Those with a mathematical literacy background were not likely to use algebraic methods. A number of these students stated that they experienced difficulties with “solve for x”.

How they experienced the assessment tasks

Students appeared to be comfortable with the standard of assessment tasks, stating that the tasks consisted of both easy and challenging questions. Once again, reference was made to the challenge of not being able to use a calculator in tutorial test 1.

They also stated that the assessment tasks helped them identify their strong and weak points and assisted them with revision of the study material, thus (no comma) providing helpful preparation for the examination. The assessment tasks were fun and educational and kept them focused on the module, many of them stating that they were doing well in the module. Students were also of the opinion that working throughout the semester and not leave studying to the last minute would more likely yield better results.

The assessment tasks

Assessment for the semester consisted of four tutorial tests and two semester tests. A summary of the students’ performances in the tutorial tests and semester tests is shown in the next four tables.

Table 3: Tutorial test averages (out of 20)

<table>
<thead>
<tr>
<th>Tutorial tests</th>
<th>Content</th>
<th>Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Chapters 1, 2</td>
<td>1A: 13</td>
</tr>
<tr>
<td>2</td>
<td>Chapters 3, 4</td>
<td>1A: 16</td>
</tr>
<tr>
<td>3</td>
<td>Chapters 5, 6, 7</td>
<td>1A: 15</td>
</tr>
<tr>
<td>4</td>
<td>Chapters 9</td>
<td>1A: 14</td>
</tr>
</tbody>
</table>

Table 4: Tutorial test failures

<p>| Groups |</p>
<table>
<thead>
<tr>
<th>Tutorial tests</th>
<th>1A</th>
<th>1B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

**Table 5: Semester test averages (out of 50)**

<table>
<thead>
<tr>
<th>Semester tests</th>
<th>Content</th>
<th>Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Chapters 1, 2, 3, 4, 5, 8</td>
<td>1A 36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1B 37</td>
</tr>
<tr>
<td>2</td>
<td>Chapter 6, 7, 9, 10</td>
<td>1A 35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1B 34</td>
</tr>
</tbody>
</table>

**Table 6: Semester test failures**

<table>
<thead>
<tr>
<th>Semester tests</th>
<th>Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1A 1</td>
</tr>
<tr>
<td></td>
<td>1B 2</td>
</tr>
<tr>
<td>2</td>
<td>1A 3</td>
</tr>
<tr>
<td></td>
<td>1B 4</td>
</tr>
</tbody>
</table>

In tutorial test 1, students had to do all questions without using a calculator. Both groups wrote equivalent tests and some of the questions given to Group 1A are indicated below:

- $174 - 131 - 136 + 112$ (question 1.1)
- $25 \times 47$ (question 1.2)
- $6 \times (10 - 13) \div 3$ (question 1.4)
- The temperature at 5 pm was 12°C. If the temperature decreased by 3°C every hour, calculate the temperature at 11 pm. (Question 2.2)
- Calculate how many capsules a patient would require if she has to take 3 capsules every 6 hours for 3 days. (Question 2.4)
- If you add 20 mL of a drug to a 180mL drip bag and you administer the drip over a 2 hour period, calculate how much drip must be administered every 15 minutes. (Question 2.6)

Students had difficulty with Questions 1.1, 1.2 and 1.4 since they were not allowed to use calculators. In some instances, the answers were not even close to the required response. In Question 2.4 some students gave answers of 1200 or 2400. Clearly, the context was not taken into account as a patient having 1200 or even 2400 over three days could “kill” the patient. These students did not make sense of their responses and this was pointed out to them during the test review.

**Comparisons of ranking, class mark and final mark**
**Ranking versus final mark**

Each student had to rank him/herself in the 10 chapters of the module. A five point scale was used and the aggregate doubled to get a ranking of 100. This ranking was compared to the final mark for each student. The ranking and corresponding final mark for each student is shown in appendix 1.

The t-test for two related samples (Gravetter & Wallnau, 2009: 342) was used to compare the two scores for each student. The results are shown in Table 7.

**Table 7: t-test (paired two samples for means)**

<table>
<thead>
<tr>
<th></th>
<th>Ranking</th>
<th>Final Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>76.63</td>
<td>75.58</td>
</tr>
<tr>
<td>Variance</td>
<td>96.71</td>
<td>115.07</td>
</tr>
<tr>
<td>Observations</td>
<td>52.00</td>
<td>52.00</td>
</tr>
<tr>
<td>Pearson Correlation</td>
<td>0.392</td>
<td></td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>df</td>
<td>51.000</td>
<td></td>
</tr>
<tr>
<td>t Stat</td>
<td>0.671</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) one-tail</td>
<td>0.253</td>
<td></td>
</tr>
<tr>
<td>t Critical one-tail</td>
<td>1.675</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.505</td>
<td></td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>2.008</td>
<td></td>
</tr>
</tbody>
</table>

**Conclusion from the t-test (for ranking versus final mark)**

We fail to reject the null hypothesis (p = 0.505 > 0.005) and conclude that there is no significant difference between the ranking and the final mark.

**Class mark versus final mark**

The class mark for each student was compared to the final mark. These marks are shown in Appendix 2. The t-test (Gravetter & Wallnau, 2009: 342) was also used to compare the two marks for each student. The results are shown in Table 8.

**Table 8: t-test (paired two samples for means)**

<table>
<thead>
<tr>
<th></th>
<th>Class mark</th>
<th>Final mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>73.50</td>
<td>75.58</td>
</tr>
<tr>
<td>Variance</td>
<td>109.94</td>
<td>115.07</td>
</tr>
<tr>
<td>Observations</td>
<td>52.00</td>
<td>52.00</td>
</tr>
</tbody>
</table>
**Conclusion from the t-test (for class mark versus final mark)**

We reject the null hypothesis and conclude that there is significant difference \( (p = 0.005 < 0.05) \) in the mean difference between class mark and final mark.

**Ranking versus class mark**

In the final statistical analyses of numerical data, it was decided for the sake of completeness, to compare each student’s ranking to his/her class mark. The ranking and class mark is shown in Appendix 3. In this analyses, each student acts as its own control and it is also reasonable to use a matched design (paired t-test) (Gravetter & Wallnau, 2009: 342) to compare the ranking with the class mark. The results are shown in Table 9.

**Table 9: t-test ( paired two samples for means)**

<table>
<thead>
<tr>
<th></th>
<th>Ranking</th>
<th>Class mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>76.63</td>
<td>73.50</td>
</tr>
<tr>
<td>Variance</td>
<td>96.71</td>
<td>109.94</td>
</tr>
<tr>
<td>Observations</td>
<td>52.00</td>
<td>52.00</td>
</tr>
<tr>
<td>Pearson Correlation</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>df</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>t Stat</td>
<td>2.088</td>
<td></td>
</tr>
<tr>
<td>( P(T&lt;=t) ) one-tail</td>
<td>0.021</td>
<td></td>
</tr>
<tr>
<td>( t ) Critical one-tail</td>
<td>1.675</td>
<td></td>
</tr>
<tr>
<td>( P(T&lt;=t) ) two-tail</td>
<td>0.042</td>
<td></td>
</tr>
<tr>
<td>( t ) Critical two-tail</td>
<td>2.008</td>
<td></td>
</tr>
</tbody>
</table>

**Conclusion from the t-test (for ranking versus class mark)**

We reject null hypothesis \( (p=0.042 < 0.05) \) and conclude that there is a significant difference between ranking and class marks.

**The findings of this study**
It is now opportune to put the data analyses into context and examine the evidence from these analyses in order to answer the research question:

**Does mathematical background influence experiences?**

A close interrogation of the data from the initial survey revealed that the students came from very diverse schooling backgrounds. Table 2 also showed the diversity of the mathematical backgrounds of the students.

The evidence is clear that mathematical background did have an influence on the students’ experiences of the module and this is shown below:

- Students who did Mathematics up to Grade 12 at school tended to have little or no problem with the work. They used the opportunity to boost their marks in this module.
- Students with a Mathematical Literacy background were very familiar with the methods used in the module and coped very well. However, they tended to experience problems when more “abstract” mathematics was used.
- There were very few students who did not have some form of mathematics up to Grade 12. Although these students appeared to struggle, hard work and a concerted effort enable them to succeed.

It would appear that the module had appeal for all categories of students, thus giving them a very concrete experience of the mathematics required for nursing. During class time, students, irrespective of background, displayed a serious attitude when engaging with the content in the study guide. Students worked well in pair discussions, sharing ideas with neighbours and, in some cases, with the whole class. They began to work in a very structured manner, especially when dealing with abstract concepts and problem-solving. These experiences appeared to be in line with Kolb’s (1975) theory of experiential learning.

**Students’ reflections on the module and what they learnt from the module**

In the initial survey, it was reported that some students had misgivings about the module. However, these students and the others accepted that they had to do this module as part of their nursing degree programme. They also indicated how they planned to learn the module content and what teaching method(s) they preferred.

During the classroom observation, students displayed a great deal of enthusiasm and readiness to do the work. A mixed-method approach was used by the lecturer and this went down well with the students. The study guide and workbook exercises were well-constructed and user-friendly. This enabled students to work in a very methodical manner in class.

It would appear from the responses of the students in the follow-up survey, that students had reflected very positively on the module. They were appreciative of the study guide, which enabled them to work independently and consolidate what they
learnt in class. The class atmosphere was very conducive to learning and this enabled them to improve steadily.

They learnt many mathematical skills and concepts, which were relevant in the nursing context, and could not wait to use some of these skills during their practical training. They were able to learn from their peers, and shared ideas and solutions with them. The regular assessments in the form of tutorial tests and semester tests, kept them focused on the module and enabled them to reflect on their strengths and weaknesses. They were able to prepare for examinations with a positive frame of mind.

These reflections by students appear to be in line with key elements of Schön’s (1983) theory of reflection.

Assessments

Tables 3-6 (on page 10 of this paper) show a summary of the results of the students in the tutorial and semester tests. It would seem that performances in the tutorial tests improved during the semester. This could be seen in the consistency in averages and low number of failures. Performance in the two major tests (semester tests) was exceptional. There were similar high averages for both groups and the number of students obtaining less than 50% in the tests, was low. The two semester tests covered the entire learning material for the module and served as good preparation for the examinations. These test performances triangulate well with students’ views on the assessment tasks.

Statistical analyses

As stated earlier, the quantitative data (shown in Appendices 1 -3, pages 17-19) were subject to statistical analyses. Since each student acted as his/her own control, a matched design (paired t-test) was used. These analyses revealed interesting results.

In the first case (Table 7), there was no significant difference between the way students ranked themselves in the module and their final mark for their module. In the second analysis (Table 8), there was a significant difference in the mean difference between class mark and final mark. This also surfaced in the third instance (Table 9), where there was a significant difference between ranking and class marks.

These results also appear to corroborate the students’ experiences and reflections in the following way.

- The students’ class marks were lower than their rankings. It is possible that students may have been a bit generous in their rankings, when compared to the marks achieved during the semester.
• The difference between the class mark and final mark showed that students’ marks improved significantly in the semester, culminating in a final mark which was in excess of the class mark. This key statistic triangulated well with the quantitative data from the follow-up survey.
• The true test of students’ achievement in the module came from a comparison of the rankings with the final mark. In this scenario, students were on the mark with their rankings as there was no significant difference between the rankings and the final mark, thereby validating their rankings.

Conclusion
Mathematics service modules play a very important role in higher education, serving Sciences, Health Sciences, Engineering and Business Sciences. This study, based on a service module in the Health Sciences, showed that students attached a great deal of value to the module as they saw its relevance to the nursing field.

This study may also have relevance for other mathematics service modules. The experiences and reflections of the students in this study show there are important principles which underpin mathematics service modules. Some of these are:

• There should be a close link between the service module and the field(s) of study the module is servicing.
• A carefully-constructed study guide with solved problems in context, and a number of exercises for consolidation, will enhance student learning in the module.
• Regular assessments in the form of tutorial and semester tests keep students focused and assist in their learning. This also helps them identify both their strengths and weaknesses. Good or improved performances in assessments keep students motivated and maintain their interest in the module.
• Lecturers of service modules, noting that students are not “regular” mathematics students, should use a variety of teaching methods, thus ensuring that students are actively engaged during lessons and contributing to their learning in the process.
• Students should also be encouraged to share ideas and solutions with neighbours, and in some instances, with the whole class. This will enable them to build up confidence and become more positive.

The implementation of these principles into the teaching and learning of mathematics service modules can play a very significant role in improving students’ performance in these modules.

Acknowledgements
The writer of this paper would like to thank Ms D. Webb for going through the paper and checking the language and Mr J.E. Simakani for his unselfish assistance with the statistical analyses.
Ethics

In this study, ethical measures included assurance of confidentiality and anonymity, and obtaining the informed consent of the participants. This allowed the writer to meet the standards considered appropriate for research to be conducted in a morally acceptable manner (Borg and Gall 1989).

References


## Appendices

### Appendix 1: Ranking versus final mark

<table>
<thead>
<tr>
<th>Student</th>
<th>Rating</th>
<th>Final Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>86</td>
<td>80</td>
</tr>
<tr>
<td>2</td>
<td>66</td>
<td>63</td>
</tr>
<tr>
<td>3</td>
<td>82</td>
<td>97</td>
</tr>
<tr>
<td>4</td>
<td>76</td>
<td>91</td>
</tr>
<tr>
<td>5</td>
<td>78</td>
<td>83</td>
</tr>
<tr>
<td>6</td>
<td>82</td>
<td>73</td>
</tr>
<tr>
<td>7</td>
<td>80</td>
<td>77</td>
</tr>
<tr>
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<td>80</td>
<td>80</td>
</tr>
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<td>9</td>
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</tr>
<tr>
<td>10</td>
<td>60</td>
<td>78</td>
</tr>
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Describing and analysing the resources used to solve equations in a Grade 10 mathematics class in a Cape Town school

Derek Gripper  
University of Cape Town, South Africa  
Derek.gripper@uct.ac.za

In this paper I report on a pilot study in which I examine the resources used to solve equations in a grade 10 lesson at a former Model-C school that is participating in a research and development project in Cape Town. An initial encounter with learners noted the dominant use of procedure and a focus on ‘what the mathematics looks like’ as resources used by learners to solve for linear equations. These dominant resources were utilized in a teaching experiment to encourage the use of more explicit deductive reasoning by learners as they went about solving linear equations. The learners were subjected to a series of short tests on equations and their written solutions were analysed and described in ways that are not obvious to an initial reading of the situation. This pilot study suggests that quasi-mathematical objects and operations are often present in procedurally embodied mathematical activity and are a likely cause of learners’ errors. The evidence extracted from learners’ work suggests that the
unnecessary quasi-mathematical complexity generated by the actual pedagogy in play might in fact be contributing towards their failure.

**Introduction**

In a study of a group of Brazilian learners’ written mathematical work by Lima & Tall (2008) they describe aspects of the operational activity of the learners who attempt to find solutions to equations as follows:

To shift the number 2 in the equation $3x + 2 = 8$ to be next to the number 8 requires not only ‘changing sides,’ it also requires the mystical operation of ‘change signs’ to get $3x = 8 - 2$ and to be able to perform the subtraction operation to get $3x = 6$. To solve this equation by ‘moving the 3 over’ involves shifting it over the other side, but now it needs to be ‘put underneath’ to get $x = 6/3$. (Lima & Tall, 2008: 8)

Their description echoes our own observations of the teaching and learning of equations in Cape Town schools. It is all too familiar and it is not surprising that similar conclusions are reached in the work of researchers (Jaffer, 2010b), who support the claim by Lima & Tall (2010) that a procedural approach to solving equations can lead to errors. Also mentioned by Jaffer (2010b) is the problem that learners face when definitions are not provided. This research follows on from Davis & Johnson (2007), aptly entitled *Failing by Example*, where they outlined problems encountered by learners when there is an absence of a mathematical grounding of computational activity, the result being a failure to generalise successfully. They have also referred to the predominance of the use of the image of a solution procedure previously seen as a problem-solving resource.

Lima & Tall (2010: 1) rightly say that “[w]hile it is the duty of mathematics educators to improve student learning, it is also a responsibility to understand why so many students end up performing ‘rules without reason’ that lead to failure.” They refer to studies in cognitive development that diagnose learner’s mistakes “in terms of mal-rules that involve erroneous forms of operations”. According to those studies, learners appear to be making mistakes for a variety of reasons like misinterpreting solution techniques and the lack of meaning that they attribute to the mathematical symbols. The main features of Lima & Tall’s (2008; 2010) descriptions are of what they refer to as procedural and embodied activity. What appears lacking in their report, however, is any suggestion that the learners fail because of any unnecessary mathematical or quasi-mathematical complexity generated by the actual pedagogies in play. Hence the question that initiated the empirical investigation discussed in this paper, which resulted from an attempt to see whether it is possible to set up a teaching experiment where the dominance of procedural and embodied resources can be disrupted, and then to test the learners to see what emerges in their written work.

**From the literature**

**The need to describe the pedagogy**

Brousseau (1997) emphasized the need to develop a specific scientific approach to the problems of teaching and learning mathematics. This was a response to the need expressed succinctly by Chevallard (2007: 8) when he said: “The legitimacy of any teaching institution derives in part from its promise to represent faithfully the knowledge that it claims to teach.” The question that Brousseau attempts to ask is: “What are the necessary conditions for a situation to implement the specific mathematical knowledge it defines?” (Bosch, Chevallard & Gascón, 2005: 3).

Brousseau and those associated with him refer to the need to keep mathematics pedagogy under close surveillance, noticing that it is quite common,

[w]hen a teaching activity has failed, the teacher can feel compelled to justify herself, in order to continue her activity, take her own formulations and heuristic means as objects of study in place of genuine mathematical knowledge. (Brousseau, 1997: 26).
When analogies are used in didactical situations it is possible that learners “try to read the pedagogic intentions without involving themselves in the mathematics” (Brousseau, 1997: 27). What is really produced becomes the key issue. These researchers refer to the dis-articulation of school mathematics, the assumption that the kind of mathematical activity that the learners carry out is mainly a consequence of the kind of mathematics that exists at school. They focus on questions like: What are the mechanisms of didactic transposition that can explain the phenomenon of the dis-articulation of school mathematics? So, according to the literature, we know what is going on, but we just don't know what it looks like in our South African schools or what conditions are described. Chevellard and others have developed an Anthropological Theory of Didactics, which demands that mathematical activity be modeled (Bosch, 2005). A diagram (Figure 2) of the ‘process of didactic transposition’ as described by these researchers helps to situate this type of research.

**Figure 1.** The process of didactic transposition (Bosch, Chevellard & Gascón, 2005:4)

Brousseau (1997: 41) talks about the “constitution of knowledge” and the resultant maladjustment from the pedagogy, but does not explicitly categorize the vagaries of knowledge that emerge from the kind of empirical evidence referenced in this paper. What emerges from the research done by Davis (2010a; 2010b; 2010c) and others is that these ‘mathematics-like’ procedures appear to complicate or make unintelligible the mathematics concepts being taught. Research thus far suggests that mathematical concepts are not properly grounded (Davis & Johnson, 2008) and that domain changing is occurring (Basbozkurt, 2009) in ways that are likely to be, to say the least, confusing. Roberts (2009: 4) initiates the important question of the role of language in what comes to be constituted as mathematics, “how the form that language takes can influence what comes to be constituted as mathematics”. Her paper reflects on the difficulties that learners have in developing syllogistic reasoning in their learning context by observing, for example, the absence of transitive verbs in teaching practices. Mackay (2009: 13) describes “... practices with respect to a type of pedagogy that de-emphasizes the individualizing of learners ...”. The results of Mackay’s study show that the type of solidarity present in the classroom might in fact be slowing down the pace of teaching and learning. It appears also to be the case that in communal forms of pedagogy there is very little exposure to mathematical definitions and principles. Jaffer (2009; 2010a) shows how the structuring effect on criteria is influenced by the orientation of teachers and learners to privileged texts. Her study (2010a: 12) “makes speculative suggestions about the relationships between the existence and degree of context-dependent criteria and learner performance”. Jaffer (2010b: 132) also makes reference to the dominance of the use of procedural and iconic resources in mathematics lessons. She hypothesizes that the prevalence of these resources is a “means of compensating for the context-dependent orientation to meaning that working class learners exhibit on entering schooling.” The question that is explored is whether the consequence of this “compensation” is that mathematics is rendered more complicated and abstract for these learners.

**Describing learner errors**

Brodie & Berger’s (2010) search for a framework to describe learner errors in mathematics might fail to categorize some of the errors that emerge as a consequence of pedagogy. They agree that learner errors are often produced by misapplications of standard algorithms and that such misapplications are
not necessarily explicable by a misconception. What we would expect in a field like mathematics education is the use of a mathematics encyclopaedia as a resource. With such a resource it becomes obvious that errors in mathematics lead to inconsistencies. The problem seems to be that learners do not have the recognition and realisation rules to resolve inconsistencies. Brodie & Berger (2010: 180) have provided a broader account of learner errors and have “remove[d] the explanation of errors from the mind of the learner and locate[d] it in the interactions between learner, teacher and Mathematics.” This seems to be a move in a direction that will support the research indicated here, but such a framework will need to categorise errors that emerge from the particular constitution of the school mathematics in question.

Researching equations

As already mentioned, Lima & Tall (2010: 2) refer to the shifts that take place in the solving of equations and describe learner’s action as involving the “shifting of symbols around in their imagination and on paper, such as ‘move a term to the other side and change its sign’”. They refer to such ‘operations’ as procedural embodiments, but do not, however, mention that such ‘operations’ are not really mathematical in nature. Instead, they refer to the fragility of using such procedural embodiments as indicated in the work of learners. Lima & Tall (2010: 6) agree that some learners “build increasingly complicated procedures that are likely to become increasingly unstable”, but do not link that observation to pedagogy in any causal way. Tall’s (2009) idea of a met-before could be problematic if what has been met-before involves teaching methods that include quasi-mathematical objects and operations likely to lead to inconsistencies, so that the errors that result from such a ‘met-before’ cannot, therefore, always be attributed solely to the idiosyncrasies of the learner.

There has been a great deal of research about equations and the concepts associated with the equality sign, most notably by Kieran (1981; 1985), as well as Filloy & Rojano (1989). Their work will not be discussed here but it is noted by researchers building on their work (Farmaki, Klaoudatus & Verikios, 2004: 399), that “teaching the algorithm of solving equations can hardly be considered as a way towards the development of algebraic thinking.” However, research by Filloy, Puig & Rojano (2008: 97) notes that it is important “[t]o recognize problems in learning new concepts, deriving from the way in which [learners] are taught and from the teaching strategies used to teach pre-algebraic material.” What is of interest is that they ask what can be said about the disjuncture between the activity of the learners and the teaching?

A method

Disrupting the dominant resources

I created an opportunity through a research programme to teach a Grade 10 class for four successive days at a former Model-C school in Cape Town. This was to be the first of a few interventions at five schools participating in a research and development programme. In the context to be discussed, I focussed on the teaching of equations. I decided to perform a teaching experiment. Between 33 and 36 out of 38 learners attended the four classes from which the data for this pilot study is extracted. The learners were tested on key aspects of the topic equations. The testing took place for 7 minutes at the beginning of each of four successive lessons. The first test was a preliminary investigation. The lessons themselves were designed to encourage a deductive form of thinking and to develop an understanding of the need to preserve the equality in the equation. Each test was marked out of five marks and returned to the learners during the next lesson. The test scripts were scanned before being returned so as to facilitate an analysis of the learner’s work. The aim was to try to describe how the learners viewed the mathematics content by considering how they operated on the mathematical objects engaged with. Their progress over the four days was monitored and analysed. An attempt was made to categorise the learners’ operational activity.

Focusing on the mathematical activity

I decided that a focus on the mathematical activity would provide a clearer description of what was happening. In this context, when talking about a definition of an equation, it seemed at first as if the learner’s had not been taught. However, there was certainly evidence of teaching as there was often a
reference by learners to ‘changing sides’ and ‘what you do to one side you do to the other’. The question that had informed this attempt to disrupt the learner’s procedural and embodied (imagistic) approach to solving equations was based on why it was necessary to use a ‘shift’ operation. What is, after all, the relationship between the pedagogy and the learner’s activity? It seemed important to focus on the operational activity in the classroom to try to get at the criteria that learners are possibly picking up from their teachers.

The experiment

The initial test was based on what the class teacher indicated they had been busy with in previous lessons. They had been introduced to equations, but had not been exposed to any definition of an equation. Most of their work had been in the form of worked examples using a solution template provided by their teacher. The assumption was that this was the usual way that they experienced mathematics. Their experience of equations most likely had a beginning with the work they had done earlier on straight line graphs. The first test I gave the learners at the beginning of the first lesson tested them on their knowledge of what an equation is and then asked them to solve a simple linear equation. The third question exposed them to a situation where the expression was an equation at the level of expression, but not at the level of value. The reason for this was to further test their understanding of what an equation was. The second test was both a response to what they failed to understand and an evaluation of the same ideas as the first test. They were also exposed to more difficult equations to see if they could reproduce the explicitly deductive method that they had been exposed to during the first lesson. The deductive method was embedded in the calculation. The third test and fourth tests were similar to the first two with the question on the definition of an equation altered. A question about extracting solutions of a quadratic equation was introduced in the last two tests mainly to see if the learners understood multiplication by zero.

Following the initial test, an attempt was made to exploit the visual as a tool to introduce the deductive, disguised in the calculation. The assumption was that the learners were likely to view the equation as a spatial distribution of symbols and so the learners were encouraged to work with an equation by working with the expression in a way that introduced deductive thinking. The aim was to get the same form and deduce the value of \( x \). For example,

\[
\begin{align*}
x + 1 &= 9 & \text{(but } 9 = 8 + 1) \\
x + 1 &= 8 + 1 & \text{(looks the same - using the iconic)} \\
\text{so } x &= 8 & \text{(deductive move)}
\end{align*}
\]

and other equations, like

\[
\begin{align*}
2x - 3 &= 9 \\
2x - 3 &= 12 - 3 \\
2x - 3 &= 2 \times 6 - 3 \\
\text{so } x &= 6
\end{align*}
\]

In this method the equivalence of forms focuses attention on equality. The deductive argument is that if the individual elements that constitute the form are the same then those parts of the expressions that are different must be the ‘same’; i.e., have the same value. The idea is to exploit the image of something looking the same in order to introduce mathematical deduction into the learner’s work. The hope is that they might eventually become addicted to deductive reasoning referred to by Danzig (2005) as mathematical reasoning.

Results from the tests

While there was some apparent improvement (see Figure 2) in the learners’ understandings of the topic over the four days, it was not significant. There was an initial improvement after the first day, but then results seemed to level out a bit. This might have been due to the learners encountering other difficulties, like struggling to understand the idea of a variable, and their inability to apply their newly
acquired definition to their new approach to solving linear equations. Understanding if \( a \times b = 0 \) then either \( a = 0 \) or \( b = 0 \) also proved to be a difficult concept for many learners and as this was tested in Tests 3 and 4 this could have also interfered with learners’ attempts to grasp the idea. In the light of this experiment this might have been a mistake, but was included to keep up with the content being covered in the other grade 10 classes.

Figure 2. Average learner scores on tests.

There are signs of a more positive trend if we consider the number of learners who attain 60% (3/5) or more for the tests (see Figure 3): Test 1 - 3 learners; Test 2 - 21 learners; Test 3 - 22 learners; Test 4 - 26 learners. A change from 3 learners getting 3/5 or more in test 1 to 26 learners getting 3/5 or more in test 4 reflects a more positive picture and suggests that at least something positive was happening for the learners with respect their knowledge of linear equations. The number of learners who attained 5/5 increased from 1 to 8. The number of learners absent was not that significant in this class but is reflected in the graphs by a symbol ‘A’.
Analysis of the learner’s test work

Test 1: Luke’s answer (Q1, Figure 4) reflects what he has been learning and that he has been listening in class. There is, however, no reference to the need for equality to be preserved in an equation. Borowski & Borwein (2002: 186) define an equation: “A formula that asserts that two expressions have the same value”. The equality of the two co-expressions appears to escape Luke and he concentrates on how the procedure looks in his understanding of an equation. Luke writes (Q2, Figure 4) that \( |1 - 9| = 8 |\), an error which appears at first glance as careless, but once scrutinized can provide evidence to support the argument being developed here, namely that operations like ‘shift to the other side and change the sign’ can be problematic. An equation, as Luke’s work suggests, has been defined by such quasi-mathematical operations that can produce the desired result but can also lead to errors. He has not kept his eye on preserving equality and the ‘magic’ of ‘shifting to the other side’ has let him down.

Most learners (65%) understood an equation as a demand for a calculation to find an answer or as a problem to be solved by finding the unknown, \( x \). Others understood an equation to be ‘a collection of terms with an equal sign’ or ’an expression with an equal sign and an answer’. Leonie’s description of an equation (Q1, Figure 5) is revealing in this regard. For a few, an equation was seen as “a line on the Cartesian plane” – “you need to find the \( x \) and \( y \) intercepts and slope”, reflecting what they had met before when they covered straight-line graphs. A few learners could not write anything. The most promising result came from a learner (1 out of 35) who described an equation as “a sum that is equal to another”. This learner also seemed to, let’s say, have a sense that \( x + 1 = x + 3 \) is not an equation at the level of value (even if it is at the level of expression). However, her later work (not shown here) revealed that her knowledge was somewhat unstable.
Test 2: A few of the learners made an attempt to learn the definition, but for many learning a definition seemed an unnecessary exercise and was foreign to them because most definitions have been removed from their realised curriculum. This is certainly evident in Dianne’s answer (Q1, Figure 6) where she does not attribute meaning to an equation. The definition that they had been given in the first lesson did not appear to have immediate relevance to the topic that they were engaging with. A procedural form of thinking dominated. Many learners did, however, attempt the new way of maintaining equality and were successful, but often could not extend that knowledge to deal with a more difficult problem (Q3, Figure 6). What was very common in some of the other learners’ work was the habit of replacing $x$ with the value that they thought it represented, thereby arriving at the answer.

![Figure 5. Test 1 – Leonie’s work](image)

![Figure 6. Test 2 – Dianne’s work](image)
Test 3: There was some improvement in learner’s understanding of the key features of an equation. A new type of question was introduced where the equation was no longer linear. With this came the realisation that variable was not properly understood. Many learners, like Anele (Q3, Figure 7), simply placed both possible values of \( x \) into the equation; OR became AND. The notion of multiplying by zero produced similar results as those referred to by Lima & Tall (2010). The need for only one of the factors to be zero appears forgotten or has not been considered.

\[
\begin{align*}
Q3. \quad \text{In the equation } (x-3)(x+2) &= 0 \text{ try to give the possible values of } x. \\
(3-3)(-2+2) &= 0 \\
&\quad \Rightarrow x = 3 \text{ and } x = -2
\end{align*}
\]

Figure 7. Test 3 – Extract from Anele’s work

Test 4: There was again a small amount of improvement in the last test, but for Sharon (Q2, Figure 8) the magic of ‘doing the same to both sides’ or ‘shifting and changing signs’ re-emerged and led to errors. A \(-1\) was moved to the ‘other side’ and ‘the sign changed’ but also left where it was, perhaps to maintain an image of the new method that had been taught. She appeared to have forgotten that her statement in Q1 concerning the equality of two expressions was something that needed to be rigorously observed. Quite likely she was reverting to an old habit of trying to remember what things looked like in the procedure that she had initially learned. About half the class were able to give values for \( x \) in Q3, although many continued to produce solutions like Anele had done in Test 3 (Figure 7).

\[
\begin{align*}
Q1. \quad \text{An equation is a mathematical statement that shows the equality of two expressions. What does that tell us about the equation, } x + y &= a + b? \\
\text{THOSE TWO EXPRESSIONS ARE EQUAL}
\end{align*}
\]

\[
\begin{align*}
Q2. \quad \text{Solve for } x \text{ in} \\
\frac{x}{3} - 1 &= 3 \\
\frac{x}{3} - 1 &= 3 + 1 \\
\frac{x}{3} &= \frac{4}{3} \\
x &= 4
\end{align*}
\]

Figure 8. Test 4 - Extract from Sharon’s work

Individual learner’s work across the tests reveals that they were often able to reproduce the new method for solving equations, however substantial misconceptions remained about the concept of variable. Thabo (Figure 9) found it difficult to incorporate the definition into his understanding of an equation or to accept that \( x + y = a + b \) is an acceptable equation with \( x + y \) having the same value as \( a + b \). He did, however, manage to solve for \( x \) (Q2, Figure 9). When he attempted Test 4 (Figure 10) he was without a suitable definition for an equation and was unsure of how to solve for \( x \) in an equation similar to the one in Test 3 that he had successfully solved.
There were learners who could produce adequate responses to the questions that they faced in Test 3 and Test 4, as well as make use of the new means at their disposal for making both sides look the same without any trickery. Madhur (Figure 11) was able to produce clear and correct work in Test 2 (5/5) and to maintain this for the subsequent tests. Her 2/2 for Test 1 suggests that the type of questioning might have been, to say the least, unusual.
Figure 11. Test 2 - Madhur’s work

Lindiwe (Figure 12) was another learner who was initially struggling to come to terms with a method where ‘signs were changed’. This problem appeared quickly resolved by Test 3 (Figure 13).

Leonie’s earlier understanding of an equation (Figure 5) was procedural and embodied, but she quickly adapted her method (Figure 14) and appeared to be able to reproduce a definition of an equation without any apparent difficulty. Her response to Test 1 made the experiment worthwhile as she quickly became empowered to engage with equations without immediately employing quasi-mathematical methods.
Looking for categories to describe the vagaries of operational activity in play

What was valuable was the evidence that emerged from the learners’ work that suggested that the way in which they think about mathematics and perform computations might be a consequence of the pedagogy. While it was not difficult to see that the use of procedural knowledge and ‘remembering how things looked’ dominated the resources used by learners, something else appeared to be emerging about the use of quasi-mathematical methods. If we refer to a mathematical encyclopaedia we find no reference to operations directly corresponding to ‘changing sides’, ‘changing signs’, ‘shifting over the other side’ or ‘put underneath’. The field of real numbers is not described by any such operations even if the practiced use of such ‘operations’ can enable learners to produce statements recognised as solutions to linear equations. The reference of Johnson & Davis (2010) to the use of algebraic symbols as a resource for regulating the work of learners is evident here. Examples of learner’s work reveal that such a resource is possibly a source of errors. After all, what can be ‘shifted to the other side’? Is it number? Surely we can only perform such a pseudo-operation on objects amenable to spatial displacement.

Conclusion

This teaching exercise was not as successful as what was hoped for. There were interruptions in the length of periods, reflecting some instability in the management of the teaching programme. What is of interest, despite the disruptions to lessons, is that some evidence emerged from the work of learners that appears to support the notion that the way that mathematics is ‘pedagogised’ could well be responsible for at least some learner errors, indicating that we need an extension of existing frameworks for describing learner error to include the effect of pedagogy. It was certainly possible to reveal instances of the procedural embodiment referred to by Lima & Tall (2008; 2010), and to support Jaffer’s research (2010b) on the use of iconic and procedural resources in mathematics classrooms. It was also possible to extend the focus beyond cognition to include a consideration of the effects of the particular constitution of school mathematics on learner performance. Apart from the dominant use of iconic and procedural techniques it also appears that domain changing and existential shifting is taking place (Basbozkurt, 2010; Davis, 2010a; Jaffer, 2009). Initial results also suggest that deductive logic is often suspended, undermining the integrity of the mathematical work of learners. It
seems evident that operations like ‘shifting to the other side’ described as quasi-mathematical in the language being developed by Davis (2010a; 2010b; 2010c) appears to make more abstract and complex the mathematics that is being taught in schools.

Poincaré asked in the late 19th Century (in Sfard, 2008: 3): “How does it happen that there are people who do not understand mathematics?” For Poincaré, mathematics consists of a set of clearly defined, logical rules that should be easy to understand. Poincaré appears to marvel at the simplicity of mathematical objects. For example, if we wish to describe the real numbers formally then thirteen axioms can do the job. Sfard, on the other hand, points to the intangible, complex and abstract nature of mathematics and thinks (2008: xiv) that, in this regard, “our sense of helplessness may well be at its most acute”. She is speaking about what modern techniques of observation reveal about how learners experience ‘mathematics’ as we know it, whereas Poincaré is talking about mathematics as in an encyclopaedia of mathematics where everything is clearly formalized. This suggests that something appears to be happening when mathematics is ‘pedagogised’, as something different is often generated … even if it is for mathematics.

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By investigating the learning of calculus in an extended mathematics course by a cohort of entry level students, this study highlights the difficulties involved in concept and procedural proficiency in mathematics. The SOLO learning cycle framework is applied at the local conceptual and procedural development level in the use of formulas to determine areas of shaded parts of a circle (pre calculus) and in the learning of techniques of differentiation, particularly the chain rule. Students’ written responses are analysed using the Unistructural, Multistructural and Relational levels in the SOLO learning cycle framework. The research questions were: is the use of the UMR learning cycle in the SOLO model a useful aid in the analysis of the mathematical proficiency of entry level tertiary students? Secondly, are there limitations and pitfalls to the use of the UMR learning cycle model in analysing the mathematical proficiency of entry level tertiary students? The data collected were student produced examination scripts of a cohort of entry level tertiary students for the analysis of responses to a question of area of shaded sections of a circle and responses in two quizzes on the use of the chain rule procedures. The cohort divided into the UMR learning cycle levels for every question. The cohort also revealed that there were differences in their understanding of a trigonometric function and this too could be categorised along the UMR levels. The use of the UMR learning cycle at the micro level opens areas for analysing mathematical proficiency at the micro level and points to areas of uncertainty that the students face. Sometimes, however, placement along the UMR level may be as a result of factors other than the proficiency of the study at that micro level. This indicates that a wider pool of questions and problems need to be presented before more definitive decisions can be made about the proficiency level a student could be placed at within a certain stage.

Introduction

This study engages with the shifts in mathematical thinking of a cohort of entry level students within a formal stage of development as reflected in their written texts against the background of the development of concepts in calculus and pre calculus in an entry level mathematics course. The shifts occur because students are required to access higher thinking skills in order to solve increasingly complex, though routine mathematical procedures, using rules and techniques. The design used to investigate these student shifts are tests and quizzes, which students must respond to. The student texts are their responses to set questions, designed to test their ability to perform mathematical procedures and solve problems.

With reference to the SOLO model, especially in terms of its learning cycles, it is assumed that students engage with the mathematics in the course and work within the formal (symbolic) stage. However, structurally, they are not all at the same level:

The structure of the learned responses that occurs within each stage, using the appropriate elements and operations, becomes increasingly complex. The essence of the Biggs and Collis (1982) formulation is that structurally the complexities at each stage are the same. (Collis, Romberg & Jurdak, 1986, p. 3)
In other words, within the formal stage students may be differently prepared to handle complex mathematical problems or procedures. These differences can be categorised using the SOLO learning cycle levels. More so, these levels are to be found in the same order in higher and lower stages in the model. Graduating from one stage to another requires a shift in thinking ability and the ability to handle increasingly abstract and complex problem situations within one stage, until an extended abstract level is reached which bridges into the next stage, becoming the first level for that new stage.

This study looks much more at the micro situations and use is made of the notion of different levels within a stage to categorise student responses to problems. This is premised on the assumption that students must produce evidence consistently over many trials and problem solutions to show that they have reached the extended abstract level in order to access a higher stage. It is likely that evidence may be contradictory unless it is taken over a wide enough period before one can confidently make statements about a higher order (the post formal follows the formal in the model, but that is not dealt with in this study). Nonetheless, students at tertiary level are considered to be at the formal stage. Whether they are equally comfortable at this stage for every aspect of learning and thinking is not easily known, but aspects of that question can be tested by investigating their responses to problems at the micro situation. This is effectively what the study is about.

The use of a UMR learning cycle (unistructural, multistructural and relational) in the SOLO framework to develop understanding in calculus concepts and techniques such as the chain rule is presented and subsequent student responses analysed. This is presented as the theoretical framework for this study.

**The SOLO Theoretical framework (and the placement of the cohort on the scale)** (Collis, et al., 1986; Tall, 2004; Pegg & Tall, 2005)

The First mode or stage in the model is the Sensori motor mode, the acquisition of motor skills and it is assumed that the cohort had reached that mode by the time they enter primary schooling. The second mode is the Ikonic mode (the development of words and images – sign systems- to refer to objects and events - and again it is assumed that this mode had been reached at formal schooling level. These two modes may be incorporated in events in a classroom in which objects and events are utilised to develop new concepts, for example in an electrical engineering lab where a circuit board is constructed. This would be an example of the use of earlier modes in line with the nested theory of the SOLO model: the modes are not discarded as new ones are entered but are available to be incorporated or utilised in later modes, and for use at higher level.

The concrete symbolic mode

This mode would appear to be the beginning of our problems in mathematics education. The shift to language and number systems and the resultant reflective abstraction that underpins the growth of understanding and proficiency in these systems provide an essential platform for success in higher mathematical environments, be they in higher grades in school or at tertiary level. The cycles of concept development, the growth of procedural and conceptual thinking and the development of relational thinking can all be said to rely on a level of abstract thinking which has its roots (or certainly growth) in this mode.

**Formal Mode**
This mode, which represents the jump from an arithmetic system to an algebraic system in mathematics, is a logical next step up from the concrete symbolic in the sense that the concrete symbolic leads to the formal (that is, without the need for a reference in real terms) and the development of algebra, eventually leading to calculus. The SOLO model, however, maintains that all previous modes or stages in the developmental framework remain in use, in a nested form and may be accessed at any time.

It is within this mode, however, that the greatest danger of mathematics as a list of symbols and rules without meaning is encountered. The focus on procedures, often at the expense of meaning, leads to a lack of motivation and a fall down in results. This trend, of a discipline with little or no reality, continues at tertiary level and the challenge of providing students with an enabling mathematics environment in which they can construct their own meaning is counteracted by various realities, including the completion of a syllabus in a restricted time and a student body which knows very little other way of doing mathematics either.

The UMR learning cycle is represented by the:

- Prestructural response: when no relevant aspect is used in the problem
- Unistructural: use of only one relevant aspect to solve the problem
- Multistructural: use of multiple relevant but disjoint aspects
- Relational: use of several relevant aspects related into an integrated whole
- Extended abstract: takes the whole process into a higher mode of learning (Collis, et al. 1986, p. 207)

The development of abstract thinking in mathematics is also premised on the presence of basic interpersonal communicative skills (BICS) and cognitive academic language proficiency (CALP) for speakers of other than mother tongue which requires a reading, listening, oral and written proficiency (see Cummings, 1979). Also the demands placed on students to understand are compounded by the expectation of written, as opposed to verbal proficiency in tests, as this requires a degree of formalism which may be determined in terms of their academic literacy proficiency, to begin with. In the analysis of what students are able to do, these factors briefly explored but not dealt with in any detail in this paper. The presence of CALP is vital as it plays a vital role in enabling students to access the information via lectures, tutorials and text- and notebooks, often all of which are in an academic language which is not based on the mother tongue language of many students.

In learning new mathematics, students are taken through the three levels (UMR), sometimes quite rapidly, as the example in their course of introducing the derivative concept illustrates:

U: reminder of gradient of a straight line

M: gradient of straight line applied to average gradient of a curve between two points; limit concept

R: Gradient of a curve at a point (combining multiple responses and integrating them to produce a new concept)

Research Questions

1. Is the use of the UMR learning cycle in the SOLO model a useful aid in the analysis of the mathematical proficiency of entry level tertiary students?

2. Are there limitations and pitfalls to the use of the UMR learning cycle model in analysing the mathematical proficiency of entry level tertiary students?
Methodology and data collection

The methodology used is the analysis of text and the use of the SOLO levels to categorise student understanding of the main concepts.

In the first analysis, excerpts of student texts are considered. Attempts are made to place aspects of these student responses within the SOLO UMR levels. The texts are student produced examinations scripts.

The question under examination is to determine the area of the shaded part of the circle (figure 1). To determine the solution it is assumed that the students “know” the following rules and formulas: area of a triangle (using trigonometry since no right angle in the triangle), area of a sector of a circle and the area of a segment of a circle (not required in this case). The task is to calculate the two areas (triangle and sector) and subtract one from the other. The difficulty lies in the false perception that the shaded area is a segment of the circle. For this to be valid B should have been the same point as C and E should have been the same point as E, both lying on the circumference of the circle. So it is likely that some students had the problem wrong because of perception. By performing any one calculation, even the wrong one, the unistructural response is selected; two or more calculations but not connecting them is multistructural; two or more calculations and integrating the results (subtraction) is the relational response. The problem was an unseen one and therefore it contains the three levels.

![Figure 1. Question on area of the shaded region using radian measure](image)

In terms of the taxonomy for the solution of this problem, the following is suggested (table 1): prestructural if no attempt is made to solve the problem; structural if one attempt is made, whether wrong or not; Multistructural if several attempts are made, but not linked and
relational if several attempts are made and integrated to produce a solution (even in the case where those solutions were wrong, as long as the logical connections are made).

**Table 1:** The SOLO learning cycle applied to a test question on areas of shaded parts of a circle

<table>
<thead>
<tr>
<th>SOLO learning cycle</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>prestructural</td>
<td>No attempt is made</td>
</tr>
<tr>
<td>Unistructural</td>
<td>One attempt is made</td>
</tr>
<tr>
<td>Multistructural</td>
<td>Many attempts are made but not integrated</td>
</tr>
<tr>
<td>Relational</td>
<td>Attempts are integrated to solve the problem</td>
</tr>
</tbody>
</table>

The data are from 52 students: student produced texts taken from one test covering pre calculus topics and two quizzes covering the chain rule in calculus. The selection presented in the pre calculus sample deals with the student responses to one question which requires the use of techniques in finding areas of sectors and segments in circles using formulas developed with radian measure (figure 1). A summary is made of the spread of responses, using the UMR learning cycle. Also, a content analysis is made of 5 responses (figures 2-4).

The content analysis makes use of the notion of syntax and semantics in mathematics as described by Radford (2004), in which syntax refers to the external symbolic representation with its rules and surface structure and semantics deals with the deeper structure or meaning. In my analysis of the student texts, I am restricted to focus on the syntax of the mathematics. This is mainly because the test questions lean towards the procedural, requiring some, but not huge insight, to solve. There is, however, space to surmise possible psychological inferences, based on the manner of the student responses. These inferences are speculative at best, but may offer supportive factors in an attempt to understand the mathematical proficiency of the cohort.

The quizzes on calculus (table 2 and 3) each have a set of five composite functions. This time 26 students from the same cohort took these tests. The first set has composite power functions and the second set has composite tangent functions. Their derivatives can be determined using a multistructural approach, the assumption being that the use of the chain rule for a composite function involving two functions have been established before the quizzes are taken, except for the last one in each case, which requires a new relational response, since three functions are now make up the composite function. Student responses to both quizzes are analysed, using the SOLO learning cycle model.

The first three functions require a standard approach: differentiate the function relative to its argument and multiply the result by its argument. The fourth function requires a further action and requires of the student to “hold off” the final result until one more step is made. Although this is a repeat step the process involved requires a higher level of thinking and action. This fourth question, being unseen, as this is the first time the cohort are challenged to produce a correct response, becomes an item that discriminates well between the cohort. The willingness and ability to suspend that final answer and repeat the process of differentiation within the present process of using the chain rule, requires a degree of confidence brought about by mathematical comfort and proficiency. Those students who perform this procedure with comfort stand ready to make further leaps towards the next stage in the SOLO model (or practically, to advance to further topics in the course). Elsewhere it is said they have crossed a threshold (Meyer & Land, 2005). The levels within the chain rule concept, as presented in part by the quizzes, are geared to grow the development of
mathematical thinking about functions and composite functions and their derivatives. For students in an applied programme this is the prelude to applications within their discipline, including using the chain rule in other areas of calculus such as integration, though in reverse. Seeking ways to understand a difficult concept often involves understanding its constituent parts or elements of it which are initially more accessible, in this case those composite functions involving only two functions. The intended outcome is that the student i) recognises and is able to ii) solve all manner of differentiable functions, many of which will require use of the chain rule. Thus the investment in bringing a concept such as the chain rule to bear, through these initial elementary levels, is worthwhile as the complexity of mathematics increases in higher courses. The chain rule, in terms made popular by Meyer and Land (2005), could thus be seen as a threshold concept. This would help to explain student difficulties with the concept.

<table>
<thead>
<tr>
<th>1. Determine the derivatives of the following functions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>function</td>
</tr>
<tr>
<td>1. ( y = (x^2 + 3x)^6 )</td>
</tr>
<tr>
<td>2. ( y = (\sin x)^6 )</td>
</tr>
<tr>
<td>3. ( y = (2x)^6 )</td>
</tr>
<tr>
<td>4. ( y = (\sin 2x)^6 )</td>
</tr>
</tbody>
</table>

**Table 2.** Student quiz on the learning cycles in the chain rule procedure (power function)

<table>
<thead>
<tr>
<th>2. Determine the derivatives of the following functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>function</td>
</tr>
<tr>
<td>1. ( y = \tan x^2 )</td>
</tr>
<tr>
<td>2. ( y = \tan^2 x )</td>
</tr>
<tr>
<td>3. ( y = \tan 2x )</td>
</tr>
<tr>
<td>4. ( y = 2\tan^2 x^2 )</td>
</tr>
</tbody>
</table>

**Table 3.** Student quiz on the learning cycles of the chain rule procedure (tangent function)

**Results.**

Area of the Circle question

It is perhaps not unsurprising that about half the students either failed to address the question (prestructural) or made one attempt (unistructural)(table 2). In a test situation students may well chose to ignore certain questions which seem too hard to do. Their non choice is then seen as a very real choice. An example on this is candidate marked A (figure 2). This student as merely repeated the whole sketch without any attempt to answer the question. The student actually drew the sketch and wrote down the full question. What could be the reason for this? Sometimes students fill up the time in the examination centre in this way: they don’t want to leave early and risk being exposed!

Around one quarter of the students made only one attempt. The candidate whose work is marked B (figure 2) correctly determined that the angle at the centre of the circle was \( 60^\circ \),
presumably

by inspection since there is no evidence of working this out; similarly the value of the radius was 6 cm, again with no evidence that this was worked out. These are thus not considered as attempts in terms of the model, but perhaps fall into the category of recalled knowledge (so
knowledge from an earlier mode, say the concrete symbolic). The single attempt is the use of the formula for the segment of the circle (a wrong choice, as mentioned in the methodology section above).

There is some evidence on the script (the recall of the centre angle and the correct size of the radius) to suggest that this student overlooked the shaded area and would, upon being corrected, not easily make the same mistake next time. The calculation of the area of that segment of the circle was correct, indicating a comfort with these sorts of calculations.

Still a further quarter made several attempts but failed to integrate those to get a correct solution, thus placing them in the multistructural level of the model. The candidate whose work is shown as D (figure 3) made several attempts. In i) the candidate correctly determined the size of the

![Figure 3. Student texts: Multistructural]

radius. In ii) the student makes use of a geometric construction to determine the value of the perpendicular bisector of the triangle. Attempted but then scratched out is a determination of the area of the sector of the circle with an incorrect arc. These are many attempts but these are unrelated and therefore not integrated. The scratched out parts are indicative of the pursuit of a strategy, even though that strategy is wrong. This is an example of a “many attempts” which do not constitute enough consistency which makes integration possible. The solution E on the other hand contains many attempts which can be integrated, but are not. After correctly calculating the angle at the centre ($60^\circ$), probably by inspection, the student then uses this information to calculate the area of the sector (but uses an incorrect value of the radius) (lines 1-5 left hand side). This is discarded in favour of an attempt to calculate the
area of the segment, which is abandoned. In lines 2-5 on the right hand side the student determines incorrectly the area of the triangle (the .5 is missing from the formula). Further down the page the student tries to determine the value of the radius again, this time using an obscure formula which relates in part to the formula for the area of a triangle (it contains the .5 that was missing before). Then to conclude, the student uses this new information to calculate the area of the sector again. So this attempt (E) contains all the elements which, together, should provide the solution. However, there is evidence of much confusion, and some of this evidence is in the manner in which the student erases work and repeats strategies with other information. Even then, nowhere is there evidence that the student was trying to integrate the results, thus this is an example of a multistructural attempt.

The solution C contains all the main responses, including use of the cosine rule to determine the angle at the centre (lines 1-5) and an incorrect value for the radius (line 6). These different responses are then integrated to create the desired solution (line 10-12). This would represent a relational level response.

The Chain Rule quizzes

The composite power function responses refer. As expected, all the students responded...
complexity. For example, the derivative of a function and write the answer as one composite function with the derivative of the argument where the argument is one function. The mistake is to differentiate the argument as well as the function and write the answer as one composite function with the derivative of the argument as the new argument. In the procedural rule, the student struggles to hold the added complexity. For example, the derivative of $2^x$ would be written as $6(\cos^2 x \cdot \sin x)$ in such a case. Now, in the quiz, having started with three functions as a set requiring similar treatment, There was one non-attempt. Ten students successfully solve the problem. Sixteen students fared worse in the composite tangent function quiz and that made comparison across the group. There was one non-attempt. Ten students successfully solve the problem. Sixteen students fared worse in the composite tangent function quiz and that made comparison of the argument or the function and certainly when both were used in the last function. The test, to see whether determining the derivative of the last question would provide a comparable split in the group was hampered by this discomfort, but led to other interesting questions. To sort through their responses and provide some categorisation and explanation for them, the first two questions (table 3) were considered together, to start with. For the $\tan x$ function students who gave the wrong response either considered the power as a power for the $\tan x$ function or saw the square correctly as belonging to the $x$ but in the derivative of the $\tan x$ function failed to keep the argument and replaced it with only $x$. This diversion from the main task immediately raised the possibility that a UMR learning cycle could be explored for the students understanding of trigonometric functions of the sort displayed here. Clearly, not all the students had reached the relational level in that regard. The analysis of responses to these two questions also raised the question about what role the UMR learning cycle played, not only in determining readiness for higher levels within a stage, but also across a stage at the same level. Of course, if students were only learning the syntax of mathematics and therefore at a surface level, it may explain best why they were performing at a complex level using the chain rule but misinterpreting composite trigonometric functions. There are many possibilities, including the lack of familiarity with the signs, in this case the meaning of the constant $2$.

Lastly, I considered whether, of the group which succeeded in solving the first two questions, there would be a split with the last one (table 3), as this involved two power functions, i.e. one composite square function involving a composite tangent function. Of the group who failed at the first hurdle, one or two managed to determine correctly one or at most two derivatives, especially for $x^2$ and in one case for the tangent function with the correct argument. This latter student did not give the correct response for an easier derivative at the start. This last response again shows how easy it is to assign a level in the UMR cycle at a micro level, without taking a huge enough sample of problems per subject.
The group who succeeded at the start broke up with the last question. Since this was a composite function involving an argument that was itself composite, this question compared favourably with the parallel question in the power quiz. The presence of the symbol 2 in three places, however, undid many students. The coefficient 2 was treated as part of the tangent function and not as the constant; consequently a number of students\textsuperscript{13} “carried” the 2 into every derivative. An example: \(2(\text{tan}^2x^2)(4\text{tan}x^2.2\text{sec}^2x^2)\). This student also “carried” the original function into the solution, a tendency that was seen to be not that uncommon among the group and is discussed in the next paragraph. Of the remaining group, it was possible to delineate their responses into a micro UMR cycle, as follows:

U: those who made one attempt and determined the derivative of one of the arguments, notably \(x^2\)

M: those who made two or more attempts, notably \(x^2\) and the tangent function, though some changed the argument from \(x^2\) to \(x\).

R: those who successfully determined the derivative of the function

It remains to say something briefly about the use of written responses by some of the cohort, in terms of their cognitive academic literacy proficiency (CALP) in a mathematics context. The tendency to write the question as part of the answer was very prevalent. An example of that was: \(\tan^2x\) followed in the next line by \((\tan x)^2\) followed in the next line by the derivative with no indication where the question stopped and the response began.

\textbf{Summary and recommendations}

This study makes use of the SOLO learning cycle model UMR to investigate the

\textsuperscript{13} Since the qualitative analysis is the main method used here and the details of the number of students mentioned do not in themselves lead to any meaningful insights, no attempt is made to quantify the breakdown of students for these questions.
mathematical proficiency of a cohort of entry level students. An analysis of their responses in a test question and on two quizzes testing their understanding of procedures using the chain rule revealed clear differences among the cohort. The cohort divided into the UMR learning cycle levels for every question. The cohort also revealed that there were differences in their understanding of a trigonometric function and this too could be categorised along the UMR levels. The use of the UMR learning cycle at the micro level opens areas for analysing mathematical proficiency at the that level and points to areas of uncertainty that the students face. Sometimes, however, placement along the UMR level may be as a result of factors other than the proficiency of the study at the micro level. This indicates that a wider pool of questions and problems need to be presented before more definitive decisions can be made about the proficiency level a student could be placed at within a certain stage. It was also clear that, within the formal stage, students divided along the UMR levels for the three questions. This indicates that although all students were in the formal stage, not everyone was at the same level. The responses to the questions involving the composite tangent functions may indicate that some students still have a need to be linked to the concrete symbolic stage in order to improve their understanding of, in the case of the study, composite functions and especially composite trigonometric functions. Such findings point to and assist planning for lectures and classes in these areas. The complete SOLO model makes provision for using earlier stages or modes in later one. These modes are said to be nested modes, available for use as need be. The results of a UMR learning cycle study may point to the use of these modes, as was the case here. Typically, students may divide along the lines of those who need to draw understanding from earlier modes in order to understand concepts within the present one versus those who stand ready and eager to advance to the next, higher stage.
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The multiplicative conceptual field: What have we learnt in 30 years?

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In this paper we seek to answer the question, “What have we learnt concerning the learning and teaching of elements of the multiplicative conceptual field over the past 30 years?” We note the pivotal role of the multiplicative conceptual field (MCF), which includes fractions, ratio and proportional reasoning, in the journey from natural numbers to real numbers and from arithmetic to algebra. Research studies that are qualitative and quantitative, small-scale and large-scale, theoretical and empirical, and in various combinations of research designs are discussed. In particular we confront the apparent dichotomy between large-scale experimental design studies that report in generalities and small-scale studies that focus on detail. We conclude that the research has been extensive and that there has been substantial progress. This conclusion raises further questions. Why do reports from systemic studies depict a bleak picture concerning the learning and teaching of this cluster of concepts? What are the possible explanations for the large gap between the achievements of theoretical research and the predicament of the large scale test results to be understood? The overview in this paper is not meant to be comprehensive: The broad brushstrokes serve to illustrate features of the mathematics education landscape.

Introduction

As a collective mathematics education community, we might sometimes wonder whether we have made progress over the past 30 years in unraveling the complexities of learning and teaching the cluster of concepts comprising multiplication and division, fractions, ratio, rate, proportion, probability, and percent. These mathematical concepts, together with the emerging cognitive constructs and the situations for which these concepts are required, constitute the multiplicative

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14 The term situation is used by Vergnaud (1988) for any typical everyday context in which a particular mathematical construct will be embedded. The situation would then provide the means for learners to engage
conceptual field (MCF). The MCF notion and term were defined by Vergnaud in the early eighties, and published in the English literature in 1983. Proportional reasoning, a critical cognitive process which underpins the successful mastery of this field, has been described as the capstone of primary school and the cornerstone of secondary school mathematics (Lesh, Post & Behr, 1988). The importance of the multiplicative conceptual field for providing the groundwork for the learning of algebra has been noted by Vergnaud, (1997) and others. Lamon (2007) notes both the significance and the complexity of the field.

Of all the topics in the school curriculum, fractions, ratio, and proportions arguably hold the distinction of being the most protracted in terms of development, the most difficult to teach, the most mathematically complex, the most cognitively challenging, the most essential to success in higher mathematics and science, and one of the most compelling research sites. (p. 629)

**The 30 year journey**

In 1979 Vergnaud built on both the important work done by Piaget, spanning both a mathematical and a psychological perspective, and the work of Vygotsky, in relation to language and the importance of scaffolding scientific concepts, but stressed that more work needed to be carried out through studies specifically located in mathematics education. In particular he averred that while mathematics may arise in part from social construction, nonetheless its peculiar and different abstract nature has one inescapable consequence: it is nonetheless impossible to offer a valid theory of mathematical learning and acquisition without grounding and referencing that theory within mathematics itself (1988; 1994; 1997; 2009).

Also in 1979, Usiskin, from University of Chicago Schools Mathematics Project (UCSMP), challenged the view that common fractions would lose their importance in the curriculum; he argued that, on the contrary, fractions would increase in use. In 2007 Usiskin again commented on the complexity of the fraction concept and its important function in the network of related mathematical topics including algebra.

The work by the Rational Number Project in the 1980s on elaborating the different components of rational number, and related studies, provided the foundation for further research in this field (Behr, Harel, Post, & Silver, 1983). In 2007 Vamvakoussi and Vosniadou reported on research into learner understandings of rational number and concluded that a radical conceptual shift is required for the conceptualization of rational number, rather than the mistaken presumption that rational number system is merely an extension of the natural number system. Also in 2007 Lamon, after reviewing the research in the past 30 years, makes a both attempt at outlining a framework for research in the field that optimally requires a research design that can accommodate the complexity of the field and learners development within the field. Her longitudinal study blazes a trail for just such studies.

In 1969 Nelson posed the question, “Is percentage a rational number or a ratio?”: In 1995 Parker and Leinhardt concluded that percent is a complex construct that can represent a fraction, or a ratio, that includes all the complexity of the rational number concept, and that in addition is used as a function and a statistical description.

Vergnaud, in 1979, stressed the importance of representation, noting the distinction between the signifier (the symbol) and the signified (the internal reference). In 2006, both Steinbring and Duval independently highlighted the importance of semiotics in mathematics15.

In 1992, Webb asks whether a distinct theory of assessment is required for to address the complexity of mathematical development. He notes that assessment is integral to mathematics instruction. Currently the two sites, the classroom and large-scale assessment have different purposes. In the last

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15 We are aware that this broad brushstroke description is leaving out important contributors.
decade progress has been made, most notably in Western Australia where the results of systemic testing are fed back to the schools for analysis and interpretation. An additional development is that the application of the Rasch measurement model enables information at the individual level. This development answers the criticism by Webb that teachers are given very little assistance in the technical details of testing. The Rasch model also provides validation checks for researchers, perhaps providing the impetus for differently designed research where tests are sensitive to development.

While this brief overview of shifts in research focus within the multiplicative conceptual field over the past 30 or so years is indicative of theoretical depth, there is other research which provides a rather bleak picture.

A bleak picture across continents

Studies across the world purporting to assess attainment in the MCF cluster of skills report disappointing results. In the United States, the National Mathematics Advisory Panel Report (NMAP, 2008), after only including studies which they regarded as having “scientific rigour”\(^\text{16}\), concluded that difficulty with fractions (including decimals and percent) is pervasive and constitutes a major obstacle to further progress in mathematics, including algebra. A great deal of research has argued that in order to attain entry into algebra, students first have to successfully master the components of rational number. To this end, the U.S. Department of Education’s National Center for Educational Evaluation and Regional Assistance (NCEE) initiated the Middle School Mathematics Professional Development Impact Study (MSMPDIS). The study was designed to address the problem of low student achievement in topics in rational numbers. In spite of 68 hours of input from the service providers, there was no significant improvement in teacher knowledge. Neither was there impact on student achievement and only slight impact was evident on what was perceived to be improved teaching practice (Garet et al, 2010).

In the United Kingdom, the Increasing Student Competence and Confidence in Algebra and Multiplicative Structures (ICCAM) study (Hodgen, Küchemann, Brown, & Coe, 2009) tested a cohort of 11 to 14 year olds in 2008, on tests previously used by the Concepts in Secondary Mathematics and Science (CSMS) study in the early 1980s. ICCAM found that over the period of more than 20 years there was only slight improvement in decimal problems, but deterioration in fraction problems and very little change in learner ability to solve problems requiring ratio and proportional reasoning.

France’s national assessment surveys in 1993 and 1997, show that at the beginning of secondary school, only “one student in three appeared to have grasped the functioning of the decimal system” and was able to “succeed with a set of items about the simplest operations of multiplication and division of decimals ...” (Duval, 2006, p. 106).

In Australia, Stacey and Steinle (2006) conducted a longitudinal study into the understanding of decimal notation and concluded that the learning of decimal fraction notation was rather haphazard with different types of misconceptions emerging at different phases of Years 5 to 10.

The TIMSS study showed South African Grade 8 learners achieving very little success on items demanding ratio, proportion and percent type knowledge (Long, 2006). The programme of national and provincial testing over the past ten years has also reflected dismal results (Howie, 2001; Moloi & Strauss, 2005; Reddy, 2006).

Evidence from research

While this evidence seems to point incontrovertibly to the fact that the mathematics education research

\(^{16}\text{See Cobb et al (2008) and Thompson (2008) for critical analysis of this report.}\)
has failed to meet its own primary objectives, we argue that there is a wealth of research addressing mathematics education issues. The research studies invoked in this section focus on the mathematical structure and the nature of the interrelationship of MCF concepts, the acquisition of these concepts by learners and the complex processes underlying teaching. In addition there has been a particular focus on proportional reasoning as a core process underpinning the elements in MCF. Because the development of mathematical thought is intricately connected to representations and symbols, the study of semiotics has featured strongly in the mathematics education literature. And finally, because what is reported is determined by the approach to testing and assessment in general, we report on a statistical model that provides both a more nuanced approach to measurement and a gauge for the validity of tests.

**Nature of mathematics**

Much of the research addresses epistemological issues of mathematical structure in regard to multiplication and division (Greer, 1992); fractions and decimal numbers (Steffe, 1993), ratio, rate and proportion (Behr et al; 1983), percent (Parker & Leinhardt, 1995) and emerging algebra concepts (Kieren, 1992; 2004). Some of the research deals with a concept in isolation, such as fractions, or in pairs such as fractions and ratio, however for the most part the studies focus on the interconnections of concepts within and beyond a conceptual field, for example Carraher (1996) elaborates the connections between fractions, ratio, functions and algebra.

**Acquisition of concepts**

In addition to what can be described as a purely mathematical focus, there is a wealth of research focusing on the cognitive acquisition of the same family of concepts. In some cases there is a concentrated focus on acquisition of particular topics, but there is also work, as Vergnaud proposes, “embracing, in a single theoretical glance” the complex interactions of situations, mathematical concepts, cognitive processes and the symbolic representations, across the range of developmental phases. Both the epistemological analyses and the cognitive analyses are invoked in studies which investigate the teaching of elements of MCF, either singly or in conjunction.

**Teaching design experiments**

Again, there is a plethora of design research in which teachers have drawn on research in the field and converted the theory into classroom practice, among others Lamon, (2006a; 2006b). In some cases there have been formal teaching design experiments (Adjiage & Pluvenage, 2007) and in other cases teachers report on a sequence of lessons that have been designed for the purpose of developing the appropriate cognitive schemes in learners, most notably in the sequence of “teaching for abstraction” steps designed by Mitchelmore, Mc Master and White (2007). Lamon (2007) embarked on a watershed longitudinal teaching design experiment, across 4 years, from Grades 3 to 6, where the focus of the experimental group was on the complex interrelations of the multiplicative conceptual field, building on the research of the past 30 years, notably the Rational Number Project research, and Vergnaud’s theory of conceptual fields (1983, 1988). The control group followed a programme which followed standard practices. After two years the experimental groups lagged behind the control group, but after 4 years the experimental group exhibited sound rational number knowledge.

**Proportional reasoning**

There has been a bold attempt on the part of some researchers to regard proportional reasoning as the core skill underlying all of the intermediate and senior phase mathematics. Beginning with the Tourniare and Pulos (1985) review of proportional reasoning, which includes attention to Piaget and Inhelder (1958), Noelting (1980), the CSMS research (Hart, 1981) and Vergnaud’s theory of conceptual fields (1983, 1988), there has been consistent focus on proportional reasoning.

Lesh et al (1988) acknowledge Piaget’s work on proportional reasoning and agree in part with the stages that Piaget describes, however they make a claim for the development of localized knowledge

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17 For a more extensive review see Long (in process)
that is developed through the careful design of instructional sequences. They have a strict definition which holds that proportional reasoning "involves a sense of co-variation and of multiple comparisons, and the ability to mentally store and process several pieces of information" (p. 93), and do not consider the procedural "cross-multiplication" strategy as appropriate in this category of proportional reasoning.

Heller et al (1990) building on the work of Lesh et al, propose that a qualitative component, which they label directional reasoning, is a necessary precursor to proportional reasoning which then requires an additional quantitative component, and the application of numerical skill. While the focus on proportional reasoning was an attempt to solve the complexity of the multiplicative conceptual field and the learning of mathematics generally, it appears that the need for a more complex approach involving semiotics is required and unavoidable.

Semiotics
The insight into the learning and teaching of mathematics through careful attention to representation, and the unifying relationships of the representation triad, mathematical concept, referent or object and sign or symbol, as developed by Steinbring (1998, 2006) and Duval (2006), does much to uncover the complexity of mathematics itself and hence of the learning of mathematics.

Steinbring (1998) extends our understanding of the relationship between the triad, mathematical concept, mathematical symbol and reference, by identifying developmental stages of relationship between this triad. The initial stage is described as empirical, where there is a direct reference from symbol to concept and reference. This stage while a necessary starting point is not conducive to mathematical thinking as the "true mathematical object, that is the mathematical concept, may not be identified with its representations" (Steinbring, 2006, p. 137), because this direct labeling restricts the concept’s abstract power.

A structural relationship which can be mediated through relational diagrams, such as some forms of decimal charts, is more conducive to moving between representations. Vergnaud (1988, 1994) provides relational diagrams that support the solving of simple and multiple proportion problems.

A third phase occurs when conceptual relations are generated and organized into a system of theoretical relationships. Duval (2006) notes that throughout history “the development of semiotic representations was an essential condition for the development of mathematical thought”(p.106). He further asserts that “changing the representation register is the threshold of mathematical comprehension for learners at each stage of the curriculum.”(p.128). This notion of thresholds that require comprehension at successive stages resonates with the work of Meyer and Land (2005) on ‘threshold concepts’. Threshold concepts, are troublesome prior to mastery, however once mastered open up “new conceptual space” which leads to “transformed thought”, and the “adoption of an extended discourse.” (p. 374-375). The conceptual shift from natural numbers to rational numbers noted by Vamvakoussi and Vosniadou (2007) could be described as a ‘threshold’ stage.

Summary of mathematics education research: from theory into practice
In summary, the strands of mathematics education research, that have kept in their sights the aim of developing powerful abstract knowledge have been in the public domain for at least 30 years, in fact from the early work of Piaget, and are worth serious consideration. They are characterized by searching for the means by which learners can make this knowledge their own, through taking seriously the learner’s current immanent mathematical conceptions and extending these conceptions towards more abstract mathematical concepts.

The complex theory, provided by, for example, the Rational Number Project (from 1979), Steinbring (1998; 2006), Duval (2006) or Vergnaud (1979, 2009) may not have direct and immediate application to the teacher in the classroom. However there are cases where an astute teacher or teacher educator has picked up the ideas, for example the idea of measure spaces and transformed these notions into
classroom instructional sequences. Shield and Dole (2008) drawing from the work of Bell (1993) use the idea of “structure and context” to help students to observe that “the same mathematical structures can occur in different contexts” that require proportional reasoning. If the mathematical structure “is recognized in a new context, then solution methods similar to those used previously can be applied to the new context” (2008, p. 10). The mathematical structure that is modeled in a representation of measure spaces is attributed to Bell (1993) and Lamon (2006a, 2006b) but is also present in the work of Vergnaud (1994). Lamon herself as stated earlier has included the substantive research of the past 30 years in a longitudinal teaching design experiment (2007).

The importance of representational tools of this type as a teaching tool is invaluable. Diagrams, performing the function of representational tools serve to make explicit the hidden structure of the mathematical problems. They also provide the scaffolding between natural language and mathematical symbolic notation (Vergnaud, 1983). The two representations, Vergnaud’s representation of a class of problems as “simple direct proportion between two measure spaces” (Behr, et al. 1992, p.297), and Shield and Dole’s use of this representation to illustrate a simple proportional problem are shown in Figure 1.

![Simple proportion](image)

**Figure 3:** Representation of simple proportion (Vergnaud, 1994; Shield and Dole, 2008)

The fact that the Shield and Dole article is published in a teaching journal is indicative of the translation of mathematics education research into teaching practice.

**Research insights and systemic test results**

Given the seeming contradiction between reported intervention achievement results such as those noted earlier, and the apparent consequentiality of the new insights emerging in the discipline of mathematics education, we pose the following questions:

*How is the large gap between the achievements of theoretical research on the one hand and the predicament of the large scale test results to be understood? Have we as a mathematical community failed to meet our primary objectives? And if not, why has the increased knowledge not manifested classroom practice? And furthermore why has the progress in theoretical and empirical research not produced better results?*

*Mathematics education research has not met its objective*

The first hypothesis that mathematics education research has not met its primary objective must be rejected out of hand. A survey of the research highlights much detailed investigation into particular topics, and more often engagement with a cluster of topics. Some research has provided an overview of a developing topic starting from the early grades and showing the trajectory to high school, for example, Steckroth (2009) tracking the route from calculation to calculus. Kieren (2004) also provides an extended view which highlights the distinctions between arithmetic and algebra and elaborates the core components of algebraic thinking, and then very importantly proposes a definition that could be useful to teachers of the early grades.
Progress is slow

The hypothesis that progress is indeed slow is worthy of consideration. It must be acknowledged that in some places the progress appears constant, sustained, abreast of the research and makes a valuable contribution to teaching and learning, such as the University of Chicago Schools Mathematics Project. Another well-functioning pocket may be the community of Australian teachers contributing to and drawing from The Australian Teacher, in which over the past five years there have been many research informed articles supporting the teaching of concepts within MCF, of which Shields and Dole is an example. These outcomes may be contrasted with less successful attempts to improve mathematical learning elsewhere, for example the reported poor teaching in some schools in South Africa. There are pockets of excellence in middle class schools and there are projects which are succeeding in bringing the best of research into rural classrooms, namely the Ukuqonda Institute in the North West (see Human & Setati, in process). We have to acknowledge that progress is slow; there is an inevitable lag in conveying the best of research but also in eliciting the creative potential of teachers, for whom mathematics may not have been a favourite subject! We do not doubt the constellation of problems impacting mathematics teaching in South Africa that require analysis, but focus here only on the impact of what we regard as progressive research which we believe is the bedrock of sustained change in classroom practice.

Research is ignored

The MSMPDIS study does not appear to have taken into account the substantial research in the area of rational number, judging only from the list of topics presented. An investigation of the study materials themselves would be necessary but the title “Percents are ratios” (Garet, et al. 2010, p.104), suggests a lack of as comprehensive an understanding of percent as that exhibited in Parker and Leinhardt (1995). In addition we note methodological problems, such as the acknowledged fact that MSMPDIS measures were constructed to “capture the quantity, not the quality, of the measured practices”, as a fundamental flaw. An additional fragility was that the measure of classroom practice was based on “one observation per teacher” (p.67). That research is ignored is also endemic in South African research, based on the notion that teachers cannot manage the complexity.

Testing programmes are inadequate

An additional explanation for lack of noticeable progress is that testing programmes are on the whole inadequate for establishing the finer nuances of understanding that may be generated in some schools by some teachers. Vamvakoussi and Vosniadou (2007) note that the presupposition that learning is additive may work against the building of sound concepts. Perhaps the common testing model, generally made up of a collage of items that cover the curriculum but that are not specifically constructed to present a coherent developmental path, is not able to detect the changes that may be happening. Certainly the test reported by Stacey and Steinle (2006) in their longitudinal study on decimal notation, does not exhibit a developing construct. The thirty items on decimal notation have exactly the same structure. “Which is greater? 8.245 or 8.24563?” and variations on this form, which according to the researchers is designed to pick up misconceptions, rather than measure a developing cognitive construct.

Of particular concern to Cobb and Jackson (2008) in regard to educational testing, is that knowledge claims from an educational measurement perspective reflect a “particular conception of the individual” (p. 574). This apprehension arises from the fact that:

(t)he knowledge claims refer to an abstract, collective individual or statistical aggregate that is constructed by combining measures of psychological attributes of the participating students (e.g. measures of mathematics achievement). This statistically constructed individual is abstract in the sense that it does not correspond to any particular student (2008, p. 574).

The observation by Webb (1992), that mathematics requires a theory of assessment, is critical.

The implicit inference is that the particularity and the consequentiality of individual learning and individual teaching is swamped in aggregative reporting. A statistical model which utilizes
“individual-centred statistical techniques” and therefore alleviates some of these problems was developed by Georg Rasch in the 1950s (Rasch 1960/1980, p. xx).

The Rasch model for measurement

Underpinning the model is the notion of fundamental measurement, which has at least two implications, the first is that a construct has to be defined and operationalised in terms of development along a hierarchical continuum. Location at points along the continuum indicate a learner’s degree or extent of acquisition of the concept, indicating more of or less of the construct of interest. Likewise the items are located along the same continuum exhibiting greater or lesser inherent difficulty. In the Rasch framework, the differences between the locations on the continuum for a particular person and each particular item are the sole factors affecting the probability of that person’s successes or failure on the corresponding items (Andrich & Marais, 2008).

The second implication is that the Rasch model does not arise from the conventional approach of obtaining data and subsequently selecting adequate statistical models from a wide class of models. In contrast, like all measurement data processes in the physical sciences, it arises from the careful construction of instruments from which recorded data will exhibit measurement-like properties (Andrich, 1989).

By representing learners and items on a common continuum, it is possible to make inferences for a particular individual learner or cluster of learners at some point on the continuum, about which particular selection of items at nearby locations will suggest tasks and learning experiences close to some current personal proximate zones of development (Van Wyk & Andrich, 2006; Long, Dunne & Craig, 2010).

The power of the Rasch model is that it permits inferences at the levels of the individual person and the individual item, and their interaction. This diagnostic power arises from the use of discipline-specific expertise that constructs and selects items which are both appropriate in form and content but also exhibit a range of complexity that adequately targets the likely spread of person abilities under study (see Long, Dunne & Craig, in process).

A collection of studies applying the Rasch model have emerged in the mathematics education literature in recent years. Stacey and Steinle used the model on an arbitrary data set and by seeking to exhibit circumstances no continuum was invoked for the instrument construction; they did not utilize the model’s strengths (see Marais, Dunne & Long, in process). By contrast, Misailidou and Williams (2003) established a scale of proportional reasoning against which to diagnose learner misconceptions and could also provide a measure of proportional reasoning attainment. A second analysis was performed to diagnose the presence of the tendency for using the additive strategy.

An additional strength of the Rasch model is to provide validation of the items. The model enabled Misailidou and Williams (2003) to reflect on the quality of the items used for eliciting proportional reasoning in learners. The levels of reasoning established were similar to those found in Hart (1981), but a further finding was that the additive strategy was developmentally more advanced than other error strategies. This observation confirms other research which shows additive reasoning as a first step towards multiplicative reasoning, as in the term preproportional reasoning used by Lesh et al (1988). The Rasch model provides operational criteria for checking the validity of a test. The strength and validity of the test is directly related to the theoretical development of the construct. The more fine-grained the theoretical work informing the hierarchical development of the construct and the corresponding test items the better the instrument. And the Rasch model will alert the test designer to the anomalies arising from poor test construction.

The Rasch model, by locating both individual items and individual learners on the same scale,
provides an effective answer to the criticism expressed by Cobb & Jackson (2008), that statistics only describes a “statistically constructed individual” (p. 574). This class of Rasch models enables “individual-centred statistical techniques” where each individual is characterized separately (Rasch, 1960/1980, p. xx).

Conclusion

We conclude, in regard to the first question concerning the effectiveness of research, that the plethora of theoretically informed qualitative studies, including many for which a quantitative dimension is added, have contributed substantially to our knowledge base.

Whether the ideas have permeated educational systems in general, impacted on curriculum design and become established in the practice of classroom teaching is a second question. The pendulum has swung from the “new mathematics” built on solid mathematical foundations in the 1950s and 1960s, to an emphasis on children’s developing cognitive processes. While the mathematical focus must be kept in mind, “sensitivity to the crude beginnings may lead to a developmentally appropriate mathematics curriculum” (Ginsburg & Seo, 1999) that continually engages learners with threshold concepts and finds the route through to new conceptual spaces, is of paramount importance.

The third question is whether the instruments we currently use for establishing progress are sensitive enough to provide the evidence of development or growth. The Rasch model we believe provides the operational criteria for establishing and developing measures that are fair and that require reflection and revision of assessment instruments, and through these processes provide teachers with accurate and appropriate information at the individual learner level on which to base their practice. The operational criteria demanded the Rasch model not only provide a benchmark for scientific research but serve also the cause of social justice (Andrich & Marais, 2008). We believe that application of the Rasch model, together with testing that takes into account the complexity of mathematics, and professional development of teachers in this regard may pave the way for better mathematics education.

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Critical Analysis of Teaching Mathematics: A theoretical perspective

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Abstract

Research findings show that learners’ achievement in mathematics in South Africa have been below expectations for the past five years and both the public and the Ministry of Education have expressed dissatisfaction with the standards of mathematics attainment among school leavers. Several studies, both large and small scale have identified the concerns in mathematics teaching and learning in South Africa. Various attempts have been made by the Department of Education to address the challenge these include the introduction of the Curriculum 2005. There is still raging debate as to what the best form of knowledge is that teachers require to effectively teach mathematics. This paper is a theoretical and non-empirical attempt to tease out critical underpinnings in teaching of mathematics that include mathematics content knowledge, pedagogical content knowledge as well as knowledge of the curriculum.

Introduction

The teaching of mathematics has always been met with admiration by those who do not teach the subject, fear and concern by neophyte and under qualified teachers and excitement, zeal and passion by those who enjoy and excel in the subject. It is still a debatable issue as to what is the best mathematics for teaching, what the best instructional approaches are and what sort of mathematics must be taught to teachers of mathematics at institutions of higher learning (Ball et al. 2005; Adler, 2004, Hill et al 2008). It is being proposed in most mathematics research papers that teachers should adopt approaches that ‘involve learners in working together on authentic problems, posing their own questions, formulating conjectures and discussing the validity of various solutions’ (Schifter, 1994:1). Essentially such approaches develop learners’ problem-solving and critical thinking skills (Luneta, 2008; Miller & Hudson, 2007). Studies over the past decade both in the developed and in developing countries consistently reveal that the mathematical knowledge of many teachers is critically thin. It is also strongly acknowledged that the teaching and learning of mathematics needs improvement and that much attention must be paid to the art of teaching mathematics and the acquisition of essential skills that enhance problem-solving and critical thinking (Van De Walle, 2007).

South Africa spends proportionately more on education than many other developing country in the world, yet its learners perform far worse than those of other developing countries in international tests as well as national examinations (TIMSS, 2003; DoE, 2006). This indicates that the public education system is inefficient and making ineffective use of the financial resources. The unevenness in the mathematics achievements of South African learners in relation to race poses even more concern. In 2004 for instance, from 39 939 (8.9%) learners who wrote Higher Grade mathematics out of 467 985 learners that sat for the Senior Certificate, only 7 236 (1.5%) African learners passed and out of that figure only 0.5% achieved a ‘C’ or higher symbol (DoE, 2006). The Country’s poor performance in mathematics especially at grade 12 level is strikingly illustrated in graph below.

HG maths results for 2004
The pedagogical and content knowledge

The importance of both mathematics pedagogy and mathematics content knowledge for teacher of mathematics has been acknowledged in a number of papers on mathematics teaching (Yeo, 2008; Ball, 2003; Shulman, 1986, 2001; Adler, 2004; Even, 2000). For mathematical knowledge to be easily accessible by teachers, pedagogical content knowledge (CPK) should integrate with subject knowledge or content knowledge. Yeo (2008:621) calls this mathematics pedagogic content knowledge (MPCK) and that it ‘has a strong influence on children’s learning outcomes. Ball (2000) and Hill et al (2008) assert that the depth of teachers’ MPCK determines their mathematical instruction and illustrations in a lesson, the evaluations exercises they provide, the cognitive demands of the tasks they set and their reactions to children’s work. Reforms abroad and in South Africa have been for teachers to relate mathematics to real life situations (C 2005). Some debate have proposed teachers to do more mathematics courses with emphasis on content knowledge, other have hinged on the instructional aspect of the subject with emphases on the teaching and curriculum knowledge and some research has advocated for the revamping of the mathematics methods course work and professional development programmes to focus more closely on the mathematics contained in classrooms, curriculum materials and students’ learning (Ball et al., 2005). Shulman’s (1986) notions of content knowledge and pedagogical content knowledge have been reviewed and amplified by other scholars who have also noted that for effective teaching and learners’ optimum achievements, content knowledge alone is not sufficient and that
teachers needed the knowledge of how to transform the mathematics content into segments accessible to the learners (Schofield, 1981; Ball, 1991).

Conceptual and procedural knowledge of the content the teachers teach and learners learn are critical forms of knowledge for both teachers and learners of mathematics (Zakaria & Zaini, 2009). Procedural knowledge is the one that enables learners to recognise symbols and is mechanical knowledge that does not include conceptual understanding but the ability to make procedures (Kanyalioglu, et al., 2003). Baki (1998) defines conceptual knowledge as the knowledge that can symbolise mathematical concepts; relate each other and based upon abilities to make procedures with mathematical concepts. In Kanyalioglu et al., (2003), Baykul (1999) asserts that procedural knowledge is symbols, rules and knowledge used in solving mathematical problems and on the other hand conceptual knowledge is that which relates to the understanding of mathematical concepts and how they relate to each other.

Teachers’ lack of conceptual understanding has been linked to ineffective teaching (teachers–centred) (misaligned pedagogical content knowledge) that has resulted in learners’ conceptual under development (Rowland et al. 2009, Mooney et al., 2005; Centre for Development Enterprise, 2007). Conceptual understanding has been divided into several categories – as a sense of proportion – mathematical relationship with the world; understanding the central idea; relationship among ideas; knowledge has to be elaborated and represented in more than one way or form – learners have knowledge of lots of details and examples in the field. The last aspect of subject matter knowledge is the ability to solve and reason about real life problems mathematically. Hence, knowledge of the subject would include understanding of processes that relate to mathematics as used by mathematicians and the links between the various fields of the subject (Bush, 2005; Luneta, 2003).

As earlier noted, the aspects of conceptual understanding combine with teacher’s ability to represent and interpret important and complex ideas in mathematics in ways that are understandable and accessible to learners called pedagogical content knowledge (Shulman, 1986) need to be addressed in teachers’ education discourses. While pedagogical content knowledge is critical for mathematics teachers, effective mathematics instruction demands deeper comprehension of the principles that underpin the laws of mathematics (Adler, 2004). Reform such as a change in mathematics curriculum must be informed by teachers’ views and participation because of the complex nature of teaching mathematics. That means the introduction of new mathematics curricula must be informed by teachers’ grounded interpretation of the new content into teachable chunks.

Teaching mathematics is a complex undertaking and teachers and teacher educators are yet to determine the mathematics for teaching. Instruments, strategies and methods of investigations have not yet been developed to address mathematics for teaching. It is still not known how the various characteristics of knowledge, the knowledge attributes and groupings such as subject knowledge, pedagogical content knowledge, knowledge of the curricula and knowledge of how learners learn mathematics should be investigated in order to articulate the mathematics necessary for teaching. There is still no blue print to the most appropriate approaches to the teaching of mathematics. There is still need to investigate further what constitutes effective instructions and learning of mathematics in order to understand the complexities of teaching mathematics and the difficulties and challenges facing teachers and teacher educators (Adler, 2004; Ball; 2003). Changing the mathematics curriculum in the midst of all this does not help the mathematics teacher or the learners. In the same breath it is important to understand that new curricula were born out of the need to address previous
imbalance and dissatisfaction with the old curriculum in South Africa (C2005) and out of the need to improve instruction and knowledge acquisition in other countries.

Research to identify the sort of mathematics teachers need for teaching (Adler, 2004; Ball, 2003) show that the complexity of teaching mathematics is compounded by the assumption that there is a certain form of mathematics that teachers of mathematics need to know for teaching which is different from the ‘everyday mathematics’. Shulman (1986) identified content knowledge and pedagogical content knowledge as important forms of knowledge necessary in teaching and teacher education programmes. For effective teaching all these forms of knowledge are integrated by the teacher during classroom discourses. The knowledge forms created an increase in the interpretation of pedagogical content knowledge and the other knowledge for teaching strands. There is a new discourse emerging which attempts to distinguish and acknowledge that there is a different form of knowledge called mathematics for teaching that is used in teaching practices and instructions (Adler, 2004; Ball, 2003). Debate still rages whether this form of mathematics can extricable be defined and made accessible to teachers.

In arguments on teacher education, the redesigning of teacher education to strengthen its conceptual base, its connection to both practice and theory and its capacity to support the development of powerful and appropriate teaching skills have formed the major points of departure Vital et al., (2005). There have been and there still are major debates on what the appropriate form of teacher education is. One approach that has been deemed effective is the replacement of campus-based preparation with school-based on-the-job training focused on the pragmatics of teaching (Darling-Hammond, 2000), which, in this way, supplements pedagogic content knowledge with knowledge-based practice. There is a body of empirical evidence that suggests that the extent and quality of teacher education matter for teachers’ effectiveness. The diverse demands of society and the learners have put great strain on the demand for creative mathematics teachers of high standard. Darling-Hammond (2000:167) states further that

Teaching for problem solving, invention and application of knowledge requires teachers with deep and flexible knowledge of subject matter, who understand how to represent ideas in powerful ways, can organise a productive learning process for students who start with different levels and kinds of prior knowledge, assess how and what students are learning, and adapt instruction to different learning approaches.

Adler (2004) argues further rowing mathematics for teaching involves unpacking the compressed mathematics that mathematicians cherish and use. This is one of the differences between teachers of mathematics that are grounded in content knowledge, pedagogical content knowledge, knowledge of the curriculum and knowledge of how learners learn mathematics and mathematicians. Teachers work with mathematics as it is being learned and work with decompression or unpacking of ideas. Adler (2004:9) asserts that mathematics teachers must engage into discourses of mathematics that subscribe to the pedagogy that is embedded in the reform that adheres to decompression or unpacking of mathematics in ways that ‘elicits and value learner thinking’. Mathematics teachers must be articulate in mathematics content and for them to be able to address effective instructional practices for mathematics teaching should also have ‘conceptual-knowledge-in-practice that attunes
teachers to the demands of teaching’ (p.7). However mathematics teacher educators have themselves not researched their own instructional competences and have preoccupied themselves with the mathematics teacher in the classroom. The majority of South African learners are from rural and township settings, the majority of mathematics teachers are from rural and township settings and the irony is that the majority of mathematics teachers educators are from the suburban setup and inept with the rural and township setup.

Research (Adler, 2004; Luneta, 2010) in mathematics in South Africa show that teacher mathematics course are more prevalent in instructional approaches that are procedural and theoretical in nature and little on learners acquisition of conceptual knowledge. There is also evidence that mathematic teachers currently do not know enough mathematics (Boon, 2005; Ross &Bruce, 2005; Lewis, Perry & Murata, 2006) hence it is critical that they engage in mathematical practices that help them to unpack and decompress mathematical concepts if they are to effectively engage with their learners. One of the teachers in the interviews in an ongoing research (Luneta, 2008) revealed that:

_The problems with most of these topics are mainly due to us as teachers. Most of us do not understand them and therefore struggle to teach them. We were not taught how to teach calculus for instance. Teachers education course are not in tune with what goes on in our classroom let alone the new curriculum._ (Teachers interview, November, 2007)

In South Africa therefore there has to be a change in both the teacher educators as well as the teachers’ ideas about the nature of teaching and learning mathematics. The teachers will have to undergo a process of disequilibration of prior ideas of teaching and reconstruct new and more powerful ones. The new instructional approaches should include among others valuing of students’ construction of mathematical concepts and extended debates about mathematical ideas. The difficult part is that this will require a turnaround in the culture of teaching from old pedagogies to new powerful one that put learners at the centre of inquiry.

Even (1990) insisted then that the teaching of mathematics should hinges on teaching mathematics for understanding and meaningful learning. The teachers’ role is to assist learners to understand mathematics and learn it meaningfully. In order for the teachers to teach mathematics meaningfully they will need solid knowledge of the subject matter. Professional development and teacher education reforms should address teachers’ subject knowledge and how to improve that. Teacher preparation programmes must have strength in subject matter orientation of beginning teachers. Examinations that are set for pre-service teacher must have a focus on teachers’ proficiency in their subject matter. The subject matter knowledge for teaching was earlier defined as the number of subjects teachers took at college or the number of standard tests passed. These measures did not reflect teachers’ knowledge of the subject matter. Qualitative analysis of teachers’ knowledge has helped teacher educators to move away from a simplistic list of competencies to a more concrete understanding of teachers’ subject matter knowledge (Adler, 2004). There must be intensified support for teachers by the institutions of higher learning and the Department of Education and these should be through provision of effective part time and fulltime courses by the former and comprehensive and adequate workshops informed by both the instructional and content needs of the teachers, by the latter as the employer.
While teacher education has been criticised for a long time, there is evidence that teachers who have had more preparation for teaching are more successful with students than those who have had little or none (Ashton & Crocker, 1986; Darling-Hammond, 2000; Evertson et al., 1985; Greenburg, 1983; Haberman, 1984; Luneta, 2003; Olsen, 1985). Teacher education has been criticised as ineffective in preparing teachers for the task of teaching, unresponsive to the societal needs and the world of work and its demands, and hence remote from practice (Stuart, 2008). The criticism has not only come from outside the profession but from within it as well (Goodlad, 1990; Holmes Group, 1986). Despite grounded knowledge that there are desirable knowledge and skills for teaching, there is still a general conception that knowing a subject is enough to allow one to teach it well. This is one of the reasons that teaching is one of the few professions that allow unqualified people to practise in its schools and classrooms. Research in both developed and developing countries has shown that well-trained and certified mathematics teachers are generally better rated and more successful with students than teachers without this preparation (Ashton & Crocker, 1986; Darling-Hammond, 2000; Evertson et al, 1985; Greenburg, 1983; Huberman, 1984, Olsen, 1985). In all fields of learning, research has found that mathematics teachers who are grounded in knowledge of teaching and learning are more highly rated and more effective with students, especially at tasks requiring higher-order thinking and problem solving (Darling-Hammond, 1999).

What then need to be done in theory?

Even (1990) further assets that conceptual knowledge is knowledge rich in relationships and networks of concepts. New concepts learnt complete a table in ones or add a node of cognition making the understanding of mathematics more stable. Conceptual knowledge must be learnt more meaningfully. Procedural knowledge is the mathematical knowledge of the language of mathematics to complete tasks through algorithms and is the understanding of the procedures required to complete a mathematical task. It is the knowledge of mathematics that does not include conceptual understanding, but include the ability to make procedures (Kinyalioglu, et al., 2003). Procedural knowledge can be learnt without meaning. Research show that school mathematics emphasise procedural knowledge and little on conceptual knowledge and meaning.

Knowledge of the subject matter is regarded as an important factor in teacher effectiveness (Rowland et al., 2009; Mooney et al., 2005). However, it has also been pointed out that pedagogic knowledge which includes knowledge of teaching and learning, teaching methods and curriculum is more frequently found to influence teaching performance and ‘often exert even stronger effects than subject-matter knowledge’ (Darling-Hammond, 2000:167). It is hence envisaged that pedagogical skills interact with content knowledge to either enhance teacher performance or undermine it. Teachers need to be grounded in both pedagogic content knowledge and content knowledge. Byrne (1983:14) suggests that:

Insofar as teacher’s knowledge provides the basis for his or her effectiveness, the most relevant knowledge will be that which concerns the particular topic being taught and the relevant pedagogical strategies for teaching it to the particular types of pupils to whom it will be taught.

Pedagogical content knowledge is regarded as a stored set of prepositional theories applied in practice (Probyn, 2000). However, Schon (1983) challenged this notion and instead suggested that pedagogical content knowledge is constructed of a reflectively processed and increasingly refined repertoire of cases, used as references to frame new situations and
problems. Gess-Newsome and Lederman (1999:10) further argue that it is necessary to create a continuum of models of teacher knowledge. One end would have no pedagogical content knowledge but teacher knowledge explained by the intersection of three constructs: subject matter, pedagogy and context. At this end teachers’ interaction with learners is explained as ‘the act of integrating knowledge across these three domains’. The other end has pedagogical content knowledge performing as a synthesis of all knowledge needed in order to be an effective mathematics teacher. Gess-Newsome and Lederman (1999:10) assert that ‘in this case, pedagogical content knowledge is the transformation of subject matter, pedagogy and contextual knowledge into a unique form – the only form of knowledge that impacts on teaching practice’. The distinction between the two ends is that teaching at the former end is the integration of knowledge while at the latter end it is the transformation of knowledge.

During the integration of knowledge the mathematics teacher draws from the three knowledge bases of subject matter, pedagogy and context. Effective teaching is the appropriate way in which the mathematics teacher selects and integrates various strands from the three knowledge bases to create effective learning opportunities (Rowland et al., 2009; Van De Walle, 2004; Ma, 1999). Teaching is then the presentation of content to learners in some context using an appropriate form of instruction (Mooney, et al., 2005; Gess-Newsome & Lederman, 1999). According to these writers an expert teacher is one who has well organised individual knowledge bases that are easily accessed and called upon during the act of teaching. When observing an expert teacher the transition from one knowledge base to the other is almost effortless, giving the appearance of one single knowledge base for teaching. Effective teaching is both the integration and transformation of all knowledge bases into a focused and well articulated lesson. This happens spontaneously as an expert teacher is in the act of teaching and gives the appearance of a seamless shift from one knowledge base to the other. It is also important to note that the shifts do not linearly follow the pattern of subject matter, pedagogy and then context, but that an expert teacher can relate a particular subject to a specific context before thinking about the pedagogical approach required to teaching it.

Reliance on one extreme of the teaching knowledge continuum has brought about an emphasis by some mathematics teachers on the importance of content over pedagogy, which results in teaching that has little regard for content structure, classroom audience and contextual factors (Luneta, 2003). The other extreme results in teachers emphasising pedagogy over content as is the case in primary teachers’ training curricula where teachers are trained as generalists rather than specialists in specific subjects. Such training assumes that pedagogical knowledge of one subject would be enough for a teacher to teach the other subjects effectively. This argument points to the fact that teachers should be articulate and recognise foundational knowledge bases of subject matter, pedagogy and context and adequately relate them to pedagogical content knowledge.

Through continuous professional development teachers need access to both content knowledge and pedagogic content knowledge (Cooper & McIntyre, 1996; Furlong & Maynard, 1995; McIntyre & Hagger, 1996). Teachers’ workshops and seminars should provide opportunities to use both to interrogate the other and to develop a dialect between theory and practice while bearing in mind the fact that finding the interface between the two has proven rather problematic (Carr & Kemmis, 1986). The professional development programmes for teachers should address teachers’ skills in enhancing knowledge in problem-solving, critical thinking and argumentation in the learners as advocated for in the National Curriculum Statement (C 2005). Interviews with teachers (Luneta, 2008a) further revealed
that a majority of mathematics teachers still lack the knowledge base necessary to develop assessment tasks that instil in learners or enhance learners’ problem-solving and critical thinking skills. This point has been cemented by the fact that when tasks have been set by teachers in their classrooms learners have excelled and done well, but when the same learners are exposed to nationally developed tasks such as those in national examinations their performance has tended to go down drastically (TIMSS, 2003).

**The learning of mathematical concepts**

Cognitive scientists and learning theorists (Piaget, 1952; Vygotsky, 1978, Bruner, 1960 Gagne 1985; Skemp, 1971; Polya, 1957, Shulman, 1986) have identified general frameworks and models of knowledge. Hiebert and Carpenter (1992) introduced procedural and conceptual knowledge as being essential to mathematics. Schneider & Stern (2010:178) define conceptual knowledge as “one providing an abstract understanding of the principles and relations between pieces of knowledge in certain domains” and procedural knowledge as that which enables us to quickly and efficiently solve problem.

Researchers (Hill, et al, 2008; Rittle-Johnson and Alibali, 1999; Zakaria & Zaini, 2009; Hiebert, 1986; Star, 1999; Haapasalo & Kadijevich, 2000; McCormick, 1997; Fuller, 1997) have all acknowledged the importance of procedural and conceptual knowledge for mathematics teachers and the roles the two knowledges play in enabling learners to acquire the skills of problem-solving and critical thinking. Teachers who are grounded in the conceptual and procedural knowledge of the mathematics they teach ensure that the learners are exposed to mathematical knowledge and understanding through: investigation, exploration, discussions and sharing of ideas (Zakaria & Zaini, 2009:202). Rittle-Johnson and Alibali (1999: 175) define conceptual knowledge as ‘explicit or implicit understanding of the principles that govern a domain and of the interrelations between pieces of knowledge in the domain’. Faulkenberry (2003) regards conceptual knowledge as knowledge that is rich in relationships and relates to the principles that refine understanding of mathematics and also refers to the interconnections between ideas that explain and give meaning to mathematical procedures. This knowledge is very important to teachers of mathematics because it enables them to define and explain mathematical concepts in ways that enable learners to understand and articulate mathematics in their own but correct ways. This is the learners’ knowledge construction referred to earlier in the constructivist approach to teaching. Eisenhart, Borko, Brown, Jones and Agard, (1993) define procedural knowledge as mastery of computational skills and familiarity with procedures, rules and algorithms for solving problems. This knowledge enables teachers and learners to justify their solutions to problems but with little or no knowledge as to why a particular method, operation or formula is used to find the solution to the problem (McGehee, 1990). Conceptual knowledge is acquired through conceptual understanding (McCormick, 1997). The receiver of knowledge must first understand the concept. In trying to understand the concept the receiver of the concept name relates it to concept image that is evoked in the brain. According to Tall & Vinner (1981:152) the concept image is “the total cognitive structure that is associated with the concept, which includes all the mental pictures and associated properties and processes activated at a particular time when the concept image is evoked”. When the concept is well articulated to the learner by the teacher and the learner understands its meaning, the appropriate concept image is formed. This becomes the concept definition of the learner and might not be exactly
the same as the teacher’s. It is at this point that Tall and Venner’s theory of concept image formations interact with the constructivist theory of knowledge construction by the learner. Errors and misconceptions are aggravated and perpetuated if the learner attempts to incorporate new knowledge into inadequate or defective concept images. The correct mathematical concept that the teacher articulates to the learners is regarded as the concept definition which is the appropriate meaning of the concept as defined by the community of practitioners, in this context, the mathematicians and mathematics educators. Mathematical knowledge acquisition is the transformation of knowledge from the forms in which it exists (e.g., contexts, texts and mathematics teachers’ heads) into forms that the learner can understand and use. Mathematical errors and misconceptions occur when learners fail to incorporate or acquire procedural and conceptual knowledge associated with their concept images. Mathematical procedural knowledge is usually specific to particular tasks, while mathematical conceptual knowledge is often more generic. Figure 1 show that if the mathematics teacher effectively articulates the concept to the learners using the appropriate content knowledge and pedagogic content knowledge, the learners may understand the concept and form or relate it to the appropriate concept image and definition. The learners will use the constructed conceptual knowledge in the procedure for solving the problem. Conversely if the teacher has weak content knowledge and pedagogic content knowledge, the learners may not acquire the concept definitions in a manner that enables them to effectively articulate the conceptual knowledge independently and confidently. A weak knowledge base can lead to misconceptions and errors. Figure 1 also illustrate that if the teacher’s instructions are predominantly procedural they can lead to learners acquiring more procedural knowledge than conceptual though a learner, through independent inquiry, can reinforce the procedural knowledge and acquire conceptual knowledge.
A research at Stanford University (Brown 1969) on how children learn mathematics and the development of mathematical concepts in children found out that the formation of simple mathematical concepts and a reasonably good mastery of hypothetical reasoning in young children start at an early stage, and they are not naturally restricted to concrete operations. The study also found out that while the rate of acquiring overall mathematical learning is much lower for low-attainment group the retention of mathematical learning was the same among children of low, average and high intelligence when original learning tasks are graded to the learner’s achievement levels. One of the roles of the teacher in a mathematics class is to make learning as meaningful as possible at every stage of the child’s conceptual and analytical development (C2005). Careful planning of the sequence and pace of teaching is therefore essential, to ensure so far as possible that pupils learn their mathematics schematically and not by rote.

In order for teaching to be effective and learning to be meaningful, the teachers has to understand the knowledge and the skills that the learners already possesses (Rowland, et al., 2009, Mooney, et al., 2005), what Skemp (1963:46) calls schematic learning, that is ‘an organised structure of learning, which makes use of and builds more knowledge on to the
structure’. Every new thing should therefore contribute to the developing of competencies and form part of the images of the world of that learner (Burton, 1994). Learners therefore try to associate the mathematics they learn with their experiences. Whether they succeeded or not they are always trying to make sense of the mass of signals they are receiving. When they don’t succeeded in correlating or when they end up behaving in a way which indicate that they have not been successful it is not for lack of trying (Burton, 1994). It is therefore not that the learners have not worked hard enough but instead something has obstructed their understanding of the mathematics being taught.

Ercikan, McCreith and Lapointe (2005) cite a number of studies on research done on mathematics learning and factors that enhance or inhibit effective mathematics learning and these include: student attitude and background, curriculum and instruction, home environment, peer environment, teacher practices socioeconomic status (Beaton & Dwyer, 2002; Kellaghan & Madaus, 2002; Wilkins, Zembylas & Travers, 2002); Wilkins et al (2002) classified these factors into: a) personal and these are learners’ prior achievement, age and motivation or self concept); b) instructional variables and these are the amount or quality of instruction provided by the teacher; and c) environmental variables that relate to home, teacher, the classroom, peers and media exposure. Of all these variables the ones most cited as related to learners’ mathematical achievement consistently in numerous studies (Reynolds & Walberg, 1991; Tsai & Walberg, 1983; Young, Reynolds & Walberg, 1996; Walberg, 1984, 1992; Ercikan et al 2005; Campbell, 1995; Grey, 1996; Mullis and Stemler, 2002) were learners’ personal and home environment variables.

A number of models and learning theories have been developed for the learning of mathematical concepts.

Models and theories for the learning of mathematical concepts

Mathematics, due to its abstractness and structure, requires a systematic approach in sequencing the learning of mathematical concepts and a certain hierarchical order, though not fully established by research does exist. There is however no simple path in building the mathematical ideas (Freudenthal, 1991). The learning of mathematical concepts can be approached from a behaviourist or constructivist approach. Some new mathematical concepts can be introduced by the teacher while others can be constructed by a group of learners guided by the teacher. Freudenthal (1991) argues that since there is no simple predetermined path in building mathematical ideas learners should discover their own paths: resort to reinvent mathematising rather than mathematics; abstracting rather than abstractions; schematising rather than schemes; formulising rather than formulas; algorithmising rather than algorithms; verbalising rather than language.

It was Bruner (1976) who suggested the spiral curriculum. This is an approach whereby each mathematical idea is introduced at an intuitive manner and is represented by using familiar concrete notational forms. Bruner suggested three theorems for the acquisition of mathematical concepts: the notational, the construction and the contrast and variation theorems. That is, starting from a low level of acquiring a concept (notational), to an intermediate level where the learner constructs his or her own representation and finally by contrasting and varying the concept acquired at an abstract level. An example of this could be the idea of the function. A function can be represented initially as $|x| = 2\, + \, 3$, then as $y =$
$2x + 3$, then as $y = f(x)$ and finally as $f \rightarrow x:2x+3$.

For Holmes (1985) and Klausmeier (1979) concepts are related to form higher order ideas called generalisations. Concepts and generalisations exist in our minds and are constructed as we mentally process experiences. Lesh and Landau (1983) and Dienes (1971) use the idea that mathematics is the study of structure and the content of mathematics consists of structures. To do mathematics ‘is to create and manipulate structures’. These structures comprise of pictures, manipulative materials, spoken language and written symbols. The structures and processes used in creating and manipulating are the ‘conceptual models that mathematicians and mathematics learners use to solve problems.’ Again here the authors suggest that the teaching of concepts should be structured from the concrete to the abstract.

Learning especially mathematics is a complex undertaking. However, considerable emphasis in learning mathematics in recent years has been placed on the desirability of understanding, rather than on being able to memorise routines and demonstrate particular basic skills (Orton & Frobisher, 1996; C2005). In order also to deal with, understand and appreciate the problems that the teachers face in teaching mathematics, there is need to know how children learn mathematics. As Nunes (1996:2) put it ‘If we want to teach mathematics to children in a way that makes all children numerate in today’s’ world, we have to know much more about how children learn mathematics and what mathematics learning can do for their thinking.’

The problems of teaching and learning mathematics seem to have been with the education fraternity for a long time. Dr. Hassler Whitney, former President of the International Commission on Mathematics Instruction, summed up this situation by saying:

‘For several decades we have been seeing increasing failure in school mathematics education, in spite of intensive efforts in many directions to improve matters. It should be clear that we are missing something fundamental about the schooling process but we do not even seem to be sincerely interested in this, we push for ‘excellence’ without regard for causes of failure or side effects of interventions, we try to cure symptoms in place of finding the underlying disease and we focus on passing of tests instead of meaningful goals.’ Skemp (1989:23).

Much of the satisfaction inherent in learning mathematics is that of understanding, making connections, relating the symbols of mathematics to real situations, seeing how things fit together and articulating the patterns and relationships which are fundamental to our number system and number operations (Haylock, 1991). It is popularly viewed (Luneta, 2008; Costello, 1991) that learning mathematics is essentially about developing skills and that such procedures are the foundation of mathematical competence. The skills are all in different components. Learning mathematics also involves some memory capacity, the ability to acquire and retain knowledge. The classification of the kinds of learning involved in mathematics is well accounted by Floyd in Costello (1991). These are learning schemes that distinguish the learning of facts, skills, conceptual structures, problem solving strategies and attitudes.

**Implications for teaching mathematics**

Valuing students understanding of concepts implies that one would be able to assess the students understanding of the concepts and use knowledge of students’ current understanding of the concept to make instructional decisions. Pre-service teachers will appreciate the need to
understand students’ comprehension of mathematics concepts if they are exposed to the readings of students’ common misconceptions and limited conceptions followed by interviews or tutoring experiences (Hansen, 2006). Video taped sessions of classroom instructions should be used for reflections into the instructional approaches. It is easy for pre-service teacher to detect students’ misconceptions during the reflective sessions. Teacher should be able to distinguish between what the students understand and what they can do. The key to teachers’ knowledge of how students understand concepts lays in the relationship between the teachers’ relational or conceptual knowledge and procedural knowledge. Teachers’ goal is to ensure learners’ procedural and conceptual understanding and that the assessment tasks enable students to delineate understanding as well as exhibition of conceptual knowledge. Teachers should know that conceptual knowledge would not imply procedural knowledge and vice versa. Pre-service teachers must identify the various illustrations of students’ different forms of knowledge and these include writing about, speaking about and reflecting on mathematical concepts.

Conclusion

Both mathematics teaching and mathematics teacher preparation need to improve if the results of mathematics are to reach desirable standards. Recommendations from several researches on mathematics teacher education outline that teachers need several kinds of mathematics knowledge for them to teach effectively. Teachers need knowledge of the mathematics domain, they need knowledge about the curriculum and how they can effectively use it for the benefit of the learners. Mathematics teachers should be exposed to both pedagogical content knowledge as well as the subject knowledge of mathematics. Mathematics teachers need knowledge about assessment of students’ knowledge. The teachers should be able to explain how learners acquire procedural as well as conceptual knowledge and the various instructional strategies require to enhance the acquisition of these knowledge. It is critical that teachers training institutions develop mathematics teacher education programmes that address prospective mathematics teachers’ teaching skills that reflect among others problem-solving, critical thinking and argumentation. Teacher education programmes should have a clear design and focused goals that adhere to the National Curriculum Statement. The topics to be covered should contextualise mathematics with day-to-day living examples and situations – mathematics as a living subject. Teachers must be immersed in mathematics – they must explore mathematics, regularly, reading, critiquing, developing mathematics rules and theorems. Topic at elementary mathematics must be clearly aligned to those at high school. While doing all the above will not instantly improve mathematics results in South Africa it will most certainly put teachers in the right footing for instructional improvement.

References


The US Department of Education launched its Mathematics and Science Initiative with the Secretary's Mathematics Summit held on February 6, 2003, in Washington, D.C. The following paper was presented by Deborah Loewenberg Ball of the


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Mathematical practices: generality in a Java programming context

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This research presents a case study at a South African University, involving students who had studied mathematics in a pre-undergraduate Foundation Programme (FP) and who were currently in their first year of study in Information Technology (IT). The study investigated students’ uses of mathematical practices to solve a programming task. Task-based interviews were used to answer the question: “In what ways are the mathematical practices taught in the Foundation Programme used in undergraduate study in Information Technology?” Cognitive and situative learning theories were compared in order to understand the nature of learning transfer. A situative view of learning transfer was adopted to explain the study data. The task-based interviews showed that all students used mathematical practices to solve the task to a greater or lesser extent. The use of these mathematical practices was best understood as being influenced by all past cognitive, social and cultural experiences, and was therefore not a case of “transfer” in the traditional sense of the word. Instead, the use of mathematical practices could be described as a case of “generality” from a situative perspective.

Introduction

I have on numerous occasions discussed with IT lecturers why they think that mathematics is necessary for learning IT. Some said it is not necessary. The common response from those who have mathematical backgrounds was that aspects of IT are strongly mathematical and students need to think strategically and in abstraction to be successful in these areas. In mathematics, strategic thinking is related to making “articulated and reasoned claims” (Ball, 2003) and being able to work abstractly requires the generalisation of patterns and specific instances into abstract concepts and the formulation of “rules” (Ball, 2003). Articulated and reasoned claims, abstraction and generalisation have been identified by the RAND Mathematics Panel (Ball, 2003) as mathematical practices.

At Monash South Africa (MSA) incoming students who do not meet the requirements to enter information technology (IT) studies are required to spend a year in the pre-undergraduate Foundation Programme (FP). One of the compulsory courses taken by FP students intending to study IT is mathematics, which I taught. Having recently learned about the importance of teaching students to use mathematical practices (Ball, 2003) in order to promote mathematical proficiency (Kilpatrick, Swafford, & Findell, 2001), I explicitly taught students about and encouraged them to use these practices in my teaching programme. My hope was that their use of mathematical practices would be transferred to learning in their subsequent IT studies.
According to the Monash South Africa requirements, three of the first year compulsory subjects, ‘Computer Programming I’, ‘Computer Systems’ and ‘Networks and Data Communications’ require undergraduate students to have a mathematics background. Mathematical content only in the form of basic algebraic concepts was required for these subjects, and included set notation, place value, simple and compound interest, and symbolic representation. Later courses, such as Computer models for business decisions, Data structures and algorithms, and Applications of data mining, require more complicated mathematics. Because many IT lecturers argued that abstraction and problem-solving are also very important when doing many aspects of IT, I wondered whether the mathematical practices, supposedly gained in the FP mathematics course for IT, should be at least as important for the students to master as conceptually understanding the content of such a course.

I was interested to know whether the FP students I had taught were able to use the mathematical practices in their undergraduate studies in IT. My research study was guided by the question: In what ways are the mathematical practices taught in the Foundation Programme used in undergraduate study in IT? The focus of this paper is on the ways in which a group of first year IT students used mathematical practices to do a Java programming task. Programming is a particularly interesting topic on which to do such a study because it can incorporate mathematical content as well as more general mathematical practices such as strategising and formulating rules through abstraction.

**Literature review and theoretical framework**

**Mathematical Practices**

Two important theoretical concepts frame this article: mathematical proficiency and mathematical practices. Mathematical proficiency is the term used by Kilpatrick et al (2001) to describe “aspects of expertise, competence, knowledge, and facility in mathematics” and “[captures] what [the authors] believe is necessary for anyone to learn mathematics successfully” (p.116). Mathematical practices (Ball, 2003) are what proficient users of mathematics do when they are working with mathematics. Mathematical practices include solving problems, justifying mathematical claims, reasoning, using symbolic notation efficiently, communicating mathematical ideas, and making mathematical generalizations; and have been broadly grouped into the “core” practices of representation, justification and generalisation (Ball, 2003). Such practices need to be “deliberately cultivated and developed” (Ball, 2003 p. 35) at all levels of learning so that students of any age become mathematically proficient and are able to use these practices when necessary to solve problems in other contexts.

Representation takes on many different forms when used mathematically. It may be used to describe a physical relationship, where algebraic variables and mathematical symbols are used to model situations. Such representations would, for example, be used, for example, in modelling the flow of water through a pipe, or representing the forces between particles. Alternatively, mathematical information may be represented as data in a table or in the form of a bar graph. Lastly, mathematical symbolic language is used to precisely and elegantly to describe mathematical expressions. For example, in words, one may say, “the average speed of a vehicle depends on the distance between two given points with respect to the time taken to travel between the points”. In mathematical symbols, one may write

\[
\text{speed} = \frac{s(t+h) - s(t)}{h}
\]

, to mean the same thing, having defined s, t and h.
Justification is referred to as “articulated and reasoned claims, [and] rationally negotiated disagreement” (Ball, 2003 p.32). Justification is integral to making claims, because it is the only way to convince yourself or somebody else that what is being claimed is valid. Justification of claims, methods and solutions “certifies and establishes knowledge” (Ball, 2003 p.37) and is the basis of mathematical reasoning. Different people can practice justification at different levels, depending on their levels of conceptual understanding. Therefore, the degree and complexity of argument often gives a good indication of a student’s mathematical proficiency.

Generalisation is related to working with patterns, structures or relationships – ubiquitous in mathematics – where a proficient mathematics user will try to describe these using some kind of ‘rule’ or formula written in the form of data or mathematical symbols (Ball, 2003). This shows the interrelationship of mathematical practices – generalising patterns into a rule will require competent use of representation of some form; as well as justification of the defining rule and representation selected. For example, for the series $2 + 4 + 8 + 16 + \ldots$, generalisation entails the realisation that the series follows a pattern, that each added value is double the previous value, that the next number would be 32, and that the final representation of the pattern using a general rule is $\sum_{i=1}^{n}2^i$; demonstrating the need for representation.

In this study the practices identified by the RAND Mathematics Study Panel (Ball, 2003) were used to describe what students were doing when they solved a particular IT problem. Even though the RAND Mathematics Study Panel’s (Ball, 2003) mathematical practices provide a description of how proficient mathematicians do mathematics, some aspects of these practices may be more observable than others when students use mathematics to solve problems; especially problems in non-mathematical domains. When the students solved IT problems, the practices identified by the panel were not always very clear, and so I devised some of my own terms for what I saw students actually doing when they did the task. These terms are related to the three core practices of representation, justification and generalisation in Table 1.

To describe aspects of the overarching practice of representation I used the terms ‘strategising’, ‘using representation’ and ‘using procedures flexibly’ (see Table 1.). Strategising is an aspect of problem-solving which requires conceptual understanding, and is heavily reliant on visual or mental representation (Kilpatrick et al., 2001) for problem formulation and subsequent solving. Symbolic representation and formulae are forms of representation. Mathematical definitions can be perceived as representations of mathematical truths. Mathematical symbols, formulae and definitions were grouped together as ‘using representation’ in my data analysis; and the ways in which representation was used were specified in the data analysis and discussion. Because the use of mathematical procedures usually requires some form of representation I added the practice of ‘using procedures flexibly’ under the core practice of representation. To further describe justification, I used the terms ‘understanding/explaining concepts’; ‘questioning’; ‘justifying’; and ‘disagreeing’. Questioning others’ or one’s own claims and disagreeing with others’ claims requires justification of the thinking accompanying those practices. In order to justify one’s claims, conceptual understanding together with explaining how certain concepts apply to those claims is necessary. Although “generalising ideas and recognising patterns” are two distinct aspects of rule formulation in mathematics, I described them in the single category of ‘generalising’ because they are not necessarily distinctly different when used in IT.
Table 1. Sub-categorization of the three practices of representation, justification and generalisation, as emerging from the data (Ball, 2003).

<table>
<thead>
<tr>
<th>Representation</th>
<th>Justification</th>
<th>Generalisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practices observed in the IT tasks taken from Table 2.1.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strategising</td>
<td>Understanding/explaining concepts</td>
<td></td>
</tr>
<tr>
<td>Using representation</td>
<td>Questioning</td>
<td></td>
</tr>
<tr>
<td>Using procedures flexibly</td>
<td>Justifying</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Disagreeing</td>
<td></td>
</tr>
</tbody>
</table>

Knowledge transfer

The concept of knowledge transfer from one situation to another has been subject to extensive debate. Transfer issues became increasingly contested (Carraher & Schliemann, 2002; Lobato, 2006) from the early to mid 1900’s, when cognitive theories prevailed. Much of the argument revolved around exactly what knowledge was being ‘transferred’. The debate livened considerably during the 1980’s, where situated theorists argued vehemently that since all learning is situated in the context in which it was first learned, knowledge transfer, in its original definition of the term, cannot occur (Brown, Collins, & Duguid, 1989; Lave, 1988). However, a broad range of aspects of daily life assume the success of transfer of schooled mathematical knowledge (Britton, New, Roberts, & Sharma, 2007; Britton, New, Sharma, & Yardley, 2005; Hatano & Greeno, 1999).

Recently it has been argued that people do use basic mathematical concepts in new situations (Carraher & Schliemann, 2002; Hatano & Greeno, 1999; Salomon & Perkins, 1989). However, much debate exists concerning whether or not transfer of complex conceptual understanding to new complex contexts can occur. Lave (1988) questions the validity of past transfer experiments in this regard, while researchers such as Salomon and Perkins (1989) define different ‘kinds’ of transfer that can take place.

What has become clear is that the phenomenon called ‘transfer’ is understood differently by situated theorists and cognitive theorists, and positions taken on transfer depend largely upon the theoretical lens through which one gazes. Two important aspects of this are firstly, disagreement about what is transferred; and secondly, about how transfer should be measured. A cognitive view focuses on the “what” of transfer. From a cognitive perspective, the question of transfer takes into account the amount of overlap between old and new contexts (Perkins & Salomon, 1989; Salomon & Perkins, 1989; Simons, 1999) or familiarity with the knowledge to be transferred (Alexander & Murphy, 1999). Where knowledge is automated or practised in a small range of situations and used in similar situations, “near transfer” (Alexander & Murphy, 1999; Simons, 1999) or “low road transfer” (Perkins & Salomon, 1989; Salomon & Perkins, 1989) is said to have occurred. Conversely, little or no overlap between two contexts can promote the occurrence of “far transfer” (Alexander & Murphy, 1999; Simons, 1999), or “high road transfer” (Perkins & Salomon, 1989), which requires “deliberate mindful abstraction of a principle” (ibid. p.22).

Looking at possible mechanisms of transfer brings a new focus onto the concept of transfer. A situative perspective examines how knowledge is used in novel situations, rather than what is transferred to novel situations. Situative transfer studies take into consideration the complex social learning and experiences of people and how these experiences influence decisions they might make or how they might solve novel problems. Situative theorists suggest that the word
“transfer” is replaced with “generality” or “productivity” (Greeno, 1997); or “generative learning” or “intercontextuality” (Engle, 2006), which is “learning that results in the flexible use of what has been learned in a wide range of relevant future situations” (ibid. p. 452). These new terms imply transfer should be understood differently – as learning that has undergone alteration socially, experientially and cognitively, and used to generated new understanding.

Typical cognitive transfer research pre-specifies the mathematical content expected to be transferred, and then investigates what content the subjects transferred to novel problems. The environments in which the transfer studies take place are contrived by the researchers, and are also separated from the ordinary experiences of their subjects (Lobato, 2006). A situative theory of learning does not lend itself to the study of pre-specified transfer of mathematical practices and should be investigated in the natural environments in which the new problem contexts are situated. In my study I decided that I would focus on a situative view of transfer; or rather generality, or generative learning. A situative perspective provides a broader explanation of how students can solve novel tasks in a new domain and it allows for an explanation of unusual or unexpected ways in which these problems are solved. Although one might have some idea of what mathematical practices might be needed to solve novel IT problems, it would be inaccurate to pre-specify that certain practices and content must be used in order to solve the problems (Lobato, 2006).

Methodology

A qualitative case study was conducted, providing a ‘thick’ description of the participants’ experiences (Babbie & Mouton, 2001; Cohen, Manion, & Morrison, 2000; Gomm, 2004), and allowing the reader to experience the world from the participants’ points of view (Gomm, 2004). In addition, a qualitative study allows a situative perspective on generative learning to be explored. The participants in the study were first-year undergraduate Information Technology students, sub-majoring in Computing or Business Systems at Monash South Africa (MSA), and who had also been in the pre-undergraduate Foundation Programme (FP) the previous year.

Task-based interviews (Goldin, 1997) were used to qualitatively explore the use of mathematical practices in the undergraduate IT course, Java I. Task-based interviews were chosen as a research instrument, because observing and interviewing students performing computing tasks, while interviewing them at the same time, was helpful for understanding and pinpointing whether and how mathematical practices were useful in these computing tasks. Doing tasks allowed students to actually demonstrate mathematical practices, as opposed to merely talking about them.

All students in the study were studying the same six first year undergraduate core subjects in IT, with their other two subjects being non-mathematics ‘electives’. Purposive sampling was used to select the subjects. This is because I needed to identify “respondents, who could express their thoughts, feelings [and] opinions – that is offer a perspective – on the topic being studied” (Merriam, 1997 p. 85). Students were selected depending on how much I thought they might participate in the interviews – those who I thought would readily volunteer their insights.

Four tasks were originally used for the interviews. Two were mathematical (a prime numbers task and using Boolean logic), and two were non-mathematical (setting up a simple banking system and analysing network security). In this report I focus on one of them: the “prime numbers task”, requiring Java programming, because it required use of mathematical conceptual understanding as well as the more general practices of abstraction and problem-
solving in an IT context. The task was set by the Java subject lecturer, who also had a mathematics background, in response to my request to provide a task from the Java I course that would elicit use of mathematical practices.

The prime numbers task read as follows: “Write a programme to print all the prime numbers between 1 and 100”. Conceptually, the student had to know and understand the definition of a prime number. Procedurally s/he needed to “test” any number for its ‘primeness’. S/he typically would need to think of a number and then mentally ask, “Can this number be divided only by itself and one?” and then either accept or reject the number as prime. The task dealt with generalisation at different levels. Defining a prime number for recognition by a computer programme symbolically required generalisation of the definition, in terms of the correct syntax of the computer language. Strategic thinking entailed the need for the students to consider that a prime number is divisible only by itself and one. In addition, they needed, as well as to consider what makes a number not prime. This was necessary because the programme required a definition using Java syntax that would tell it how to recognise and accept prime numbers, and reject non-prime numbers.

João and Alain, two third year IT students, and who had previously been my mathematics students in the Foundation Programme, helped me in three ways. First, they provided worked solutions to the task. Second, they spent time with me discussing the mathematical practices embedded in the prime numbers task, while I probed and argued about the intricacies of the task and how mathematical practices might be used in its solution. This activity was not done in order to pre-determine the practices students should use to solve the task, but to help me to understand how mathematical practices could be used. I intended to analyse how, if at all, mathematical practices were used by the students as they did the task. Third, they sat in on the interviews to help me question the students while they did the task. This was necessary because of the insufficiency of my knowledge of computing and I did not want to miss opportunities for discussion through my lack of knowledge. The respondents were comfortable doing the task in their presence because they had been tutor-mentors to the same students while they were in the FP.

Eight students worked in pairs in the task-based interviews. The four interviews were video-recorded, so that facial expressions, silences and gestures, as well as discussion, could be recorded. The students were requested to ‘think aloud’, in order to aid me in identifying the kind of mathematical thinking that they were using. All interviews were conducted in English, although English was an additional language for all but one student. On occasion, students noticeably struggled to express themselves, but were given time to explain what they meant.

I acknowledge that the interview environment was not the natural learning environment (the lectures and tutorials) of the students. It was set up by the researcher (myself) in order to observe something pre-defined by the researcher. Given the scope of this research project, it was not possible to extensively observe students’ practices and interactions their natural learning environments. Therefore, I had to make do with the unnatural environment and data collection, and have taken it into account in my interpretations of what I observed.

Data analysis and discussion

I began coding the data with the three overarching practices of justification representation and generalisation, but these turned out to not be specific enough as a framework for analysing exactly what students were doing as they completed the IT tasks. I therefore generated codes from the data, using the method of constant comparison (Lincoln & Guba, 1985). This
method resulted in the terms discussed in Table 1. These descriptive terms were then related back to the three overarching practices of representation, justification and generalisation. The interviews were analysed in terms of the number of times the students used the specific practices to complete the task. Average frequencies were calculated to indicate the extent to which these practices were used. After calculating the average frequencies I described the incidences in relation to these categories.

All students used all of the mathematical practices to a greater or lesser degree. Concerning the prime numbers task, the programming itself required conceptual understanding of programming and syntax, which were not mathematical in content. The discussion that ensued between students swung between the mathematics of the task and the syntax of the programme. Therefore, when reporting the practices I observed during the completion of the prime numbers task (see Table 2), I differentiated between the total number of incidences of the practice concerned (normal font) and those that were specifically mathematical (bold font in brackets).

Table 2. The mathematical practices used to solve the prime numbers task

<table>
<thead>
<tr>
<th>Prime numbers task (specifically mathematical practices in bold – others are programming related)</th>
<th>Using procedures flexibly</th>
<th>Understanding/explaning</th>
<th>Strategising</th>
<th>Using representation</th>
<th>Generalising</th>
<th>Questioning</th>
<th>Disagreeing</th>
<th>Justifying</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rudo and Tungamirai</td>
<td>1(1)</td>
<td>9(6)</td>
<td>24(17)</td>
<td>4(3)</td>
<td>3(2)</td>
<td>1(0)</td>
<td>9(4)</td>
<td>16(10)</td>
</tr>
<tr>
<td>Jennifer and Carol</td>
<td>4(0)</td>
<td>7(5)</td>
<td>22(11)</td>
<td>7(7)</td>
<td>7(7)</td>
<td>2(1)</td>
<td>6(4)</td>
<td>9(6)</td>
</tr>
<tr>
<td>Ditso and Keabetswe</td>
<td>1(1)</td>
<td>9(5)</td>
<td>16(12)</td>
<td>5(4)</td>
<td>7(5)</td>
<td>4(3)</td>
<td>2(1)</td>
<td>12(6)</td>
</tr>
<tr>
<td>Kaone and Yvonne</td>
<td>1(1)</td>
<td>4(4)</td>
<td>12(7)</td>
<td>8(8)</td>
<td>5(5)</td>
<td>2(2)</td>
<td>5(4)</td>
<td>7(6)</td>
</tr>
<tr>
<td>Mean frequency (to the nearest whole number)</td>
<td>2(1)</td>
<td>7(5)</td>
<td>19(12)</td>
<td>6(6)</td>
<td>6(5)</td>
<td>2(2)</td>
<td>6(3)</td>
<td>11(7)</td>
</tr>
</tbody>
</table>

The following section provides more detail about the practices the students used when they were doing the prime numbers task. Thereafter, I discuss all the observed practices with respect to the overarching categories of representation, justification and generalisation, and draw conclusions about whether or not I can argue that mathematical practices were used in IT, according to a situative perspective.

“Using Procedures Flexibly”

All of the students reminded themselves of what constitutes the set of prime numbers and then planned how to test whether a number is prime or not. Included in their discussions was conversation around even and odd numbers, and how prime numbers relate to these. Yvonne and Kaone specified that a prime number is not divisible by anything except one, but later realised their mistake through discussion and corrected themselves, saying “divisible by itself and one”. The others defined a prime number as being “a number divisible by itself and one”.

---

18 All names are pseudonyms
19 The value in bold font is included in the value on its immediate left
All the students were surprised by the fact that writing the programme to list or print the primes between 1 and 100 was actually very complicated at a Java I level. They were not aware, as they quickly defined prime numbers, that knowing what a prime number is, was not the same as writing a computer programme applying their understanding of the definition.

**“Understanding/explaining concepts”**

Table 2 shows that understanding/explaining concepts featured often while the students worked with the prime numbers task. Although it was not the most commonly-used practice, it was used frequently enough to show that they used conceptual understanding of prime numbers to help them to plan their Java programme. It was interesting to observe how the students used this understanding in the IT domain. One way to write the programme would be to specify in the programme what makes a number not prime. None of the students except for Rudo realised, until I pointed it out to them, that every number between 1 and 100 is divisible by itself and one. Rudo had specified this aspect of prime numbers early on in her discussion with Tungamirai but did not carry her understanding through to the new context of writing the programme. None of the others attempted to specify that the number the programme selects must also not be divisible by anything else until after I had questioned them on this. After realising that they needed to use a deeper understanding of prime numbers, they commented that the task was more difficult than they had first thought because their mathematical understanding needed to be linked with Java programming syntax. Considering prime numbers in this way is an example of how prior understanding can be used in different ways in order to be useable in new contexts (e.g. Carraher & Schliemann, 2002; Lobato, 2006; Perkins & Salomon, 1989). When mathematics is used in another domain, the practice of understanding mathematical concepts might be altered, so that they may be generatively used to solve the new problem. This is consistent with what generative learning theorists argue about how prior knowledge may be used in novel problems.

**“Strategising and using representations”**

An average of 25 incidences in the prime numbers task showed that strategising was used frequently. The students needed to be able to understand what the problem was, so that they could decide on the best strategy to use to solve it. Ditso and Keabetswe clearly showed their competence in strategising when doing the prime numbers task. Before they had even considered the contents of their programme (step 4 in Figure 1. below) they had written a scheme of what the task entailed (steps 1-3) – a form of representation that they would use to solve the problem. The representation was a pathway to problem formulation (Kilpatrick et al., 2001). Writing down their strategy demonstrated how interlinked and interdependent the mathematical practices are. Step 4 in Figure 1. shows Ditso’s and Keabetswe’s use of representation of how they intended their programme to be written. A “class diagram” is often used as part of planning, as it shows generally what should be considered in the different aspects of the programme. These two students were going to draw a class diagram that contained the class name (prime number), its attributes and variables (for example, the fact that a prime number must be an integer – which will be in the form of symbolic representation of the variable), and the behaviour(s) of the defined variable (for example, stating that a prime number is divisible by itself and one).
The others who did this task also showed what they planned to do, but their plans were less clear and logically structured than that shown in Figure 1. Sometimes the planning was mental and not written down. Jennifer verbalised her planning throughout the initial stages of the discussion, frequently starting with an idea and rejecting it without a reason for rejection, almost before the idea had finished being verbalised.

Tungamirai was the only student to be taking Java II at the time of the interviews. He elected not to use any of the Java II techniques he knew because Rudo had not done Java II and might not understand his suggestions. He often acted as a “sounding board” for Rudo’s ideas – questioning her and commenting on her ideas, rather than offering any of his own. However, after realising that all numbers are divisible by themselves and one, he became more active in the planning process. At this stage he suggested that not only must they reject all even numbers except for two, but also they must reject any numbers that are divisible by 2, 3, 5 and 7; and start their programme loop at \( \text{number} \geq 8 \). He did not go higher than “divisible by 7”, and did not explain why he stopped at that value. He did not explain any of this reasoning aloud and moved through this series of ideas extremely quickly and mentally. When he realised that the task was a lot more complicated than merely coming up with a quick strategy to list the required prime numbers, he started to verbalise again, and considered Rudo more in his deliberations.

“Generalising”

The prime numbers task required the students to be able to formulate their testing of numbers for their ‘primeness’ into some sort of rule, or definition, before they could write the rule into a computer programme. This is where most of the students struggled. Generalising (rule formulation from recognising and working with patterns, and general use of pre-formed mathematical rules), was difficult to identify much of the time. Table 2 shows the frequency
with which generalising was used in the prime numbers task. I suggest that I did not see this practice often because many students did not reach a stage where they could start writing the programme they had been designing. Writing the actual programme would be more likely to reveal occurrences of generalising.

The clearest demonstration of the practice of generalising was by Yvonne and Kaone. They defined the variable for their loop as “number”. They subsequently generalised the concept of a prime number (in their definition, a number divisible by itself and one) into a “rule”, represented as: \[ \frac{\text{number}}{\text{number}} = 1 \text{ and } \frac{\text{number}}{\text{number}} = \text{number} \]. It is clear in this case how representation is integral to the formulation of a rule to describe a prime number.

“Questioning, disagreeing, justifying”

These three practices are grouped because questioning or disagreeing with another’s suggestion would likely be associated with a degree of justification of why there was disagreement or why a suggestion was valid. It was therefore difficult to separate occurrences of these practices. Many incidences of justification were observed when the students did the prime numbers task. Jennifer and Carol, and Ditso and Keabetswe all made suggestions and justified their thinking, but they generally appeared to be in agreement with each other. Table 2 shows very little disagreeing taking place between Ditso and Keabetswe. Typically they would discuss one person’s ideas, using justification rather than trying to justify a clear counter argument. Jennifer and Carol questioned each other, but it was more for the purpose of clarifying something than deliberately pressing the other for justification. Justification of an idea, when it occurred, acted to strengthen a suggestion rather than justify a disagreement or counter suggestion.

Rudo and Tungamirai argued with each other, and it was usually Tungamirai who questioned Rudo’s ideas and encouraged her to justify them by producing counter arguments. Though Rudo did not use verbal justification very much, she appeared to be thinking clearly through the task problems. It was difficult to determine the extent to which she used mathematical argumentation in solving IT problems – Perhaps much of her problem-solving and justification was internal – it was difficult to ascertain.

The mathematical practices of representation, justification and generalisation

The eight practices that I observed the students using to help them solve the prime numbers task were incorporated into the overarching practices of representation, justification and generalisation as a final indication of mathematical practices that were used to solve the prime numbers Java programming problem. The total usages of practices in the task are shown in Table 3.

Use of representation was expected because the students were required to understand and use symbolic representation as key aspects of doing the prime numbers task. Table 3 shows clearly how frequently justification, which takes place when people use aspects of mathematical reasoning, was used by all students who did the task. Justification was used significantly more than any other practice, which not only indicates its importance in IT, but also shows that the students were able to use this practice to do the task. Generalisation, as stated earlier, was not observed to a great extent – possibly because the students did not get as far as writing the actual programme, where generalising might have been used more.
Table 3. Incidence of representation, justification and generalisation observed in the prime numbers task.

<table>
<thead>
<tr>
<th>Names of students</th>
<th>Representation</th>
<th>Justification</th>
<th>Generalisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rudo and Tunga</td>
<td>5</td>
<td>59</td>
<td>3</td>
</tr>
<tr>
<td>Carol and Jennifer</td>
<td>11</td>
<td>46</td>
<td>7</td>
</tr>
<tr>
<td>Ditso and Keabetswe</td>
<td>6</td>
<td>41</td>
<td>7</td>
</tr>
<tr>
<td>Kaone and Yvonne</td>
<td>9</td>
<td>30</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>31</strong></td>
<td><strong>176</strong></td>
<td><strong>22</strong></td>
</tr>
</tbody>
</table>

To summarise, a number of ‘sub-practices’ was useful for gaining some insight into how the students used mathematics to solve IT tasks. The ‘sub-practices’ have in turn been described in terms of the overarching mathematical practices of representation, justification and generalisation (Ball, 2003). Insight into how students might perceive the importance of mathematical practices to solve IT problems was given by Tungamirai in the following conversation after completion of the task:

’cos I was actually thinking to myself as we were going through this, ‘I’m not using maths in any way here’. But I hadn’t actually realised that I was actually using all the things I had learned. But it’s not the same like in the practical like we did in maths. It’s just that way of thinking like we used in maths, like to problem solve, to generalise, and all the supporting stuff. So in the end, like, you might not see it physically as in doing the maths, but you are given that background where you are able to have systematic thinking and systematic approach to solving a problem … solving things, y’know? And that is actually what we learned. And I think if you don’t have maths you won’t be able to do IT – or you don’t have maths thinking. I don’t think the content is really relevant – it’s just the thinking and the approach you take.

The “supporting stuff”, as Tungamirai described it, is actually the “real stuff” of mathematics, the practices of understanding/explaining concepts, using representations, questioning, justifying, disagreeing, strategising and generalising, for non-mathematics IT tasks. From a situative perspective, Tungamirai’s comment explains how mathematical practices can be relevant and usable in IT. Following from these findings a question now needs to be asked: In what ways do these findings provide information about whether or not mathematical practices were generatively used in the IT domain?

Conclusions and implications

A situative perspective on learning describes learning through understanding how all social and cultural aspects of a person’s life are parts of the learning experience. The notion of transfer of specific and separate mathematical practices does not make sense in such a perspective. The present study illustrates the argument that mathematical practices are apparently not transferred directly from the mathematics to the IT context. If students were to draw what they needed to solve IT tasks from all of their past experiences, it means that their mathematics class was only one of those experiences and their mathematical knowledge would have been used together with other aspects to solve the IT problems. The practices were being used by people who had continued to learn academically and socially since the practices were first introduced. The new experiences brought into the task situations will have changed the ways in which the students interpreted and solved the new tasks. I suggest that this scenario is a description of generative learning, where human agency, linked with social
context, directed the choice of when, where and how existing knowledge could be used (Engle, 2006) to solve tasks in a new domain.

In order to explain to the students what my study was about, I had to tell them that they needed to explain what sorts of mathematical knowledge, in addition to content, they might be using to solve the IT tasks. This request would have acted as “cuing” (Alexander & Murphy, 1999), or a “focusing phenomenon” (Lobato, 2006), or “framing” of content and purpose (Engle, 2006); and would most likely have stimulated the linking of mathematics to the IT context. Once students started working on the task together, their understandings, experiences, social backgrounds, etc, will have been distributed over the pair (Brown et al., 1989; Rogers & Ellis, 1994; Vygotsky, 1978), so that completion of the task (or not) was performed by the pair and not the individuals. The shared knowledge present between two people meant that one person’s comments and ideas could be taken up and built on by the other person (Rogers & Ellis, 1994). Shared knowledge goes even further than this. Unverbalised thought processes stimulated by the question and related comments would have been simultaneous with verbalised suggestion, argument and justification (ibid.). This would have been aided by their discussions while working with the task – bouncing ideas off each other, accepting or rejecting these ideas, and finally coming to consensus about the final product. From this perspective identifying how mathematics was generatively used to solve the IT tasks was complex. I was able to examine whether or not the IT problems were solved, how they were solved, and where the students made direct reference to the mathematics that they might have used. I could not conclude that there was “failure to transfer” if the students did not specifically refer to mathematics knowledge during the interviews.

Mathematical practices were used in conjunction with mathematical content knowledge, where necessary. The practices used are more likely to be generatively used mathematical practices because they were most likely developed as intertwined strands in mathematics classes rather than in another domain. Note that I do not argue that these practices necessarily originate only in mathematics. If one was to understand the use of knowledge as the transfer of identical packets of knowledge from one context to another (see Lobato, 2006 for further information on this) one might be more likely to want to identify a single origin of that knowledge. Alternatively, knowledge used in new contexts may be understood as having multiple origins, and is used however, wherever, and whenever necessary. If this is so, then the conclusion can be made that mathematical practices may have been generatively used in an IT context but were used selectively with the aid of other experiences and knowledge, to solve the IT problems. So the IT specialists who I spoke about at the beginning of the paper are partially correct – students do need mathematical practices for further study of IT. This study has shown that they use them generatively in solving IT problems. What this study cannot claim is whether such practices are the only useful knowledge for success in the IT domain.

References


Quantitative literacy for undergraduates: students’ perceptions about the quantitative literacy course at the University of Cape Town, South Africa

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ABSTRACT

The idea of Quantitative Literacy for undergraduates and its significance has received various interpretations but there is no universal agreement on what Quantitative Literacy should constitute. There has been a lot of attention recently (from 1999 onwards) on the development of literacy courses, Quantitative Literacy included, in the South Africa tertiary education landscape. In this paper I argue that the implementation of a Quantitative Literacy course brings with it inherent challenges depending on how the undergraduates perceive the course. Undergraduate students in the Faculties of Humanities and Law who do not meet pass criteria on Quantitative Literacy tests (equivalent to the National Benchmark tests in Quantitative Literacy) are enrolled in the Quantitative Literacy courses at University of Cape Town (UCT). The overarching aims of Quantitative Literacy courses for undergraduates are to improve the quantitative reasoning skills (mathematical and statistical) and graduate throughput. This article is written from my perspective as both a researcher and a Quantitative Literacy lecturer, and it examines the views and attitudes of one hundred and forty undergraduate students in the Faculties of Humanities and Law about the Quantitative Literacy course. The study uses of questionnaires, focus group interviews and course evaluation reports to gather data. Discussions on this paper focused on: students’ views about the Quantitative Literacy course at the beginning of the course and at the end of the course. Although there were some improvements realised at the end of the semester, the research findings show that some of the undergraduate students who participated in this study struggled with the framework and conceptualisation of the Quantitative Literacy course on enrolment.

Key words: Quantitative Literacy, curriculum materials, Mathematics, Mathematical Literacy, Quantitative reasoning.

INTRODUCTION

The concept of a Quantitative Literacy course for undergraduate students is not new at the University of Cape Town as it has been in existence for the past ten years. There have been several changes during the past ten years in terms of the curriculum (the balance between content and contexts), the general teaching and learning approaches, and the development of curriculum materials. The year 2009 culminated in the introduction of what seemed to be a
context-driven curriculum, where the content played a supporting role in the teaching and learning of Quantitative Literacy. The undergraduate students for Humanities for 2009 who were studying Quantitative Literacy were a unique group, in the sense that they had been exposed to different kinds of mathematics in high school. These students’ educational experiences in quantitative matters had been dominated by what they learned in subjects such as Mathematics and Mathematical Literacy in high schools. As a result, undergraduate students who were afforded the opportunity to study the Quantitative Literacy course joined the course with pre-conceived ideas. There was a tendency from the students to believe that instruction in Quantitative Literacy was similar to what they had already experienced in high school. It was hypothesised that by the time they completed the course their perceptions about Quantitative Literacy would have changed. Undergraduate students’ perceptions may not have been limited to the Quantitative Literacy course only, but could have extended also to how the students interacted with the course materials. Understanding the students’ views and approaches to learning in the Quantitative Literacy courses and their beliefs about the curriculum materials helped in the re-conceptualisation of the course and in the enhancement of its teaching. The purpose of the study was to investigate the changing views of undergraduate students about a Quantitative Literacy course. This study ran alongside and was integrated with another study currently being conducted in the Numeracy Centre also at University of Cape Town. The current study investigated the 2009 curriculum reform initiative from the perspective of the materials and the lecturers’ experiences of teaching with the new materials. This paper was guided by the following research questions:

1. What are the students’ attitudes towards being in the Quantitative Literacy course?
2. Is there a change of the students’ views about Quantitative Literacy by the end of the Quantitative literacy course?

THEORETICAL BACKGROUND

Conceptualising Quantitative literacy

In the previous section we made reference to the fact that the undergraduate students who enrolled into the Quantitative Literacy course come from different mathematical backgrounds and educational experiences. At high school level, some of the students studied traditional mathematics whilst some studied Mathematical Literacy. Within the South African context, both Mathematics and Mathematical Literacy are regarded as exit subjects for students leaving high school to enrol in tertiary institutions after completing Grade 12. In addition to the two subjects mentioned above, a small cohort of the students enrolled came with international qualifications in mathematics from their respective private schools or countries. In terms of what constitutes Mathematical Literacy, the Department of Education in South Africa defines it as follows:

“Mathematical Literacy provides learners with an awareness and understanding of the role that mathematics plays in the modern world. Mathematical Literacy is a subject driven by life –related applications of mathematics. It enables learners to develop the ability and the confidence to think numerically and spatially in order to interpret and critically analyse everyday situations and to solve problems (Department of Education, 2003a. p9).

In contrast to the above definition of Mathematical Literacy and its application, traditional
Mathematics is deemed too abstract with an over emphasis on learning rigorous logical reasoning, algorithms and theories of abstract relations (Graven and Venkat, 2007). In essence traditional Mathematics is different from Mathematical Literacy in the sense that Mathematical Literacy has a context construct embedded in it whereas Mathematics is to a large extent de-contextualised at high school. In addition, Mathematical Literacy uses contexts that are relevant to the everyday life of students, thus one can say the Mathematical Literacy learner grows laterally. On the contrary, Mathematics grows vertically up the abstract ladder (NCED, 2000, and Saenz-Ludlow and Presmeg, 2006). It is evident that the two types of mathematics have different purposes, Mathematical Literacy is intended for the acquisition of life long skills in the application of mathematics to real everyday contexts while Mathematics is intended for those students who are pursuing careers where mathematics is the mainstay (Mhakure, 2007., and Graven and Venkat, 2007). In this study our main focus was the students who both studied Mathematical Literacy or Mathematics in high school and were studying courses in the Faculties of Humanities and Law. Conversations about Mathematical Literacy, Quantitative Literacy and numeracy are topical agendas in mathematics education today. In South Africa, conversations on numeracy led to the introduction of Mathematical Literacy as an alternative subject to high school Mathematics. Whilst the introduction of Mathematical Literacy was welcome in educational circles in South Africa, it brought forward questions on what courses should be studied by the holders of a Mathematical Literacy qualification when they enrol in tertiary institutions (Prince and Archer, 2008).

The undergraduate group that participated in this research have written a Quantitative Literacy Test on enrolment into the faculties of Humanities and Law. As from 2010 the Quantitative Literacy Test (QLT) will be replaced by similar tests known as the National Benchmark Tests (NBT). The NBT are criterion-referenced tests aimed at determining whether students have achieved specific skills (quantitative reasoning skills) or concepts and finding out the level of quantitative reasoning skills of students on enrolment. In this case a dichotomous view of criterion-referencing is adopted when a student can or can not apply basic mathematics to find solutions to given tasks or questions (Huitt, 1996). Higher Education South Africa (HESA) (2006:11) summarises NBT as follows:

“Benchmark tests assess performance with respect to learning outcomes (content standards) in a specific content domain (subject, learning area) along a continuum on which the expected level of minimum proficiency (benchmarks/performance standards) has been set for a specific purpose (e.g. entry into higher education”

In cases where the students fail to attain a threshold mark of seventy percent (70%), then they are deemed to have failed the QLT, hence are classified as not having the requisite quantitative literacy skills. The students who do not attain the threshold pass mark in the quantitative literacy test are obliged to attend the Quantitative Literacy courses (MAM1014F for students in the Faculty of Humanities and MAM1013F for students in the Faculty of Law). Essentially there is very little difference between the two courses (MAM1014F and MAM1013F) except for the slight contextual discipline orientation. At this juncture let us give a theoretical definition of Quantitative Literacy as defined by Estry and Ferrini-Mundy (2005:10): “Quantitative Literacy is the ability to formulate, evaluate, and communicate conclusions and inferences from quantitative information”. Both Quantitative Literacy and Mathematical Literacy have fluid definitions. These variations on their meaning are largely derived from socio-cultural and political constructs of the societies where they are practised. From PISA’s perspective, Mathematical Literacy is also viewed as: “…the capacity to
identify and understand the role of mathematics in the world, to make well-founded mathematical judgements, and to engage in mathematics in ways that meet the needs of an individual’s current and future life as a constructive, concerned, and reflective citizen” (OECD, 1999:41). Madison (2006) and Hullet (2003) describe Quantitative Literacy as a habit of mind and not a list of skills to be adopted. They argue that essential components of Quantitative Literacy reside in an individual’s ability to re-contextualise a quantitative argument from a familiar context to an unfamiliar one. In addition, Quantitative Literacy practices thrive better in a collaborative environment between students and their mentors within specific disciplines at tertiary level, and should establish a platform in which students practice and apply Quantitative Literacy beyond their disciplines to quantitative situations they will encounter in their day-to-day activities of university lives (Madison and Dingman, 2010).

The next point I would like to discuss is the construct nature of Quantitative Literacy. We also argue that since Quantitative Literacy is about making inferences from quantitative information within social contexts, then this quantitative information is a product of someone’s data gathering process. This means that our understandings of the data presented to us will largely depend on our re-construction, re-conceptualisation and re-contextualisation of how the data was collected or constructed. The point here is that for us to be able to evaluate, communicate conclusions and draw inferences from quantitative information we should have a situation where: “understanding these statistics also requires thinking critically about the social process by which these numbers are brought into being” (Best, 2007:3).

Let us re-visit the cohort of students who were enrolled for Quantitative Literacy course having “failed” the Quantitative Literacy Tests on admission to the university. The assumption here is that, although not conclusive, these students did not meet the required minimum mathematical competencies or skills to enrol into the Faculties of Humanities and Law. By minimum competencies we mean, students have not mastered the general mathematical and statistical concepts that will allow them to engage and solve problems involving quantitative data with confidence in future particularly as such problems were related to the specific courses that the students were registered for (Sutcliffe, 2001).

In the South African context, about thirty five (35%) of the teachers teaching high school mathematics (both Mathematics and Mathematical Literacy) are not well trained in their subject areas. There is a perception that these teachers with their limited content of mathematics (academic mathematics) and pedagogical understandings (mathematical knowledge) have a tendency of short changing the high school students in terms of acquisition of the required mathematical skills to successfully study undergraduate courses (AMESA, 2002). Students enrolled in the Quantitative Literacy with mathematical deficiencies have been taught mathematics before in a different setting, which obviously did not facilitate the acquisition of sufficient numeracy skills. Therefore teaching them Quantitative Literacy in context should provide them with a new dimension and understanding of what mathematics can bring to their own lives (MAA Report, 1998). The goal of Quantitative Literacy is to produce well prepared students who can reason quantitatively and are able to apply what they have learned to unfamiliar real contexts. Transferring and applying mathematical ideas they have learned to unfamiliar contexts is a huge challenge to most students. Madison (2006:1) argues:

‘Because students’ educational experiences in quantitative matters have been dominated by courses in mathematics, and perhaps statistics, their inclination is to
believe that instruction in Quantitative Literacy should be similar to instruction in mathematics. Fortunately or unfortunately, in this author’s experience, that is not the case, and some of the habits learned and attitudes formed in mathematics classes are actually obstacles to achieving the Quantitative Literacy habit of mind.”

Additionally, in high school practice, the traditional way of teaching largely depends on putting emphasis on what will be assessed in examinations. The traditional teaching approaches are void of problem solving and quantitative reasoning practices which are the cornerstones of Quantitative Literacy courses. I have already mentioned that the teachers do not have a strong content and pedagogical training, hence they tend to over-rely on a page-by-page textbook pedagogy. Over-reliance on textbooks exacerbates the problem in the sense that the textbooks also do not lead to a pedagogy of problem solving and quantitative reasoning (Madison, 2006., Sutcliffe, 2001. and Dingman and Madison, 2010).

Earlier on we discussed the conceptual difference between Mathematics and Mathematical Literacy. We also acknowledged that teaching for quantitative literacy requires the application of mathematics to authentic real life contexts. What is not clear at the moment is the relationship between traditional Mathematics and Quantitative Literacy. Hallett (2001: 94) in HESA (2006: 29) argues that the difference between Mathematics and Quantitative Literacy is:

“... mathematics focuses on climbing the ladder of abstraction, while quantitative literacy clings to context. Mathematics asks students to rise above the context (into a realm of theorising and abstraction), while quantitative literacy asks students to stay in context (and remain grounded). Mathematics is about general principles that can be applied in a range of contexts; quantitative literacy is about seeing every context through a quantitative lens”

In the previous paragraphs, our discussions centred on the challenges that students are likely to face when enrolled in a Quantitative Literacy course in a tertiary institution. We acknowledge that there are some high schools whose teachers are engaged in good pedagogical practices, hence are preparing students well to meet the demands of Quantitative Literacy in tertiary institutions. It is also important to acknowledge that mathematics education in general is bereft of other societal and cultural issues such as social justice, which could as well be a Quantitative Literacy agenda in tertiary institutions. Indeed we are in agreement with the fact that mathematics education, empowers with problem solving skills. However, these skills are presented to the students enshrined in a procedural pedagogy aimed at producing specific problem solving strategies (De Freita, 2008). The latter shows the conceptual gaps between mathematics educations and quantitative reasoning. These gaps could be narrow or wide depending on the quality of mathematics education or mathematical experiences the undergraduate students were exposed to in high school.

Learning and teaching Quantitative Literacy

After enrolment students are immediately set in groups of about forty five. Deliberate effort is made to ensure that the teaching groups are small and are manageable. Each group is assigned to a lecturer as a Quantitative Literacy facilitator. The teaching sessions (lectures) consist of four single forty five minute periods per day. In addition to these teaching sessions students
are exposed to MS-Excel (practical sessions or laboratory sessions or computer based tutorials) and classroom tutorials once a week for a single period of forty five minutes each. Classroom tutorial groups are generally small with a maximum of twenty students. Trained tutors facilitate in these classroom tutorials. MS-Excel tutorials are facilitated by a lecturer assisted by two trained tutors. All the above three approaches (lectures, classroom tutorials and MS-Excel tutorials) complement each other and to a large extent refer to the same genre of contexts. Having said that, it is important to note that during lectures introductions and discussions on discipline specific content and contexts take place. The concepts identified during lectures are then further consolidated during classroom tutorials. MS-Excel tutorials also emphasise on consolidation work, with more thrust placed on using the MS-Excel platform to represent and analyse quantitative data. Assessment in the quantitative Literacy course is carried out through assignments, excel tutorials and written tests. In addition, at the end of the semester examination consisting of two papers, a written and an MS-Excel component are administered. The contexts used in the semester assessments are new and unfamiliar to the students. However, the types of questions or tasks which students are engaged in during the assessments are similar to the ones they have been exposed to during the course. Some institutions of higher learning use multiple-choice items as an assessment instrument to measure quantitative reasoning skills (Sundre, 2008). It stands to reason however, that quantitative reasoning comes embedded in social-cultural activities. To this effect, assessments in Quantitative Literacy should consist of an essay form and open-ended questions that demonstrate application skills and elicit numeracy and reasoning from the students. It is the opinion of this author that multiple-choice items as an assessment tool, do not adequately provide an authentic testing platform for assessing students’ quantitative reasoning skills. Council of Aid to Education (2008) find the use of multiple-choice questions inappropriate as it argues: “life is not like a multiple choice test” (p. 18). In the Quantitative Literacy course offered by my institution, UCT, rubrics are used for assessing quantitative reasoning in contextualised learning environments where students are expected to put forward written arguments. The advantages of using a rubric in Quantitative Literacy assessment is three fold: the focus of reading the students’ task through one lens (of the rubric) will help to consistently identify areas of weaknesses and strengths of students’ quantitative reasoning skills; based on the results obtained on the use of the rubric course reviews and course material developments could be fine tuned, and that the use of the rubric provides evidence as the basis to develop potential professional development activities, such as tutor and facilitator training that might enhance quantitative reasoning pedagogical practices (Grawe, Lutsky and Tassava, 2010). Our teaching and learning approach in as far as the Quantitative Literacy course is concerned is collaborative. Essentially the concept of collaborative learning and teaching involves students working together on tasks in small groups of about four. Students working collaboratively, actively exchange ideas through positive interdependence, conservations and social interactions with peers and their mentors (facilitators). The latter will increase interest among the group members leading to enhancement of critical thinking (Gokhale, 1995., Gerlach, 1994. and Macgregor, 1990). The organisation of a collaborative teaching-learning Quantitative Literacy environment is no trivial practice for facilitators. As I have alluded to earlier on, we teach heterogeneous groups or detracked lecture and tutorial groups. It then becomes imperative that our facilitators or tutors design: “instructional strategies that prompt participation by all students; and support high quality mathematical conservations within groups” (Staples, 2008: 251). Cohen (1994a) also makes references to positive interdependence among group members during collaborative learning environments. Positive interdependences manifest in two forms, that is, goal interdependence and resource interdependence. Resource interdependence arises when
each individual group member needs resources or information from another group member to complete a task, this normally happens when a group of students is working collaboratively on a project. With reference to goal interdependence, each individual member of the group will make their specific contributions towards a group product or task. In all the above cases, individual and group accountability should be stressed if student-student problem solving skills are to be promoted. Irrespective of the strategies for interaction that are used, it is crucial that the facilitators use interaction structures that promote meaningful learning and that do not encourage routine or rote learning. Cohen (1994a:22) argues “if they do too much to structure the interaction, they may prevent the students from thinking for themselves…” In the following section an example of an activity (context) used in the teaching of Quantitative Literacy is given and discussed.

Example of a context used in Quantitative Literacy

Context – Human rights and social justice

Read the following adapted extract from the reports: Crush J. (2001) Immigration, Xenophobia and Human Rights in South Africa and then answer the questions that follow.

South African Attitudes to Immigration

After 1994, the new South African government initially became anti-immigrationist, justified primarily in terms of the threat to job for citizens. Legal immigration dropped to an all-time low (less than 10000 per annum by the late 1990s). During the late 1990s, there was no obvious appetite for immigration or migration at the highest levels. Yet, the majority of South Africans surveyed (87% in 1998) still felt that too many foreign citizens were being allowed into the country.

The international data presented in Figure 2 suggests that, compared with other nations, South Africans rate amongst the most unfriendly to outsiders. There is widespread support for policies that would place strict limits on or prohibit in-migration altogether.

(a) Figure 2 has percentages on the horizontal axis. To make the graph easier to interpret, this axis should be labelled. What should the label read?

(b) In paragraph 2 it is stated that: “The international data presented in Figure 2 suggests that, compared with other nations, South Africans rate amongst the most unfriendly to outsiders.” How does the chart suggest this?

(c) Refer to the chart and comment on the accuracy of the following statement: “An equal number of respondents in both Russia and Nigeria indicated a negative attitude toward outsiders”. Explain your reasoning.

The above excerpt consists of a context on one of the most talked about social issues in South Africa. There is a lot of information on immigration, xenophobia and human rights in media and research institutions. This context also deals with issues of human rights and social justice. Our expectation is that students read through and are able to make meaning of the quantitative information given especially trying to link the information from the text to that
provided in the bar graph. In this context, quantitative reasoning skills will involve: understanding of proportions, interpretation of the bar graph and discussions about the context from both human rights and social justice points of view. Other contexts used in the Quantitative Literacy course include: personal finance, prison populations, statistics and probability and excerpts from Children’s rights.

METHODOLOGY

This study involved three phases of data collection: a questionnaire was used for data collection from the cohort of first year undergraduates that participated in the study. These questionnaires were administered one month after the semester had begun meaning that the students had only been exposed to the Quantitative Literacy course teaching for one month. Towards the end of the semester focus-group interviews took place with randomly selected students. Three focus groups of five students each participated, and part of the data came from students’ responses from the course evaluation exercise which was carried out at the end of the semester.

FINDINGS

The following section presents and discusses the findings of this study.

Demographics of participants

One hundred and forty students participated in the study. Thirty four percent were males and the remainder were females. From this cohort of students 84% were South African residents and the remainder came from outside South Africa (these included regional and international students).

Table 1: Distribution of students on the type of mathematics studied in high school.

<table>
<thead>
<tr>
<th>Number of students with Mathematics in 2008 (NCS/IEB)</th>
<th>Number of students who passed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematics in 2008 (NCS/IEB)</td>
<td>No Mathematics</td>
</tr>
<tr>
<td>47</td>
<td>24</td>
</tr>
<tr>
<td>46</td>
<td>24</td>
</tr>
</tbody>
</table>

From Table 1 it can be seen that the majority of the students who enrolled in the Quantitative Literacy course had matriculated from high school in 2008 with Mathematics, Mathematical Literacy or other mathematical qualifications. South Africa higher and standard grade examinations were replaced by Mathematics and Mathematical Literacy as from 2008. What could be of interest from the table above is the fact that twenty eight students were enrolled in the course without having studied mathematics at all at the exit level in high school. This group of students was likely to have graduated before 2008 before mathematics was mandated as compulsory.

When asked to rate themselves, it was observed that fifty eight percent of the participants said they had average ICT skills and sixty six percent said they had above average reading and writing skills. Eighty six percent came from schools where there was a school library, a
computer for every student and class sizes of less than forty students. Ninety two percent of the participants said they were taught in English as a medium of instruction in high school.

Discussions of the findings

Presentation and analysis of data from questionnaires

Table 2 below analyses and presents the views of the students one month after enrolling into the Quantitative Literacy course. A five point Likert scale response format was used. For each statement, students were asked to indicate whether they “strongly agree”, “Agree”, “neither agree nor disagree”, “Disagree”, or “Strongly disagree”. For the purposes of data interpretation the values of 1, 2, 3, 4, 5 were assigned to “Strongly agree”, “Agree”, “Neither agree nor disagree”, “disagree” and “strongly disagree” respectively (Cao, Bishop andForgasz, 2006). For the purpose of analysing the data the percentage of “strongly agree” and “agree” put together constituted an overall percentage in favour of the proposition or statement and a similar analysis also applied to “strongly disagree” and “disagree” responses.

Data presented in Table 2 below shows that there was a general appreciation of the role of Quantitative Literacy course in everyday socio-cultural and political constructs of the students’ lives. This was evidenced by higher percentages of responses in favour of the value or role of Quantitative Literacy in: future careers (58%), everyday life situations (85%), university studies (66%) and the development of good citizens who understand the demands of their society (76%). On the contrary, some of the respondents showed that they harboured some misconceptions about the Quantitative Literacy course. These misconceptions included: Quantitative Literacy is an extension of Mathematical Literacy from higher school (65% agreed), students preferring Quantitative Literacy to be an elective course (66% agreeing) and less than half (41%) of the respondents said that the selection process for attending Quantitative Literacy course was fair and that they should be attending the course.

Table 2: Views of the students about the Quantitative Literacy course at the beginning of the course.

<table>
<thead>
<tr>
<th>Total number of respondents: 140</th>
<th>Category numbers (in percentages)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statement</td>
<td>1  2  3  4  5</td>
</tr>
<tr>
<td>Quantitative Literacy is an extension of Mathematical Literacy from the high school.</td>
<td>2  4  2  5  1</td>
</tr>
<tr>
<td>Quantitative Literacy will have value for me in my career.</td>
<td>1  4  2  1  4</td>
</tr>
<tr>
<td>Studying Quantitative literacy will enable students to apply basic Mathematics to everyday life situations.</td>
<td>3  5  1  4  1</td>
</tr>
<tr>
<td>Quantitative Literacy will help me to understand mathematical skills and concepts that are necessary for university studies.</td>
<td>2  4  2  9  3</td>
</tr>
<tr>
<td>As a citizen of my country, Quantitative Literacy will enable me to understand issues like public health, national</td>
<td>3  5  1  3  1</td>
</tr>
</tbody>
</table>
When students were asked their opinions about the course in open-ended questions from the questionnaires they raised concerns from: comparing teaching and learning in Quantitative Literacy course with high school mathematics, confusing ideas about the Quantitative literacy course and they showed other misconceptions. By going through the students’ responses it was evident that there was lack of appreciation of collaborative learning as a strategy (more specifically the group work) in the learning and teaching of Quantitative Literacy course. I have selected a few comments (unedited) made by students which to a large extent summarise the views of students on particular issues. Below is a comment from one of the students:

“I see now how beneficial this course is, now that I am studying it. However I do believe, I could have worked harder in my course (Psychology) to get the level I need to be without his course. I hate the fact this course is dependent on group work because people with negative attitude affect those willing to learn”.

On the hand some students felt that their high school type of learning was being largely ignored, with preferences given to group work and learning in contexts. One can easily see the students’ frustrations from the comments they made. For example:

“I’ve spoken to plenty of other students and it seems people have no idea if they (we) are heading in the right directions in the 'Yellow pages' there are answers and no explanations??? Lectures need to be more hands-on and get people/students to think within the relevant context. I am very disappointed with the "workshop" format. This needs serious attention. (No offence, just my opinion)”

Other comments from students proposed that the course be made elective and that it is a total waste of time. One student remarked:

“This course is a high grade maths literacy, and is an insult to my intelligents, I don’t find a need for this course to be compulsory. Please make this an elective,
The above comments also show some misconceptions from the students on what the course is about, quite a sizeable number of students referred the course as high grade mathematical literacy thus drawing comparisons between Quantitative Literacy and Mathematical Literacy. Drawing similarities between high school Mathematical Literacy and tertiary Quantitative Literacy is debatable. Concluding that they are the same and that they serve the same purpose demonstrates the misconceptions about the utility and value of each of the disciplines. Some comments from the students, though showing appreciation of what Quantitative Literacy is about, do lack a deeper understanding the course. A small cohort of international students who were enrolled in the course believed that the course should have targeted South African residents only because they are the ones with less developed and inferior mathematical skills. However, the author of this paper, having worked with both international and local students in Quantitative Literacy courses, is of the view that lack of quantitative reasoning on the part of students has nothing to do with political boundaries. In addition, students felt that the Quantitative Literacy course should have been dedicated to students who enrolled in the tertiary institution without a mathematics qualification or background. On the contrary, this author’s experience shows that students who failed the Quantitative Literacy Tests should be eligible to study Quantitative Literacy irrespective of their mathematics background. About five students focussed on how students can be helped in their Quantitative Literacy course. One of the students remarked:

“Special car and Attention must be paid to those students who come form disadvantaged background because most of their subjects were taught in taught in their home language so it difficult to understand the concept”

In as far as responses to open-ended questions are concerned, I could only find two positive comments from students. One of them read:

“Quantitative Literacy, helps a lot with everyday problem solving, although I don’t feel it should be made compulsory” and “I think it is good to do this course and will help me in my career”

Presentation and analysis of data from interviews and course evaluation

Table 3 below shows the findings from the course evaluation questionnaire. Notable findings were that: at the beginning of the course only forty three (43%) percent said they were confident about dealing with quantitative and mathematical problems, however, by the end of the semester this percentage had risen to sixty one percent marking a significant improvement; sixty one (61%) agreed that the content of quantitative information will be useful for their course of study in future; sixty two (62%) concurred that they had benefited from Quantitative Literacy intervention programmes and that the general organisation of the course was good (67% agreeing) and eighty five percent said the course materials provided were useful. In as far as the responses from open-ended questions were concerned there were similarities in the findings to those obtained from closed questions. When asked whether the students would recommend the course to other students, the results showed resounding
positive responses. Comments in the mode of: “I would recommend this course to someone because it is useful in a lot of courses it will help you understand the fundamental concepts of maths which are widely used in everyday life” were frequently made. However, some students were ambivalent about recommending the course, remarking that: “I don’t know if I would or not but it’s a good course to take as a base for may be stats + other mathematical courses”. Among some of the isolated negative comments about whether or not students could recommend the course were: “I really don’t see why/how it is any relevance to my particular field…”

Table 3: Views of students about the Quantitative Literacy course at the end of the course

<table>
<thead>
<tr>
<th>Total number of respondents: 140</th>
<th>Percentage of respondents to each question who:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statement</td>
<td>1</td>
</tr>
<tr>
<td>1.1: I liked the way the classroom sessions (lectures) were presented.</td>
<td>22</td>
</tr>
<tr>
<td>1.2: The printed materials provided were useful.</td>
<td>28</td>
</tr>
<tr>
<td>1.3: The organisation of the course/intervention was good.</td>
<td>17</td>
</tr>
<tr>
<td>1.4: The work in this course/intervention was easier than in my other courses.</td>
<td>10</td>
</tr>
<tr>
<td>1.5: The work in this course/intervention was more difficult than in my other courses.</td>
<td>4</td>
</tr>
<tr>
<td>1.6: I felt confident about dealing with quantitative/mathematical problems and information before the start of the course/intervention.</td>
<td>8</td>
</tr>
<tr>
<td>1.7: I feel confident about dealing with quantitative/mathematical problems and information now.</td>
<td>9</td>
</tr>
<tr>
<td>1.8: I would recommend this course/intervention to other students.</td>
<td>14</td>
</tr>
<tr>
<td>1.9: I feel I have benefited from doing this course/intervention.</td>
<td>15</td>
</tr>
<tr>
<td>1.10: I think the content of this course/intervention is useful for my programme of study and my future.</td>
<td>20</td>
</tr>
</tbody>
</table>

Findings from focus group interviews showed that there was a positive shift in the students’ attitudes towards the Quantitative Literacy course in general. There was appreciation of collaborative learning as a teaching strategy for the course, as one student summarised: “Well I had a kind of relaxed group and we worked a lot together…” On the importance and relevance of the Quantitative Literacy course a student made the following general statement:

“Aah financial maths is just confusing at times because then you also realise that probably you used to calculate in your head when you walk into shop and want to buy that thing on lay bye or something, you were doing wrong calculations and you just think, oh my gosh, probably my mom does wrong calculations as well”
CONCLUSION

The present study sought answers to two research questions: first, it examined the attitudes of students towards being in the Quantitative Literacy course at the beginning of the semester; second, it investigated whether there were changes in the students’ views or attitudes about Quantitative Literacy at the end of the semester.

Regarding the first research question, the study showed that the students’ attitudes towards the course could be classified into three categories. On one hand students showed a lack of understanding of the Quantitative Literacy course hence regarded it as an extension of Mathematical Literacy from high school. It then stands to reason why probably 66% of the students said it should be an elective course. On the contrary, there were students who were not sure on whether Quantitative Literacy should be made compulsory or not for students studying in the faculties of Humanities and Health Sciences. Last there was a noticeable degree of appreciation of the role Quantitative Literacy could play in the students’ future careers, everyday life situations and as active citizens of their country. As far as the second research question was concerned, the study showed that the proportion of students who were confident about quantitative reasoning had increased from 43% at the beginning of the course to 60% at the end of the course. A plausible finding was the strong association between the latter and the findings from focus groups interviews and responses from the open-ended questions of the course evaluation. We are cognisant of the limiting fact that this study was carried out within one semester. However, it is reasonable to argue based on the findings of the study that there was ample evidence that the students views about Quantitative Literacy course had changed during the course of the semester. Some of these findings are consistent and corroborate other research findings from different studies carried out outside South Africa regarding how undergraduate students perceive Quantitative Literacy courses in tertiary institutions (Madison, 2006, and Madison and Dingman, 2010). Last, I recommend that for further research this cohort of students who participated in this study be tracked in order to find out what would be their views or recommendations about the Quantitative Literacy by the time they complete their first degree programmes.

REFERENCES


Developing Mathematics Learners’ Problem-Solving Skills through Cooperative Learning*

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Abstract
The study sought to determine group sizes and incentive structures that are effective for learners to develop problem-solving skills during cooperative learning. The case study was responding to the mathematics national curriculum statements in Zimbabwe that identify problem-solving and cooperative learning as important skills that learners should develop during formal learning. Incentive structures of awarding merits to groups that were successful to solve given problem-solving tasks during class presentations promoted cooperation among peers. Group sizes of three members were more effective than the other group sizes because one member the group acted as a moderator who reduced dominance by a learner. Listening to brain storming debates of learners working in cooperative groups in which peers exposed their understanding of mathematical relationships enabled a teacher teaching a large class to understand the diversity of learners’ prior knowledge. Findings from the study can provide insight on how teachers can implement problem-solving strategies in their mathematics classrooms in a ways that allows integration of learners’ sense-making with instruction.

Introduction
Development of cooperation skills in learners is one of the major goals of mathematics education at secondary school in Zimbabwe as depicted by the national curriculum statements of the Zimbabwe Junior Certificate, Ordinary and Advanced Level mathematics. Learner cooperation is encouraged for its potential to serve dual purposes in academic and social life. In the social circles learner cooperation is encouraged in order to build a community of citizens that are groomed in schools, expands to society at large and later to work places (Damian, 2001). Essential norms of cooperation encouraged in the national curriculum statements include interdependence, interaction, individual and group accountability of decisions and actions. In academic circles cooperative learning is valued over competitive learning for allowing learners to develop awareness that they can accomplish more learning and understanding cooperatively than individually. Cooperative learning has advantages in that learners actively working together in groups can retain mathematical concepts better than those who learn them individually (Johnson & Johnson, 2000). Most learners who learn mathematics individually tend to memorize procedures which they can easily forget. On a pedagogical perspective, cooperative groups can enable a teacher to reach out to all learners in a large class. In large classes teachers’ efforts to attend to learners’ individual differences during instruction are futile unless the learners are put into smaller groups that can engage in dialogue among themselves and occasionally with the teacher in turns.

Johnson and Johnson (2000) noted that merely asking learners to work together in groups does not always bring out the desired goals of cooperative learning. Learners by their nature can be competitive even when asked to work cooperatively. Previous researches on cooperative learning focused on group productivity where two or more learners working
together on an assignment or test performed better than those working individually (Slavin, 1991; Posamentier & Stepelman, 1997; Arends, 1997). This study recognizes that dual assessment tasks are troublesome because it is difficult to assess individual understanding and assign individual grades for a group product (Arends, 1997). To deviate from previous studies, learners in this study discussed problem-solving tasks, homework assignments or revised for a test in cooperative groups but each member produced individual written work for teacher assessment.

This study is an attempt to get insight into how mathematics teachers can achieve cooperative learning among learners as encouraged by the secondary mathematics national curriculum statements. The study uses the context of Grade 8 learners performing problem-solving tasks in cooperative groups. The learners were encouraged to develop problem-solving skills through cooperative means such as discussions, argumentation, evaluation of constructs, justification of decisions and reflection on constructs. Specifically the study was motivated by the need to determine group sizes, incentive structures and organizations that are effective to enable learners to cooperatively solve real world mathematical problems arising from their environment. Findings from the study might give mathematics teachers insight into how to organize effective learning groups that can foster cooperation among learners, nurture their critical thinking and facilitate a deep understanding of mathematical concepts in ways that may enhance their acquisition of problem-solving skills.

**Theoretical background**

Cooperative learning is a social grouping that is primarily concerned with learners’ acquisition of mathematical concepts and skills through positive social interactions. It involves two or more interdependent learners engaged in interactions around a common goal in such a way that each member influences the others’ decisions or thinking and group members jointly share rewards or punishment. Learning in cooperative groups has several advantages over individual learning. It can offer learners with opportunities to communicate their intuitive knowledge using a language they commonly understand. During the communication learners’ tentatively expressed thoughts can be made more explicit because peers’ ideas can be interpreted and expanded by others. Cross-examination of contributions made by peers can result in deep understanding of mathematical knowledge and can facilitate the construction of strategies that may produce viable mathematical solutions (Fawthrop 1997). Problem-solving in cooperative groups appears to be an ideal strategy that can develops learners’ skills of constructing, evaluating and reflecting on mathematical models that they are capable of designing to solve real world problems.

“Problem-solving is the process a learner uses to respond to and overcome obstacles that hinder the immediate construction of a method that can solve a real world problem” (Heddens & Speer, 1997:40). According to Polya (1957) successful problem-solving is influenced by learners’ acquisition of four basic skills of understanding the problem (expressing the problem in their own words, identifying variables in a problem, making pictorial presentation of a problem etc), devising a plan (using trial and error to establish a pattern), carrying out the plan (making necessary computations) and looking back (evaluating the reasonableness of a solution). In looking back learners evaluate their solutions in terms of the context of the problem, justify their methods, assess the viability of the solution that they obtain and search for alternative methods that can generate other viable solutions.

Cooperative groups can go through different phases of establishing membership, shared
influence, pursuit of academic goals and self-renewal (Schmuck & Schmuck, 1997). The success of cooperative groups in problem-solving depends on learners remaining in the same group long enough to establish cohesiveness (Posamentier & Stepelman, 1997). Cohesion can enable learners to develop non-threatening relationships that may allow peers to express their opinions freely without fear of rebuke from others. Peers can work cooperatively if they are psychologically prepared and secure to participate actively in performing group tasks. After developing non-threatening relationships, peers may feel welcomed and comfortable to work cooperatively. They might be free to express their opinions (whether they are right or wrong), argue, assess alternative viewpoints and weigh evidence and viability of assertions expressed by peers (Driver, et. al 2000). Where cohesiveness is established, members can trust each other, take initiatives and influence each other to work hard for the good of a group. Cohesiveness might also enable learners to believe that peers expect each member to understand group discussions so that they can articulate results correctly in whole class presentations and discussions.

**Design**
Data for this study was supplied in a case study on Michael Njororo, a pre-service mathematics teacher on full-time teaching practice at a rural Catholic boarding school. Michael was teaching a mathematics class of 45 learners doing Form 1 (Grade 8) between the third and twelfth week of a first school term (January to April). This duration allowed the learners to get familiar with first year secondary school work during the first two weeks and writing the end of term tests during the last week of the term. Form One learners were chosen for the study because of their flexibility to adjust to teaching methods during their initial year at secondary school.

In the theoretical part of teacher education the pre-service teachers were encouraged to adopt constructivist epistemologies in their teaching. They were encouraged to view mathematical knowledge as tentative, intuitive, subjective, and dynamic and to accept that it originates from observations, experimentation and abstraction using senses (Nyaumwe, 2004; Davis, 1990). During full-time teaching practice the pre-service teachers were expected to test and establish the efficacy of their conceptions of mathematics instruction and pedagogical theories that they were encouraged to adopt in their instructional practice before accepting them as knowledge that guides their practice. To facilitate learners’ active construction of mathematical knowledge, Michael used cooperative groups during instruction.

The 540 learners at this school belong to one of the four social groupings in equal numbers of approximately 135 from different grade levels generally called Houses. Each House was named after a prominent Catholic martyr who contributed to the spread of the Catholicism faith. Members of a House were to understand the life history of their founding ‘father’ and take them as role models that they emulated. House members occupied dormitories that were adjacent to each other. The dormitories and sporting uniforms of the same House shared a common color. Houses formed sporting teams that compete for prizes. Learners who excelled in different sporting disciplines during inter-house competitions formed the school sporting teams.

House members had potential to gain a merit(s) or demerit(s) during the school term for outstandingly good/bad behavior, achievement in academic pursuits and sporting activities. For a merit a House gained two points and for a demerit two points were subtracted from a House. The school organized a picnic on the last Saturday of a school term as a prize for the
The House that gained the highest number of points in a term. Going for the coveted picnic was the envy of all learners resulting in high learner discipline and competition among Houses in order to collect maximum merits.

Teachers in the school awarded merits to learners who showed outstandingly good academic performance or gave demerits for indiscipline in classes they teach. Michael gave merits to learners for good group presentations and for scoring the highest mark in an end of topic tests. He gave demerits to learners who showed poor performance or misbehave in class.

As a requirement of their teacher education programme, Michael wrote post lesson reflective texts for each of the lessons he taught. The post lesson reflective texts were written when Michael had left an instructional arena and mentally reconstructed that arena to analyze actions and events that took place and their effectiveness. The post lesson reflective texts analyzed, theorized, critiqued and reformulated/reconstructed instructional practices and explored the rationales for teaching actions and learners’ responses to them (actions). The post lesson reflective texts provided documented evidence of the dynamics and relationships that learners developed during group activities in ways that allowed making conclusions on the group sizes that promoted cooperation among learners and construction of viable solutions using Polya’s model of problem-solving. Test achievement, post lesson reflective texts and interviews with Michael triangulated the sources of data that were used to make deductions in this study.

**Group organization used**
In organizing cooperative groups Michael was influenced by task and incentive structures described by Arends (1997) and Slavin (1991). He encouraged learners to work cooperatively together and help each other to solve problem-solving tasks. Arends (1992) outlined a six-phase syntax that gave Michael insight into making cooperative group learning operational. Firstly, he stated the goals that cooperative groups were to achieve. This was followed by presentation of information in the form of text. In phase three he asked learners to meet in their groups to work on the problem-solving tasks given. Learners applied Polya’s problem-solving model to solve the real world problems presented to them in phase four. As learners solved the problem-solving tasks in groups, Michael moved around the classroom to assess group discussions and learners’ understanding of the strategies that they constructed. During phase five Michael organised group presentations to whole class in which solution strategies were scrutinized. He preferred a random choice of a group member for class presentations in order to evaluate peers’ individual understanding of group discussions. Lastly Michael gave merits to group members who successfully made class presentations and justified the methods they adopted to solve the problems. Demerits were given to members who made poor presentations.

Michael organised heterogeneous groups varying from two to five members belonging to the same House to engage in problem-solving activities. A typical problem-solving task he gave on symbolic expressions was: *Mr Farai bought a new car for $x. After using it for a year he sold it to Mr Moyo for four fifths of its cost price. How much money did Mr Moyo pay Mr Farai for the car?* Group sizes remained the same on a topic. Group durations ranged from one to two weeks depending on the length of a topic. Data presented in this paper came from four different group sizes of 2, 3, 4, and 5 members that covered six topics of factors and multiples, measurement of quantities, fractions and percentages, symbolic expressions and directed numbers.
Results
Data analysis involved descriptive statistics and a one-way ANOVA test. Calculations of the means of learner achievement in the end of topic tests made it possible to make deductions about the group sizes that promoted individual learner understanding of mathematical knowledge. Standard deviations of learners’ test scores helped to determine the spread of the marks. A one-way ANOVA test made it possible to determine whether learners’ performance in groups of various sizes were significantly different or not. Michael’s post lesson reflective texts and interviews were used to assess the level of cooperation that group members achieved during their engagements in problem-solving activities.

Table 1: Means and standard deviations of the end of topic test scores of learners

<table>
<thead>
<tr>
<th>Group Size</th>
<th>Mean (%)</th>
<th>Std deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 members</td>
<td>63.8</td>
<td>11.19</td>
</tr>
<tr>
<td>3 members</td>
<td>66.7</td>
<td>11.33</td>
</tr>
<tr>
<td>4 members</td>
<td>58.9</td>
<td>11.19</td>
</tr>
<tr>
<td>5 members</td>
<td>57.4</td>
<td>10.92</td>
</tr>
</tbody>
</table>

Table 1 shows that the means of learners’ performance in different group sizes are different. An F-test was used to assess whether the differences in learners’ performance when subjected to different group sizes was significant. Table 2 shows the p-values from a one-way ANOVA test.

Table 2: A one-way ANOVA comparing differences in the variances of learners’ performance under different group sizes

<table>
<thead>
<tr>
<th>Group sizes compared</th>
<th>SS</th>
<th>Df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>2, 3, 4 and 5.</td>
<td>2515.972</td>
<td>3</td>
<td>838.657</td>
<td>7.58</td>
<td>.000**</td>
</tr>
<tr>
<td>2 and 3</td>
<td>184.9</td>
<td>1</td>
<td>184.9</td>
<td>1.457</td>
<td>.231</td>
</tr>
<tr>
<td>2 and 4</td>
<td>552.54</td>
<td>1</td>
<td>552.54</td>
<td>4.123</td>
<td>.039*</td>
</tr>
<tr>
<td>2 and 5</td>
<td>928.011</td>
<td>1</td>
<td>928.011</td>
<td>9.81</td>
<td>.002*</td>
</tr>
<tr>
<td>4 and 5</td>
<td>48.4</td>
<td>1</td>
<td>48.4</td>
<td>.513</td>
<td>.476</td>
</tr>
<tr>
<td>3 and 4</td>
<td>1376.711</td>
<td>1</td>
<td>1376.711</td>
<td>.10.85</td>
<td>.001*</td>
</tr>
<tr>
<td>3 and 5</td>
<td>1941.378</td>
<td>1</td>
<td>1941.378</td>
<td>20.21</td>
<td>.000**</td>
</tr>
</tbody>
</table>

*p < .05  **p < .001

A one-way ANOVA test established that there was a very significant difference (p < .001) in learners’ performance when they were exposed to group sizes of two, three, four and five members (Table 2). The test could not establish the ordered pairs of group sizes in which learners’ performance was significantly different. In order to establish the ordered group pairs that had significantly different learner performance, two different groups were subjected to further one-way ANOVA tests successively. Learners’ performance in group sizes of two and three (p = .231) and four and five (p = .476) did not perform significantly different (Table 2). There were significant differences in learners’ performance (p < .05) between group sizes of two and four, two and five and three and four members respectively (Table 2). The one-way ANOVA test shows that learners in group sizes of two and five performed very significantly
differently \( (p < .001) \). Based on the significant levels from one-way ANOVA tests between paired group sizes, it could not be deduced which group sizes of two or three members were the most effective in making learners to have high achievement in cooperative groups compared to the other group types. Combining the results of Table 1 and 2 made it possible to deduce that group sizes of 3 members with a highest mean of 66.7\% were the most effective. Using the means of learners’ raw marks it can be noted that group sizes of five members were the least effective.

**Functionality of cooperative groups**

The post lesson reflective texts that Michael wrote after teaching using the different group sizes were used to evaluate group dynamics that influenced learners’ acquisition of problem-solving skills in cooperative groups. Michael organised heterogeneous groups in order to reflect mathematics classrooms as miniature societies where people of different skills co-exist.

Learners’ performances in tests, post lesson reflective texts and interviews with Michael revealed that group sizes influenced learners’ understanding of mathematical procedures and ability to work cooperatively. Learners in group sizes of five members least performed on tests as compared to the other group sizes (Table 1). During the interview Michael said that group sizes of five members faced several challenges such as:

They tended to discuss issues not related to the tasks at hand resulting in them becoming noisy and difficult to control. They were difficult to get started, organized and coordination of peers’ contributions was not easy resulting in difficulties to reach consensus. Learners of low ability had a tendency to be passive and the brighter ones dominated the discussions. (Interview: April, 2008).

Michael attributed this situation to bright learners’ tendencies to answer problem-solving tasks without being sensitive to the level of understanding of their peers. When they realized that their peers were gaining demerits in class presentations the bright learners put genuine efforts to help them to understand the procedures they adopted to solve group problems. This realization helped peers to understand group deliberations in ways that enabled them to present group solutions successfully during class presentations.

It can be noted that the issuing of demerits to learners who made incorrect presentations was a catalyst that encouraged peers in a group to work cooperatively and help each other to understand the procedures adopted to solve group tasks. It can also be deduced that group sizes of five members each worked cooperatively after some peers got demerits. This might show that they needed more time to develop ways of working cooperatively and that this benefited slow learners more than brighter ones.

Michael alluded that giving merits and demerits helped learners to work cooperatively inside and outside the classroom. In order to perform well and gain merits learners met in groups during their free time to prepare for tests. These test preparation sessions deepened peers’ understanding of techniques for solving problems on a topic to be tested.

Like group sizes of five members, pairs had problems of dominance by brighter learners. Michael said that groups of two members were usually dominated by the brighter one. This
resulted in such groups making some computational and presentation errors during class discussions. Presentation errors occurred when learners presented work in an incoherent manner that was difficult to follow. In such instances it was difficult to identify a step in which a computational error occurred.

Michael said that groups of three members worked cooperatively. He said that such groups enabled learners to develop positive interdependence, increased individual accountability of group results, improved learners' verbal communication, freely debate opinions and developed positive social interactions. Positive inter-dependency developed among learners because there seemed to exist sharing of responsibilities among them. For instance, there seemed to be a learner who moderated the discussions, another learner taking notes whilst a third learner was contributing ideas. During the interview Michael explained why the groups of three members worked cooperatively most of the time:

Though the learners had different abilities, it was rare that one learner imposed ideas to the group members. Imposition was difficult because the other two peers asked each other whether they agreed with the contribution made or not. When a peer faced difficulties to understand the contribution, the peer who looked like a moderator persistently asked the speaker to offer a more comprehensive explanation. That enabled all peers to review their current understanding and make sense of the explanations of how the problem could be approached. This often hatched debates that enabled learners to engage in brainstorming discussions (Interview: April, 2008).

Group sizes of four members tended to divide peers into pairs. In such groups a pair of learners with similar abilities sometimes supported each other and rarely valued the contributions from slower peers. Michael elaborated:

It was sometimes difficult for peers in groups of four to easily agree on contributions made by a peer. Sometimes peers paired up according to their abilities and agreed on an idea without convincing the other pair (Interview: April, 2008).

**Development of problem-solving skills in cooperative groups**

Group sizes of three members developed better problem-solving and cooperation skills than their counterparts in other group sizes. This observation is based on learners' performance in tests and clarity of class work presentations. Learners in three member groups developed respect for each other and worked cooperatively on solving a problem. They reviewed their individual understanding of the problem at hand in ways that enhanced correct interpretations of problems. Peers actively negotiated meanings of mathematical words inherent in a problem and socially constructed logical strategies that were used to find a viable solution to the problem at hand. In devising a plan the peers helped each other to use their intuitive knowledge, make logical guesses, use trial and error, and draw a table, diagram or model when looking for a pattern, equation or generalization. The cooperation attained by trio groups instilled in learners an appreciation that dialogue with peers was a useful tool for refining mathematical concepts and that conjectures can be arrived at after debating and reaching consensus. This realization dispelled the notion in learners that mathematics was a fixed and sacrosanct body of knowledge that could be attained through drill and practice without an involvement of one's intuitive knowledge.
Most learners solving problems in different group sizes did not devote time to look back at their methods once they got a solution. The learners did not look back at their methods after finding a solution because they did not see the importance of the step. Michael explained learners’ views on the looking back step:

The learners viewed the step synonymously with revision of the work they produced. As such they tended to revise their work when they finished all the problems given. They did not conceive looking for an alternative solution or reflection on the procedures used to solve a problem as important once they obtained a solution (Interview: April 2008).

Discussion
That all groups did not look back at the constructions that they made after getting a solution shows ineffectiveness of groups to develop learners’ problem solving skills. Looking back is an important step in the problem solving model that can enable learners to assess the viability of their solutions and looking for alternative viable methods. Looking for alternative solutions is necessary because some mathematical problems have more than one solution either because they are defined that way or because alternative assumptions are reasonable. Looking back can enable peers to evaluate their constructs and reflect on the procedures that they adopted in solving a problem. Reflection on a solution method is important because it is not sufficient to complete mathematical tasks without knowing why certain steps were taken. During reflection peers can quiz each other with why did that work, why was that the case, how about this, and what if questions. These are fundamental questions that can enable peers to understand the processes and procedures taken in solving a problem so that during class presentations they could convince their classmates of the logic of the methods that they adopted. As a result of reflection peers can explore different alternative methods and may invent fresh explanations, compare and contrast them and make decisions on which among them offer the best method to solve problems at hand.

The cooperative incentive structures of awarding merits to groups that performed well enabled learners in all group sizes to develop positive inter-dependence team spirit in which they tutored each other in and outside the classroom until peers mastered the procedures under review. Group members organized revision sessions in which they helped each other to prepare for tests or discuss home-work so that peers could score as much as possible in written exercises. In the revision discussions peers explained and defended their views, shared ideas and observations, assessed alternative methods, weighed evidence, argued, discussed and evaluated the appropriateness of constructs that they made.

Initially group sizes of two, four and five members promoted competition in which bright learners dominated the group activities in order to answer as many questions as possible within the given time. After realizing that some peers in a group were getting demerits for failing to present correct solutions during class discussions the group members began to appreciate the need to work cooperatively and make everybody understand group solutions. This realization enabled peers in one group to have face to face communication which promoted argumentation and sensitivity for individual differences. Such groups facilitated the development of communication skills among peers because “tentatively and clumsily expressed ideas were made clearer through discussion with peers” (Fawthrop 1996:75). For communication to prevail, words were chosen so that peers listening could understand the
intended messages. In instances where there was communication breakdown, peers communicated in the vernacular language. The groups cooperatively resolved disagreements and agreed on methods designed using a language they all understood. Debating peers’ contributions resulted in clarifications, refinements and consolidation of concepts. Group problem solving enabled learners the opportunity to read, write, interpret, argue and discuss problems using mathematical signs, symbols and terms familiar to them (NCTM, 1998).

Problem-solving in groups had potential to enhance learners’ argumentation skills. Argumentation as a social and intellectual verbal activity serving to justify or refute an opinion is an important skill that learners could develop if they are to successfully solve problems that occur in their environment. Norris (1997) supports argumentation as an important aspect in problem solving because learners come to the mathematics classroom with varying degrees of prior knowledge, skills, motivations and dispositions. Utilization of learners’ prior knowledge in the development of mathematical concepts in group discussions can enable learners to reflect on their conceptions regularly. Cooperative groups in large classes can help learners to get assistance from their peers to reflect on their understanding of mathematical concepts. In large classes it is impossible for teachers to attend to learners individually, hence discussions and argumentation in small groups may be a viable option for a teacher to attend to groups in any given lesson.

**Conclusion**

Group work motivated by cooperative incentive structures can build a team spirit among learners that may facilitate the acquisition of some problem-solving skills in ways that can improve learners’ academic achievement. Team spirit that developed as a result of group cohesiveness in this study was important for group productivity because it enabled learners to encourage and support each other when pursuing individual and group academic goals. Such groups enabled learners to negotiate the context of the problem, design a plan and execute it through performing appropriate procedures. For groups to work cooperatively, peers should work together for long periods so that members can accept each other as having equal obligations to contribute to group discussions. When cohesiveness is achieved peers worked cooperatively and interpreted the text, removed the block hindering visibility of an immediate solution path, searched for a pattern, assessed alternative methods and made generalizations. However, learners solving problems in groups in this study failed to see the need to evaluate and reflect on the group constructs. They perceived the looking back stage in Polya’s model of problem-solving as revision that could be performed after solving all problems at hand.

The results reported in this study were obtained from one school. The boarding nature of the school might have allowed learners from different groups to interact outside class time. This might make it difficult to attribute learners' performance to the effectiveness of a group size or composition. Moreover, the level of difficulty of topics in which group sizes were assessed was not the same. These aspects might compromise the validity of results from this study. Further research in schools that are different from the environments of the study school are necessary in order to develop a theory that can accounts to the effectiveness of incentive structures and cooperative groups in problem-solving.

**References**

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Development and validation of student evaluation instrument for measuring effective mathematics teaching

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Abstract

This paper reports a study on the development of a student evaluation of effective mathematics teaching instrument. A survey instrument was used to obtain students as well as teachers opinion about effective mathematics teacher from a sample of 80 students. Data gathered from the survey was combined with the framework of effective teacher of South African Norms for educators and also from literature to develop a pool of 186 statements about an effective mathematics teacher. The result obtained indicated six dimensions of effective teacher: knowledge of the subject, lesson preparation & presentation, motivation to students, communication with students and assessment. The items in the pool were vetted and item correlation was carried out between each item and summed score across all items in each subscale to produce a 30 item instruments. The instrument was pilot tested and shows a coefficient alpha reliability of 0.9473. Principal components factor analysis of the instrument used 27 items of the instrument and revealed five-factor loading: lesson presentation, knowledge of subject content, lesson preparation, motivation to learners and communication to learners as the principal factors of mathematics teaching effectiveness. The instrument therefore, can be used to measure teachers’ mathematics teaching effectiveness.

Introduction

The purpose of teaching is to promote learning and the major role of a teacher is to facilitate his/her students’ learning. Teaching entails the application of skills and the carrying out of appropriate activities that enable learners develop and ultimately exhibit the expected learning behaviours. Research shows a strong link between effective teaching and students’ academic achievement. In fact, the influence of teacher is the single most important factor that affects learning (Imhanlahimi & Aguele 2006; Ogbonnaya, 2008) because decisions teachers take about their teaching can either greatly facilitate students’ learning or serve as an obstacle to it (Wenglinsky, 2002). Goe (2007) observed that a synthesis of research studies show that some teachers are more effective in contributing to their students’ learning than others. However, it has been a challenge for any study to systematically explain the significant difference in teachers’ skills/characteristics that account for the difference in their teaching effectiveness. This can be attributed to the scarcity of valid and reliable instrument to measure teaching effectiveness.

For a teacher to be effective according to Tsang and Rowland (2005), he/she must have good mastery of the substantive syntactic structures of the subject. Also, the teacher needs to be able to unpack the subject’s content in a way it would be meaningful to the students. In other words, an effective teacher has the ability to understand a subject well enough and also present it to students in ways that establish a foundation of knowledge that the students can build on. This view of teaching effectiveness emphasises that an effective teacher has a strong knowledge base of the subject matter content and also a repertoire of pedagogical strategies that he/she can invoke in order to bring the lesson home to the students. Stretching this view further, one can say that an effective teacher must have a comprehensive understanding of the subject content and a powerful pedagogical representation of the subject. This is in concert with the primary goal of teacher education that involves the disciplinary education through which subject matter content as well as pedagogical knowledge can be acquired (Adeosun, Oni, Oladipo, Onuoha, & Yakassai, 2009).
Conceptual framework

Teachers as agents of transformation of education according to the South African Norms and Standards for Educators (DoE, 2000), are to fulfil the roles of being mediators of learning, interpreters and designers of learning programmes and materials, leaders, administrators and managers, scholars, researchers and lifelong learners, community members, citizens and pastors, assessors and learning area (subject) specialists. Hence, the fulfilment of the roles forms the hub of teaching effectiveness according to the norms and standards for educators. Similarly, the South African mathematics revised national curriculum statement, DoE (2002) states that

“the teaching and learning of mathematics aims to develop in the learner a critical awareness of how mathematical relationship are used in social, environmental, cultural and economic relations, the necessary confidence and competence to deal with any mathematical situation without being hindered by fear of mathematics, an appreciation for the beauty and elegance of mathematics and a spirit of curiosity and a love for mathematics” (p4).

The teaching of mathematics can help the students recognise that mathematics is a creative part of human activity, develop deep conceptual understandings in order to make sense of mathematics, and acquire the specific knowledge and skills necessary for the application of mathematics to physical, social and mathematical problem, among other things (DoE, 2002: 5). Therefore, effective mathematics teacher facilitates the actualisation of these curriculum goals in his/her class.

Anderson (2004) conceptualised effective teachers as those who through appropriate use of their repertoire of knowledge and skills achieve the teaching goals imposed on them by the authorities or the goals they established for themselves.

The above views and research findings show that certain teacher characteristics account for teacher effectiveness. The characteristics are complementary and interrelated and can also be grouped under knowledge of the subject; lesson preparation, organisation and presentation; effective student assessment and communication with the students. These characteristics work together to help the teacher accomplish the curriculum learning goals.

Hence, in this report, effective teaching is conceptualised as the teaching that enables learners to achieve their academic learning goals and effective teachers are teachers that possess the knowledge and skills needed for effective teaching and use the knowledge and skills appropriately to enable students’ achieve the educational learning goals or curriculum standards. Put in other words, effective teachers most posses the knowledge and skills needed to attain the curriculum goals (standards) and must also use the knowledge and skills appropriately in order to accomplish the goals.

The conceptualisation above assumes that:

- Effective teachers are masters of the subject matter
- Effective teachers are aware of the students’ intended learning goals (curriculum goals).
Effective teachers possess skills which they combine with their knowledge of the subject matter and their knowledge of curriculum goals to accomplish the students’ intended learning goals.

- The goals guide the effective teachers’ planning and delivery of lessons.
- Effective teachers design appropriate learning units that are linked to the standards.
- Effective teachers actively pursue these goals. Hence, they set their teaching goals (directly or indirectly) to achieve the curriculum standards.
- It is also assumed by the above definition that teacher effectiveness can be assessed in terms of behaviour and learning.

Evaluation of teacher effectiveness

Researchers in education have advocated various measures of teacher effectiveness but there have been some controversies over the capability of each of the measures to effectively give objective, dependable and accurate indication of teacher effectiveness. Students’ achievement, student’s evaluation of the teachers’ teaching, peer evaluation of the teacher, classroom observations, self evaluation, lesson plans, teaching portfolios and students’ work-sample reviews are some of the teacher effectiveness evaluation tools (Berk, 2005; Mathers, Oliva, & Laine, 2008; Doyle, 2004).

Students evaluation of teachers is one of the most popularly used method for evaluating teacher effectiveness. The use of students rating of teachers teaching as a means of evaluating teacher effectiveness is supported by the fact that the most acceptable criterion for measuring effective teaching is the amount of student learning that takes place. According to research, there are consistently high correlations between students’ ratings of the amount learned in a subject matter and their overall ratings of the teacher (Theall and Franklin, 2001).

The reliability and validity of student rating as a measure of teaching performance have been generally supported by large body of research (Beran & Rokosh, 2009). A review of studies by Prebble et. al (2004) on the impact of student assessment of teaching on teaching quality shows that students assessments of teaching are among the most reliable and accessible indicators of teacher effectiveness. Theall and Franklin (2001) also indicated that students are the most qualified sources to rate the extent to which teaching is productive, informative, satisfying or worthwhile. Zabaleta (2007) indicated that student ratings of teaching have become a part of the evaluation system in higher education and results from student ratings of teaching effectiveness have been used to make critical judgement in higher education (Beran & Rokosh, 2009). Evidence also shows that high school students are capable of distinguishing effective teachers (Irving, 2004).

The student evaluation instrument

The student evaluation instrument is designed to assess mathematics teachers teaching effectiveness from the perspective of the students. It elicits students information concerning their teacher’s teaching in terms of the teachers’ display of subject mastery in teaching, lesson organisation/presentation, students’ assessment and communication with students.

Development of the Instrument

Marsh & Hocevar (1991) suggested that the development of a student’s evaluation of teaching
instrument should follow the general procedure of:

- Development of a large pool of items (from literature, existing instruments, interview with students and teachers),
- Piloting the instrument to receive feedback about the items, and
- Consideration of the psychometric qualities of the items while revisions are made.

The development of the instrument began with the search for the characteristics of effective teachers/effective teaching. Based on a survey of students’ and teachers’ views of effective teacher reviews of similar studies (e.g. Irving, 2004), the South African Norms and Standards for Educators, the Mathematics National Curriculum Statement and other related literature, a framework of effective teaching that guides the development of these instruments was formulated. The framework specified the domain of interest of the study which according to Berk (1979) is a crucial first step in development of an evaluation instrument.

In order to make the evaluation specific to a particular subject content and also based on the problems teachers and students’ difficulties in trigonometric functions (see Atagana, et al, 2009), the particular focus of the study is on trigonometric functions.

By looking through the lens of the framework a pool of 186 items was developed. From the pool items were drawn for each subscale identified in the framework: knowledge of subject content, lesson preparation, lesson organisation, lesson presentation, assessment of students learning, and communication with students.

**Survey of students’ and teachers’ views of effective mathematics teacher**

The survey of high school teachers and students views of the qualities of effective mathematics teacher identified excellent knowledge of the subject matter, ability to communicate the subject clearly, always attend class, helps learners where they don’t understand, motivate learners, gives learners opportunity to ask questions and talk in class, pays attention to students learning difficulties, prepares for lesson before coming to class, explains the subject well, provides helpful feedback to students, uses examples that students are familiar with to bring lessons home, and provides relevant examples as the hallmark of effective mathematics teacher. Items for instrument were developed based the statements and as much as possible the phases and wordings used by the students and teachers were retained.

The items developed from the survey were combined with items generated from other sources: the South African Norms and standards for Educators, the Mathematics National Curriculum Statement, and other literature to generate the 186 items.

The instrument comprises items from the six dimensions of the framework guiding the study: knowledge of the subject, lesson preparation & presentation, motivation to students, communication with students and assessment.

**Vetting of the instrument**

The instrument was vetted by six teachers (three mathematics teachers, two science teachers a language teacher) and 10 high school students. They advised that some items be removed and also some grammatical changes be made to some of the items. For instance, they suggested that the word ‘learners’ instead of ‘students’ should be used since that is the word being used
more in the high school system in South Africa. This trimmed down the total number of items to 135. The 135 items were further vetted by four mathematics and science education researchers this brought down the number of items to 84. The vetting of the instrument was carried out to ensure that the items are explicit and by no means ambiguous so that the items would be interpreted correctly by respondents (Mogari, 2004).

The 84 item instrument was further subjected to rating by 7 mathematics teachers and mathematics and science education researchers who judged how favourable each item was with respect to the construct it was purported to measure using a 5 to 1 rating scale where 5 = strongly favourable to the concept; 4 = favourable to the concept; 3 = undecided; 2 = unfavourable to the concept and 1 = strongly unfavourable to the concept was used for this purpose.

Selection of items
To select the items for the instrument, I computed the correlation between average rating for each item and the total (summed) score across all item in each subscale (Trochim, 2006). From the correlation coefficients, any item that had a low correlation (less than 0.7) with the total score in the subscale was thrown out. This produced 39 items which was further scrutinized by another experienced educational researcher to produce 30 items.

The instrument consisted of the 30 items (see figure 1) in a six-point Likert type scale (three points for agreement and three points for disagreement namely: strongly agree, agree, slightly agree, slightly disagree, disagree and strongly disagree). The use of the even number scaling system eliminates the possibility of respondents opting for a mid-point (sitting on the fence or neutral) position (Cohen, Manion, & Morrison, 2007). The six-points rating exhausts the range of possible responses that respondents may wish to give that will enable effective teaching/teachers be discriminated from ineffective teaching/teachers.

<table>
<thead>
<tr>
<th>My mathematics teacher ...</th>
<th>Strongly agree</th>
<th>Agree</th>
<th>Slightly Agree</th>
<th>Slightly Disagree</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 introduced trigonometric functions in a way that captured learners’ attention</td>
<td>6 5 4 3 2 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2 gave definitions of terms/vocabularies that appear unfamiliar to learners</td>
<td>6 5 4 3 2 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3 gave satisfactory answers to learners questions</td>
<td>6 5 4 3 2 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 made lessons relevant and meaningful to learners</td>
<td>6 5 4 3 2 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 simplified the subject matter to learners</td>
<td>6 5 4 3 2 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>6 showed sound knowledge of the subject matter</td>
<td>6 5 4 3 2 1</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>7 showed learners interesting and useful ways of solving problems.</td>
<td>6 5 4 3 2 1</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>8 started lessons by connecting to previous lessons</td>
<td>6 5 4 3 2 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 ended lessons by connecting to future lessons</td>
<td>6 5 4 3 2 1</td>
<td></td>
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</tr>
<tr>
<td>10 presented sections of the topic in a logical sequence</td>
<td>6 5 4 3 2 1</td>
<td></td>
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<tr>
<td>11 related content to real life examples</td>
<td>6 5 4 3 2 1</td>
<td></td>
<td></td>
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<tr>
<td>12 was always well-prepared for class</td>
<td>6 5 4 3 2 1</td>
<td></td>
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<tr>
<td>13 summarized the main points by the end of lesson</td>
<td>6 5 4 3 2 1</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>14 was always in class with all necessary materials for teaching topic</td>
<td>6 5 4 3 2 1</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>15 related ideas to learners’ prior knowledge</td>
<td>6 5 4 3 2 1</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>16 supported lessons with useful class work</td>
<td>6 5 4 3 2 1</td>
<td></td>
<td></td>
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<tr>
<td>17 made use of different teaching techniques</td>
<td>6 5 4 3 2 1</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>18 motivated learners to pay attention to lesson</td>
<td>6 5 4 3 2 1</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Please indicate the extent of your agreement/disagreement with the following statements about your mathematics teacher, using the following scale:

- Strongly agree = 6
- Agree = 5
- Slightly Agree = 4
- Slightly Disagree = 3
- Disagree = 2
- Strongly Disagree = 1

For each question mark X in the appropriate box that corresponds to the extent of your agreement/disagreement.

<table>
<thead>
<tr>
<th>My mathematics teacher...</th>
<th>Strongly agree</th>
<th>Agree</th>
<th>Slightly Agree</th>
<th>Slightly Disagree</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 always attended classes</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>20 helped learners where they didn’t understand</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>21 encouraged learners to learn</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>22 was always punctual to class</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>23 gave individual support to learners when needed</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>24 adjusted the lessons when learners experienced difficulties in learning.</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>25 used assessment results to provide extra help to learners</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>26 explained something in different ways to help learners understand.</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>27 took extra steps to help all learners learn and achieve success in maths.</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>28 supported lessons with useful classroom discussions</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>29 gave feedback to learners about their homework and assignment</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>30 communicated the topic clearly</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 1. Student evaluation of trigonometric functions teaching instrument

**Results**

**Reliability**

The Reliability (internal consistency reliability) of the evaluation instrument was established by calculating coefficient alpha (Cohen, Manion and Morrison, 2007), using data gathered from a pilot testing of the instruments with 165 grade 11 students (tough only 109 students completed all the 30 item in the instrument). Coefficient alpha (α) value of 0.9473 was obtained from calculation using SPSS.

**Validity**

**Content validity**

The instrument underwent content and construct validity tests. Content validity of the instrument was established by grounding the instrument on the established framework of effective mathematics teacher. The use of the teachers, students and experts in the field of, mathematics and science education and psychometric tests to vet the instrument was used to further ensure content validity of the instruments (Creswell, 2008). The experts checked that each item in the instrument relate to what it was purported to measure, the scale was of appropriate length and that the language was simple to the understanding of high school students speaking English as second language.

**Construct validity**

To ascertain that the items from the content validity actually measured what they are assumed to measure construct validity was performed on the items. This was done in two phases. In the first phase, the correlation between each item and the total (summed) score across all items in each subscale (Trochim, 2006) was computed. The items that correlated highly (0.7 and above) with the summed score in the subscale were selected; dropping out the remaining items. The 30 items that were selected made up the pilot instrument (see Figure 1). The instrument was pilot-tested with a convenient sample of 165 grade 11 students from 9 classes in four high schools in North West province.

**Factor analysis**

The second phase of the construct validity was to factor analyse the result of the pilot test.
This was used to further determine if the items in the instruments measured the theorised constructs and thus strengthen the validity of the instrument. Principal components (PC) factor analysis on Statistical Package for the Social Science (SPSS) was used to determine the factor loadings of the instrument. The first step was to carry out a preliminary analysis using the output of the R-matrix. The result revealed that items 29, 19 and 22 of the instrument had respectively 11, 9 and 9 of their one-tailed significant values greater than 0.05. Hence, it was judged better to eliminate the three items to avoid singularity (Field, 2005). The Kaiser-Meyer-Olkin (KMO) measure of sample adequacy was 0.892. The Bartlett’s test of sphericity gave a value of .000. The KMO value of 0.892 falls in the range of ‘great value’ and the highly significant values of Bartlett’s test (p < 0.001) indicated that factor analysis was appropriate for the data (Field, 2005).

To optimise the factor structure and search for the best explanation of patterns in the data, factor rotation was applied. A summary of the factor analysis of the remaining 27 items of the instrument (excluding, items 19, 22 and 29) is presented in Table 1. The plot of the eigenvalues shows that the data are best represented by five underlying factors. Factor loadings less than 0.3 have not been displayed and the values are listed in the order of size of their factor loadings.

The result showed items 13, 17, 20, 23, 24, 26, 27 and 28 loaded to one factor – (factor 1). They were thought to be measuring teachers’ lesson presentation. Item 3, 4, 5, 6, 7, 9 and 12 loaded to one factor – (factor 2). They were thought to measure teachers’ knowledge of subject content. Items 2, 10, 14, 15, 16, 21 and 25 which loaded to factor 3 were seen to measure lesson preparation. Items 1, 11 and 18 loaded to factor 4, they were judged to measure teachers’ motivation to students and lastly, items 30 and 8 that loaded to factor 5 were seen to measure teachers’ communication to learners.

Conclusion
The result from the study showed that, lesson preparation, knowledge of the subject, lesson presentation, motivation to students and communication to students are the factors that determine mathematics teacher effectiveness in the context of South Africa. It also showed that the student evaluation of mathematics teaching effectiveness instrument was valid and reliable. Therefore, the instrument can be used to measure the effectiveness of mathematics teaching.

References


**Investigating the relationship between pedagogy and learner productions through a description of the constitution of mathematics**

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This paper sets out to extend the analytic resources for describing the constitution of mathematics in pedagogic contexts of schooling. More specifically, the paper explores Umberto Eco’s (1979) notions of *closed* and *open* texts together with his concept of the Model Reader as analytic resources for describing the relationship between the mathematics constituted in pedagogic situations and the mathematics produced by learners. Using the general methodology developed by Davis (2010a), the operational activity of a teacher and learners is analysed as a means of extending our understanding of the structuring effect of pedagogy on learner productions.
Introduction
The general problematic within which this paper is located is the constitution of mathematics in the pedagogic situations of schooling, specifically what is constituted as mathematics and how in school mathematics lessons. The specific focus of this paper is to explore the utility of Eco’s (1979) notions of closed and open texts as analytic resources for illuminating the relationship between mathematics constituted by pedagogy and the mathematics produced by learners.

Mathematics education in South Africa has been characterised as a system in crisis, as indexed by poor performances of learners in national as well as international tests (Fleisch, 2008). Several explanations of learners’ poor performances in mathematics exist in the literature, both psychological and sociological. This paper does not attempt to provide a causal explanation to account for poor learner performance. Instead, the question raised here is to what extent an analysis of what is constituted as mathematics in pedagogic contexts can provide insights into the operational features of learners’ productions of mathematics. The paper focuses on one lesson in one school to develop analytic resources for describing the constitution of mathematics in general.

Open and closed texts
Eco (1979) provides a semiotic description of the nature of texts, distinguishing between two types of texts – texts that can be described as open and texts that can be described as closed. He defines closed and open texts as follows:

Those texts that obsessively aim at arousing a precise response on the part of more or less precise empirical readers (be they children, soap opera addicts, doctors, law-abiding citizens, swingers, Presbyterians, farmers, middle-class women, scuba divers, effete snobs, or any other imaginable sociopsychological category) are in fact open to any possible ‘aberrant’ decoding. A text so immoderately ‘open’ to every possible interpretation will be called a closed one. (Eco, 1984: 8; italics in the original.)

[Open texts] work at their peak revolutions per minute only when each interpretation is reechoed by the others, and vice versa. [...] You cannot use the text as you want, but only as the text wants you to use it. An open text, however ‘open’ it be, cannot afford whatever interpretation. An open text outlines a ‘closed’ project of its Model Reader as a component of its structural strategy. (Eco, 1979: 9; italics in the original)

A closed text attempts to elicit a very particular reading and is consequently subject to divergent, ‘aberrant’ readings. In contrast, open texts are structured so that all the elements work together to produce a reading that converges to a particular reading.

The texts referred to by Eco include comic books, films, poems and so forth, that clearly differ from pedagogic texts. A pedagogic text is defined as “an utterance within a context of a pedagogic relationship” (Dowling, 1998). Pedagogic texts include sequences of verbal, written or gestural significations such as teacher and learner speech, worked examples or notes written on a chalkboard or a textbook. In the context of teaching and learning mathematics, pedagogy is understood as fundamentally evaluative. Evaluation distinguishes legitimate from non-legitimate knowledge statements for learners and reveals criteria for the recognition and realisation of mathematical objects or procedures in pedagogic contexts.

Consider the Grade 9 learner responses to problems on the division of exponential expressions shown in Figure 1. The series of incorrect learner responses seem to indicate that the learners do not understand the operation of division over numbers represented in exponential notation.

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20 These texts can be used as pedagogic resources but are not necessarily constructed as pedagogic texts.
Figure 1. Learners’ responses to division of exponential expression problems.

The learners’ responses might be viewed as “aberrant decodings” of the teacher’s procedure for solving problems that involve the division of exponential expressions, suggestive of responses to a text considered closed by Eco. The paper attempts to develop Eco’s notions of open and closed texts as resources for describing pedagogic texts with the aim of exploring the productivity of these resources for revealing the relationship between mathematics constituted in pedagogic situations and the mathematics produced by learners. Before doing so, a brief review of the literature that attempts to account for learners’ poor performance or difficulties experienced in mathematics will be addressed.

Learner difficulties

The theme of learner failure and difficulties with mathematics remains of enduring concern to researchers in mathematics education. Responses to the issue vary depending on the perspective from which the research is conducted. Below relevant studies from the field of psychology of mathematics education and research located within the sociology of education are examined.

A number of research studies within the psychology of mathematics education that attempt to explain difficulties experienced by learners locate the problem in the faulty ‘sense-making’, or ‘understanding’, on the part of the learner where ‘sense-making’, or ‘understanding’, is achieved through the transformation of mental structures (see, for example, Skemp, 1987; Tall, 2008; Dubinsky, 1991).

Piaget serves as the key theoretical antecedent for much of the research on learner’s ‘sense-making’ or ‘understanding’ of mathematics. Attempts at categorising different kinds of understanding can be traced to the seminal work of Skemp (1979). His binary opposition between instrumental and relational understanding (Skemp, 1976) was later extended to a triadic distinction between instrumental, relational and logical understanding (Skemp, 1987). For Skemp, instrumental understanding refers to the use of a procedure to solve a problem without knowing why the procedure works; relational understanding refers to knowing the mathematical rationale, or principles, underlying specific procedures or the ability to deduce procedures from general mathematical principles; and logical understanding refers to the ability to logically deduce a chain of inferences from a given set of premises, axioms or theorems (Skemp, 1987: 171-172).

Parallels to Skemp’s binary opposition between instrumental and relational understanding can be found in the procedural-conceptual dichotomy used by Ma (1999) in her analysis of teachers’ mathematical knowledge, and by Steinbring (1989) in his reference to school mathematics teaching and learning. For both Ma (1999) and Steinbring (1989) pseudo-conceptual or procedural knowledge is evident when procedures are employed ‘without meaning’ and conceptual understanding is present when mathematical concepts are explicitly employed. So ‘sense-making’ or ‘understanding’ is equated with conceptual understanding, where the notion of a ‘concept’ refers to mathematical concepts explicitly ascribed to the encyclopaedia of mathematics.\(^\text{21}\) Skemp (1976; 1987), Ma (1999) and Steinbring (1989) refer to procedural (instrumental) and conceptual (relational) teaching. However, the precise relation between procedural/conceptual teaching and procedural/conceptual understanding is not clearly articulated. Furthermore, Skemp argues that school mathematics can be constituted as different forms of knowledge: relational mathematics or instrumental mathematics.

But what constitutes mathematics is not the subject matter, but a particular kind of knowledge about it. The subject matter of relational and instrumental mathematics may be the same […]. But the two kinds of knowledge are so different that I think that there is a strong case for regarding them as different kinds of mathematics. (Skemp, 1979: 15)

For Skemp the constitution of mathematics is directly related to the nature of mental structures or schemas of the learner. Learning relational mathematics requires the development of conceptual schema that enable learners to connect different mathematical concepts to solve mathematical

\(^{21}\) A similar notion of “scholarly” mathematical knowledge can be found in the work of the French mathematics education researchers (Bosch, Chevillard & Gascón, 2005:4).
problems. In contrast, learning instrumental mathematics inhibits the development of conceptual schema making learners dependent on the provision of methods for solving each new type of mathematical problem.

From a sociology of education perspective\textsuperscript{22}, Dowling’s (1998) proceduralising and principling discourses resonates with the procedural-conceptual opposition advocated by Skemp (1979), Ma (1999) and Steinbring (1989).

The general quality which distinguishes principled from procedural discourse is that the former exhibits connective complexity, whereas the latter tends to impoverish complexity, minimizing rather than maximizing connections and exchanging instructions for definitions. Dowling (1998: 146)

Dowling’s definitions, in contrast to Skemp’s, refer to a description of the discourse produced by pedagogic agents rather than indexing ‘understanding’ or ‘sense-making’. For Dowling learner performance is construed as a function of the distribution of different forms of knowledge to different groups of learners. Principled forms of knowledge have the potential of apprenticing learners into mathematical discourse while procedural forms of knowledge restrict learners’ access to mathematics. Dowling’s work is productive in highlighting the effect of pedagogy on learner acquisition. However, the precise relationship between pedagogy and learners’ acquisition of mathematics is not the focus of Dowling’s work.

For Dowling and the other research studies cited above, concepts or meaning is only present in the case of principled or conceptual knowledge. However, Davis argues that:

Accepting the Saussurian proposition on the arbitrariness of the sign enables us to argue that the correlation of a mathematical symbol, term or statement with a meaning in a pedagogic situation is a matter for empirical investigation rather than simply to be taken as that which is set out in the mathematics encyclopaedia. In other words, Saussure’s proposition clears the way for us to describe the objects and operations of operational activity in the pedagogic treatment of mathematics in ways that are not bound to what is usually recognised, or expected, as mathematics. (Davis, 2010b)

The current deployment of the analytic categories of conceptual/procedural knowledge or ‘understanding’ in mathematics education are restricted to concepts or meanings found in the mathematics encyclopaedia.

Tall’s (2008) three worlds of mathematics (conceptual-embodied world, proceptual-symbolic world and the axiomatic-formal world) and Dubinsky’s (1991) Action-Process-Object-Schemas (APOS) theory have their roots in Skemp’s triadic distinction between instrumental, relational and logical understanding. These process-object theories contend that compression (Gray & Tall, 1994), encapsulation (Dubinsky, 1991), or reification (Sfard, 1991) of a process into an object is central to the flexibility required by learners to succeed mathematically. Gray & Tall’s ‘proceptual divide’ distinguishes students who flexibly treat symbols as both processes and objects from those that remain at a process level of operating on symbols. However, for Lima & Tall (2008) process-object theories are limited to describing learners’ mathematical productions in terms of the process-object shift without considering the effectivity of physical embodiment in learning. Their research concludes that students use procedural embodiments or symbol shifting (movement of symbols such as “change sides change signs”) as resources for solving equations. In some cases symbol shifting produces learner errors, and in other cases learners produce correct solutions despite the absence of the notion of an equation being explicitly deployed. Lima & Tall’s (2008) work resonates with research conducted by (Johnson & Davis, 2010) on the notion of character distribution matrices that will be discussed later. In response to Tall’s comments on the axiomatic, Davis (2010a) argues that

\textbf{[W]}hile it is generally true that teachers and their learners do not explicitly attend to axioms as they go about doing mathematics, they nevertheless do their mathematics against the background of implicitly accepted and

\textsuperscript{22} Within the sociology of education, learner performance is related to the pedagogic modality (see, e.g., Bernstein, 1996). These studies are concerned with explanations of the persistent poor performance of learners from working class backgrounds by comparison with those from middle class backgrounds.
agreed upon foundational ideas and assumptions that have an axiomatic-effect on their mathematical practices and, thereby, on what comes to be constituted as mathematics in pedagogic contexts. (Davis, 2010a: 105-106)

Tall’s three worlds of mathematics, based on Piaget’s developmental theory of learning, correspond to a developmental trajectory in mathematical thinking from conceptual embodiment to proceptual symbolism and culminating in axiomatic formalism. Learning occurs through the transformation of mental structures and learner failure is produced when the mental structures of the learner are not congruent with mathematical knowledge considered valid within the encyclopaedia of mathematics, or when encapsulation (reification) does not occur. Learner failure in a constructivist framework is, therefore, a consequence of the learner’s sense-making experience rather than an effect of pedagogy which is considered as inhibiting the development of relational understanding rather than constitutive of learners’ understanding.

The studies discussed above, particular those located within the psychology of mathematics education, appear to locate learner difficulties with mathematics in the sense-making of the learner without considering the dialectical relationship between the learner and pedagogy, i.e., the structuring effect of pedagogy on learners’ performance and the effect of the learner on pedagogy (see Steinbring, 1989; Davis, 2010a; Bernstein, 1996). Lima & Tall (2010) and Ma (1999) position learner productions in relation to pedagogy but their analyses focus on teacher’s reports on what and how they have taught a topic, not on observations of classroom teaching where student performance can be judged in relation to the criteria that emerge in pedagogic situations.

In summary, the above reflection on the problem suggests further investigation of the relations between pedagogy and learner acquisition. In order to do so, the methodology developed by Davis (2010a) for the analysis of pedagogy and learners’ acquisition of mathematics will be considered.

General methodology

Drawing on Bernstein’s (1996) sociological theory of pedagogic discourse, Davis (2010a) asserts that pedagogy is fundamentally evaluative. Evaluation distinguishes legitimate from non-legitimate knowledge statements for learners and reveals criteria for the recognition and realisation of mathematical objects or procedures in pedagogic contexts. Therefore what comes to be constituted as mathematics and mathematical thinking in a pedagogic context is rendered visible through the criteria that circulate in that context (Davis & Johnson, 2007). Learners are obliged to reproduce the legitimate text expected of them within the constraints of evaluation imposed on them. Learners are constantly subjected to evaluation and are consequently not free agents in pedagogic situations. It is, therefore, essential to consider the structuring effect of pedagogy on the learner.

The general methodology developed by Davis (2010a) enables an analysis of pedagogy and learner productions. Integral to this methodology is the notion that mathematical activity always involves decisions about the nature of the objects being operated over. The methodology entails an analysis of the scriptural practices of teachers and learners. Scriptural practices consisting of mathematical statements and their transformations are examined in terms of the objects and operations that emerge in pedagogic contexts in order to generate a description of the domains of objects and the operatory logic functioning in the pedagogic context.

We start by fixing on what it is that teachers and students do, which is then redescribed in terms of operations or operation-like manipulations. Since operations and objects are compossible, the construction of a description of an operation, or of an operation-like manipulation, also produces the construction of an associated description of the objects operated upon. From the objects we can generate descriptions of the domains over which mathematical activity operates. The selection and organisation of the particular operations and operation-like manipulations in play enable the production of descriptions of the operational logic at work. (Davis, 2010a: 102)
The objects and operations evident in the scriptural practices of teachers and learners may be mathematical or pseudo-mathematical, and likewise, the domains of objects operated over may be mathematical or collections of objects not usually recognised as mathematics. In addition to analysing the operational activity of the teachers and learners, the methodology entails examining the topic referenced by teachers with respect to the mathematics encyclopaedia. In other words, the topic is examined in terms of the definition and description of objects and the axiomatic properties of the relevant operation in relation to the domain of objects operated over.

The methodology outlined above will be used to describe the worked example on division of exponential expressions presented by the teacher and the problem attempted by learners in a Grade 9 class. An analysis of the topic of division of exponential expressions will be considered before examining the teacher’s pedagogy and the learner productions.

**Division of exponential expressions**

Let us now consider the computation $7^3 \div 7^2$, a worked example presented by a teacher to her class, from the perspective of the encyclopaedia of mathematics. The specific example can be located in the general class of problems that involve arithmetic computations over the set of objects of the form $a^n$ where $a,n \in \mathbb{Z}$, $a \neq 0$. The specific problem entails computations involving division of expressions of the form $\frac{a^m}{b^n}$ where $a = b$, i.e., $\frac{a^m}{a^n}$, or $\div(a^m,a^n)$. Division of expressions of the form $\div(a^m,a^n)$ involves the operations of multiplication over the set of rational numbers, i.e., the problem implies the existence of the object $(\mathbb{Q},\times)$.

This object has the following properties:

1) Multiplication is a binary operation and has division as its inverse operation.
2) $\forall a,b \in \mathbb{Q}, a \times b \in \mathbb{Q}$ (closure)
3) $\forall a,b \in \mathbb{Q}, a \times b = b \times a$ (commutativity)
4) $\forall a,b \in \mathbb{Q}, (a \times b) \times c = a \times (b \times c)$ (associativity)
5) $1 \in \mathbb{Q}$, and for $\forall a \in \mathbb{Q}$, $a \times 1 = a = 1 \times a$ (identity)
6) $\forall a \in \mathbb{Q}, \exists \frac{1}{a} \in \mathbb{Q}$ such that $a \times \frac{1}{a} = 1$ (inverse element)

In addition to these properties, the problem $\div(a^m,a^n)$ relies on exponentiation denoted by $a^m$, the operation involved in raising a base $a$ to the power $m$ i.e. $a^m$ is defined as $a \times a \times a \times \ldots$ for $m$ factors of $a$.

Knowledge of the axiomatic properties of the object $(\mathbb{Q},\times)$ and the definition of $a^m$ provide combinatorial resources that enable the production of a range of computational procedures that are distinct at the level of expression but equal at the level of value. An individual is free to choose different properties for a computational procedure which may be as efficient or elaborate depending on the choice of properties. Without the knowledge of the properties of the object, an individual is bound to a particular procedure. The freedom of choice resides in the knowledge of the properties of the object which regulates the production of mathematics.

A pedagogic text which makes available definitions and axiomatic descriptions of the objects it refers to provides learners with flexibility to produce different solution procedures that converge on the same interpretation. In other words, access to definitions and properties of the objects as elements of the

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23 Davis (2010a) discusses in detail a teacher’s procedure for dealing with the problem $-7+5$. The procedure for solving this problem involves splitting the signs from the numbers, (a pseudo-mathematical operation) then subtracting 5 from 7 to produce the answer 2, and finally adding the negative sign to 2 to obtain the result -2. In this case the expression $-7+5$ is treated as a string of characters which are operated on to produce signs and numbers.
pedagogic text are integral to the structural strategy of the text. Such a text corresponds to Eco’s *open* text since it delineates a ‘closed’ project for its readers/learners in that it aims to produce convergence of interpretation of the text.

Let us now examine the teacher’s worked example and analyse the operational activity in terms of the objects and operations that emerge in the procedure for solving the problem.

**The worked example**

The lesson focused on the topic division of exponential expressions. The teacher started the lesson with an example $7^3 \div 7^2$. Prior to solving the worked example, the teacher reminded learners that when multiplying exponential expressions exponents are added. She then stated that for division of exponential expressions exponents are subtracted. The teacher appeared to generalise the rule for division of exponential expressions from the rule for multiplication of exponential expressions covered the previous day. She omitted to mention that the rule for multiplication and division of exponential expressions only applies if the bases are the same.

The teacher presented two methods for dividing exponential expressions referred to as the “long method” (see Figure 2a) and the “short method” (see Figure 2b). Learners were given a choice of methods to use although it became evident later in the lesson that the teacher preferred the “long method” – one which she referred to as a method better suited for her learners.

The teacher’s procedure for the “long method” is shown in the lesson extract below:

Teacher: So here, how many sevens do you have?
Learners: Two.
Teacher: No.
Learners: Three.
Teacher: It’s seven, seven, seven. Nhe? {Right?}
Learners: Yes.
Teacher: Then you divide by how many sevens?
Learners: Two.
Teacher: So it is seven, seven. The long method is a primary. It’s a primary method not a high school method. But here you are not .. the same. Then what you do, you cancel seven and seven nhe? {right?}
Learners: Yes.
Teacher: Then seven no {and} seven. Then lo ushiyekileyo uzakuba vintoni? {Then what happens to the seven that is left?}

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24 The teacher’s “short method” is not discussed in this paper since it is evident from the lesson that the teacher focuses on the “long method”.
Learners: [Indistinct]
Teacher: Yi-answer. {It is an answer.} The one that is not being cancelled is your?
Learners: Answer.

The teacher’s first question in the above extract is ambiguous. The learners appear to interpret this question as referring to the number of sevens in the expression $7^3 \div 7^2$ but the teacher is referring to the number of sevens in the transformation of $7^3$ to 7 multiplied by itself three times. In the transformation from $7^3$ to 7.7.7 the dots between the sevens represent multiplication for the teacher but the operation multiplication is absent from the teacher’s speech and as such remains implicit. Similarly, the use of cancelling implicitly refers to division. But, again, the operation division is absent from the teacher’s speech.

Let us now look more closely at the operational activity of the teacher. The teacher’s procedure for solving the problem $7^3 \div 7^2$ using the “long method” is described below:

Step 1: Identify the number of 7s in the numerator $7^3$ by referring to the exponent 3.

Step 2: List the number of 7s in the numerator $7^3$.

Step 3: Identify the number of 7s in the denominator $7^2$.

Step 4: List the number of sevens in the denominator $7^2$.

Step 5: Pair a seven in the numerator with a seven in the denominator and then cancel out the pairs of 7s.

Step 6: Count the number of 7s left in either the numerator or denominator.

Step 7: Concatenate the base 7 to exponent 1 deduced from the number of 7s counted in Step 7.

The procedure involves a series of transformations from the initial expression $7^3 \div 7^2$ to the terminal expression 7. Each transformation is legitimate irrespective of the operations employed as long as the transformation produces an expression equal in value to the initial expression. The procedure entails the use of pseudo-operations such as ‘listing’, ‘pairing’ and ‘cancelling’. The effect of the procedure is to reduce the problem of division of exponential expressions to counting. Mathematical expressions such as $7^3$ and $7.7.7$ are treated as strings of symbols or characters that can be manipulated rather than in terms of the relations between the fundamental mathematical objects to which they refer. In other words, mathematical expressions are treated as images, or iconically.

The solution to the problem represents a spatial frame in which characters are distributed according to a particular arrangement. Johnson & Davis (2010) refer to the production and spatial arrangement of characters as a character distribution matrix:

We call such a type of regulatory text a character distribution matrix and define it as a resource for the regulation of the mathematical activity demanding the use of very particular spatial distributions of symbols in the organisation and presentation of transformations from one mathematical expression to another as a solution is generated according to a procedure. The presentation of mathematics is, of course, always subject to conventions for the display and regulation of mathematical expressions. That is, however, not the same as attempting to regulate mathematical activity by prioritising very specific spatial distributions of mathematical symbols and terms, perhaps hoping that the intended mathematics might be reproduced despite the presence of the learner. (Johnson & Davis, 2010: 135)

The notion of a character distribution matrix resonates with the use of a “changing sides changing signs” rule noted by Lima & Tall (2008) in their study of “symbol-shifting procedural embodiment”, but differs from symbol-shifting in that the data generated to populate the character distribution matrix are not described in terms of embodied actions but in terms of objects and operations.

The pedagogic text examined here, involving a procedure for the solution of the worked example, does not make available the general features of the object ($Q, x$). The pedagogic text appears to be one that is structured to elicit a very particular response from learners. The focus on the reproduction of a
particular procedural outcome without access to the fundamental properties of the object \((Q,x)\) seems to produce a context-dependent procedure that functions as a character distribution matrix for learners. The topic, division of exponential expressions, is essentially constituted as counting and remains closed with respect to the fundamental properties of the object. The pedagogic text is strongly redolent of Eco’s description of closed texts which, as we saw, are open to all sorts of “aberrant decodings”.

We now examine the example attempted by the learners of this teacher’s class.

**Learner productions**

After explaining the worked example \(7^3 \div 7^2\) to her class, the teacher asked her learners to do the problem \(8^5 \div 8^7\) on the board. The problem was attempted by three different learners and corrected by the teacher before the solution privileged by the teacher was produced. The first learner’s attempt is shown in Figure 3.

![Figure 3. Learner 1’s attempt at a solution to the problem \(8^5 \div 8^7\)](image)

The learner generated the solution to the problem by attempting to use the teacher’s worked example as a template. He started by writing three 8s rather than five. It is interesting that the teacher’s worked example had three 7s in the numerator. In fact for the third 8 he started forming the number 7 before he corrected his error. He then drew lines through the first two 8s imitating the ‘cancelling’ used in the teacher’s solution even though he had not yet transformed the denominator, \(8^7\). The teacher intervened when she realised that the learner was struggling to produce the solution:

Teacher:  Haai man! {Hey man!} Eight to the power five divide by eight to the power 7. [Pointing at the problem on the board.]
Learner:  [Silent]
Teacher:  Thethani! {Speak!}. How many eights? How many eights?
Learner:  [Silent]
Class:  [Chorus] Five.

The learner wrote two additional 8s producing 8.8.8.8.8. Although the learner’s written transformation of \(8^5\) was correct, it appeared that the fundamental mathematical object, the division of exponential expression, was absent from his criteria for solving the problem. The learner’s solution resembled the form of the teacher’s solution, suggesting that the teacher’s solution served as an iconic resource regulating the production of mathematics. The learner continued by drawing lines through the 8s in the numerator. The teacher intervened for a second time:

Teacher:  Uli-cancelisha nabani eli inani? {With what number are you cancelling this one?}. When you are cancelling you must cancel your denominator with your numerator. There is no way that you can cancel only one number.

‘Cancelling’ for this learner appeared to be part of the solution procedure but was not associated with division. The learner’s procedure suggests that the mathematical expression constituted a string of characters rather than an exponential expression.

A second learner continued the solution to the problem (see Figure 4). The learner correctly produced the transformation from \(8^7\) to 8.8.8.8.8.8.8 and ‘cancelled’ five 8s of the numerator with five 8s in the
denominator. He was, however, unable to produce the final answer; i.e., to effect a transformation from $8^5 \div 8^7$ to $\frac{1}{8.8}$ and then another to $\frac{1}{8^2}$.

Figure 4. Learner 2’s attempt at a solution to the problem $8^5 \div 8^7$

That he is unable to complete the problem suggests that he does not recognise that division is a central operation in the problem. The learner’s criteria appear to resonate with the criteria generated by the teacher who referred to “cancelling” without reference to the operation division. This learner, as well as the one described above, appeared to use the teacher’s solution as a character distribution matrix, where the solution procedure involved producing symbols to populate a template.

A third learner completed the solution to the problem (see Figure 5). She produced the ‘answer’ $\frac{2}{8}$ to the problem $8^5 \div 8^7$ and converted that ‘answer’ to $8^{2}$.

Figure 5. Learner 3’s attempt at a solution to the problem $8^5 \div 8^7$

Although it is not clear how this transformation was produced it seems likely that $8^{2}$ is a direct transformation of $8^5 \div 8^7$ using the rule, “subtract the exponents when dividing exponential expressions” provided by the teacher at the beginning of the lesson rather than a transformation of $\frac{2}{8}$.

Again, the notion of division and exponential expression is absent from the learner’s criteria for the production of the solution. The teacher asked the class to identify what was wrong with the learner’s solution, to which a learner responded:

Learner: This statement is wrong because this two over eight must not be here [Pointing at the first line of the solution $/8^5 \div 8^7/$.] It must be here. [Pointing at the second line of the solution $/8.8.8.8/8.8.8.8.8/$.]

The learner’s emphasis on the location of $\frac{2}{8}$ in the solution suggests that he did not recognise that $\frac{2}{8}$ was an incorrect transformation of $\frac{8.8.8.8}{8.8.8.8.8.8}$. The teacher eventually corrected the solution to the problem by explaining that the expected answer was $\frac{1}{8^2}$. 

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In summary, it is not clear whether any of the learners in the class possessed reliable criteria to produce the required solution. Even in cases where they were able to produce parts of the solution that looked correct, it is unclear whether knowledge of the mathematical notions of division and exponential expressions regulated the students’ solutions. An examination of the learners’ productions reveals criteria that are comparable to the criteria generated by the teacher’s procedure. Furthermore the operational activity of the learners mirrors the operational activity suggested by the teacher’s procedure. The operations used by the learners, such as ‘listing’, ‘pairing’ and ‘cancelling’, are pseudo-mathematical. The domain of objects operated over is, to a large extent, character strings rather than rational numbers. Thus, the operational activity of the learners reveals an absence of use of the definition of an exponential expression and of the operatory properties of the object \((Q, x)\). The productions of the learners can be read as “aberrant decodings” of the pedagogic text, the latter being closed with respect to the topic of division of exponential expressions. In other words, the learners’ productions illustrate that the pedagogic text does not provide access to the combinatorial resources required for the flexible production of solution procedures. Learners resort to using the teacher’s solution as a character distribution matrix, thus emphasising the context-dependent nature of the teacher’s procedure.

**Pedagogic texts and the model learner**

For Eco (1979), texts always constitute a model of a possible reader, the Model Reader, in the act of generating the text. The model reader is assumed to be capable of interpreting the text comparable to the author’s construction of the text. An open text assumes the competence of its model reader while simultaneously constructing the model reader’s competence.

> “An ‘open’ text cannot be described as a communicative strategy if the role of its addressee (the reader, in the case of verbal texts) has not been envisaged at the moment of its generation qua texts. (Eco, 1979: 3; italics in original)

In addition to assuming and constructing the competence of its model reader, an open text, as discussed earlier, constructs a ‘closed’ project by making available combinatorial resources that enable a convergence of interpretations. Closed texts, on the other hand, are structured to steer its readers along a set path through the text.

They seem to be structured according to an inflexible project. Unfortunately, the only one not to have been ‘inflexibly’ planned is the reader. These texts are potentially speaking to everyone. (Eco, 1979: 3)

So by attempting to fix a particular interpretation closed texts have the effect of producing divergent interpretations unanticipated by its author.

As discussed before, the texts Eco is concerned with differ from pedagogic texts. However, the notion of a model reader is comparable to the model learner presupposed by pedagogic texts. The model learner constitutes an analytic category that describes the competence of the notional learner implied by the operational features of a pedagogic text.

At the level of intention, pedagogic texts might be considered open because they are structured by assumptions about the competence of their model learners, since a teacher always has to decide on the extent of the prior knowledge of the learner. Secondly, pedagogic texts might be considered open because such texts set up “closed projects” for their model learners. In other words, pedagogic texts are intended to produce convergence with respect to interpretation of content. However, at the level of the actual operational activity that emerges, as discussed above, a pedagogic text may be constructed as either open or closed with respect to the particular topic referenced by the pedagogic text.

In the example discussed above, the model learner, presupposed by the teacher’s pedagogic text, does not need the notion of exponents or division to solve the problem. The iconic features of the exponential expressions rather than the notions of exponents or division regulate the production of the procedure. The model learner implied by the teacher’s “long method” might be described as a learner who is merely required to count in a particular way in the context set by computations with exponential expressions. The topic, division of exponential expressions, constituted essentially as
counting, therefore remains closed to the model learner. In contrast, we might imagine a pedagogic text constructed as an open text with respect to the topic that makes available descriptions of the fundamental properties of the primary objects indexed by the topic for use in performing computations.

**Conclusion**

This paper set out to develop Eco’s notions of open and closed texts as analytic resources for describing mathematics constituted through pedagogy and mathematics constituted by learners’ productions of mathematics. The analysis of pedagogy in terms of open and closed texts extends the discussion of the structuring relationship between pedagogy and learners’ productions by examining the operational activity of teachers and learners. Furthermore, the analysis highlights the potential for the analytic resources to describe mathematics constituted by pedagogic texts as well as the competence of the model learner implied by the pedagogic texts.

Further research is required to determine how productive the analytic resources of open and closed texts together with the concept of the model learner is for understanding learners’ mathematics performances in pedagogic situations that differ in terms of the social class membership of learners.

**References**


In this paper, we present episodes of mathematics teaching from a Grade 11 lesson on data handling, which suggested the need for an in-depth focus on the nature of teacher handling of objects and operations. Our analysis suggested that the notion of a lack of sense of ‘domain order/structure’ provided a way of understanding the breakdowns that occurred within this lesson. As such, our work extends the categorisations of breakdowns suggested in prior writing in mathematics education which have pointed to ‘domain shift’ and lack of ‘domain recognition’ as categories for thinking about problematic teaching episodes.
Introduction

An extensive body of evidence in South Africa points to gaps in the content knowledge and pedagogic content knowledge of significant numbers of mathematics teachers (Carnoy, et al., 2008; Taylor, 2010). This evidence has often been based on larger scale research, driven by the ongoing presence of poor mathematics results for the majority of South African schoolchildren, and has pointed at the overview level to the need for systemic measures to improve teachers’ mathematical knowledge.

More recent, in-depth case studies have started to focus on examining what teachers’ classroom practices can tell us about the ways in which teachers understand the mathematical objects that they constitute in classrooms through examining the operations and operational sequences they devise to act on these objects. The work of Davis (2010) and his colleagues (Basbozkurt, 2010; Jaffer, 2009) provides evidence of a phenomenon that they term as ‘domain shift’ – operational sequences on objects (e.g. ‘addition’ on ‘integers’ in a sum such as -7 + 5) that ‘shift’ the object to different domains (the counting numbers in Davis’ example). Venkat (2010) provides an example of what she terms as ‘lack of domain recognition’ from looking at teacher marking of primary mathematics learners’ workbooks in which a series of number patterns based examples are completed by learners as though they are simply ‘sums’ to be completed with no attention to the ‘pattern’ aspect – and which are marked as correct by the teacher. In both instances, the operations enacted on the object in focus suggest a lack of connection between the operation carried out and the object the operation acts upon. In this paper, we use data from a Grade 11 lesson on data handling that provide further examples of breakdowns between operations and objects, and propose a further category - ‘lack of domain order/structure’ - with which to think about these breakdowns.

Davis (2010) makes the point that a procedural orientation dominates within the breakdowns they have seen across their current and previous work in classrooms, a sentiment echoed in other empirical research with mathematics teachers in South Africa (e.g. Jita & Vandeyer, 2006). In order to understand the underpinnings of procedural knowledge in mathematics, we went back to Hiebert & Lefevre’s (1986) seminal and extended discussion of the nature of procedural knowledge. Hiebert & Lefevre’s descriptions of procedural knowledge provided us with an analytical framework that we could use to compare the operational sequences that formed the basis of the procedural orientation within our data with the ways in which procedural knowledge is conceived in the mathematical terrain.

Our discussions are presented in the following order. We begin by presenting background on the findings from the literature on the nature of mathematics teacher working with objects and operations in mathematics in South Africa. This sets the scene for the research problems that guided our investigations, namely:

*How does the teacher sequence her presentation of mathematical objects within this lesson? What breakdowns between objects and operations occur within this sequencing?*

*What can these breakdowns between objects and operations tell us about the nature of this teacher’s sense of the mathematical objects she is working with, and the domain they are located within?*
We then go on to outline Hiebert & Lefevre’s theory distinguishing between conceptual and procedural knowledge in mathematics. The authors’ descriptions of procedural knowledge in particular, were analytically salient in understanding the ways in which the operational order in our teacher’s working was similar to, and different from, the descriptions of the nature of procedural knowledge presented in their writing. The data sources and methodology that we used to identify the objects constructed by the teacher across our focal lesson are then detailed, prior to our presentation of key findings, analysis and conclusions.

**Background evidence on mathematics teachers’ working in relation to objects and operations**

Research has pointed to a bias towards procedural approaches to mathematics teaching in South Africa (Chisholm, 2005) and beyond (Kaiser, 2002; Stigler & Hiebert, 1999). This bias has been extensively critiqued on the grounds that it tends to emphasise ‘rules without understanding the reasons’ (Skemp, 1978, p. 32). Implicit in this orientation is a foregrounding of algorithmic operations and a backgrounding of the objects (or at least the meanings of the objects) that they act on. Emerging evidence, introduced above, points to complexities in the South African data on procedural dominance that suggest more than a simple backgrounding of objects/ foregrounding of operations. Jaffer (2009), Davis (2010) and Basbozkourt (2010) provide examples of teachers explaining the operational sequences needed to solve problems across a range of topics, all of which involve ‘shifts’ in the domains of the objects being operated upon or produced. Summarising the data he presents on examples of ‘domain shift’ in data from a teacher working on integer sums, Davis (2010) makes the following comment:

> The regulative criteria required by the procedure indicate that the teacher and learners do not operate directly on the mathematical objects and relations being indexed (integer sums). They operate, instead on more familiar and intuitive objects and relations (‘whole number’ sums).’ (p385)

Venkat (2010), examining a sample of learner workbooks from Eastern Cape primary schools encountered examples of teachers’ marking on tasks such as the following:

\[
\begin{align*}
0 + 1 + 2 &= 3 \\
1 + 2 + 3 &= 6 \\
2 + 3 + 4 &= 9 \\
3 + _ + _ &= 12 \\
4 + _ + _ &= 12 \\
_ + _ + _ &= 12 \\
_ + _ + _ &= 12 \\
_ + _ + _ &= 12 \\
\end{align*}
\]

Learners had completed this task as shown below and in other similar ‘calculation’ oriented ways:

\[
\begin{align*}
3 + 3 + 6 &= 12 \\
4 + 4 + 8 &= 16 \\
1 + 1 + 1 &= 3 \\
2 + 2 + 2 &= 6 \\
4 + 4 + 1 &= 9 \\
\end{align*}
\]
Problematically, the teacher had marked these insertions as correct. Whilst here as well, there was evidence of the ‘domain shift’ (from number patterns to calculations) identified previously, what the teacher’s marking in this instance indicated was that a lack of domain recognition underpinned the shift of operations to the ‘calculation’ domain. Remaining at the primary level, Ensor et al (2009) provide examples of teachers maintaining the use of concrete operation into examples where formal calculations would be more appropriate. In parallel, Schollar (2008) provides several examples of learners’ work suggesting that shifts from ‘counting’-based strategies to ‘calculation’-based strategies have simply not materialized for large numbers of learners.

In this paper, we present our analysis of examples of breakdowns drawn from a Grade 11 lesson on displaying data. This analysis suggested that there was a need to extend the categories of ‘domain shift’ and ‘lack of domain recognition’ in order to take in the nature of the breakdown relation between objects and operations that we were seeing in our data.

**Analytical framework: Hiebert & Lefevre’s theory of conceptual and procedural knowledge**

Attention has been paid over an extended period of time to the distinction between conceptual and procedural knowledge in mathematics (Resnick & Ford, 1981). Whilst more recent writing has broadened the range of strands seen as important to successful mathematical learning (Kilpatrick, Swafford, & Findell, 2001), the ongoing evidence noted above of procedural orientations to mathematics teaching in SA suggests that the division of mathematical knowledge into conceptual and procedural elements retains salience. A seminal text in this area, which retains currency due to its depth and detail in considering the links between conceptual and procedural knowledge is Hiebert & Lefevre’s (1986) chapter considering this terrain. Hiebert & Lefevre (ibid) describe conceptual knowledge in the following terms:

> Conceptual knowledge is characterised most clearly as knowledge that is rich in relationships. It can be thought of as a connected web of knowledge, a network in which the linking relationships are as prominent as the discrete pieces of information. Relationships pervade the individual facts and propositions so that all pieces of information are linked to some network. In fact, a unit of conceptual knowledge cannot be an isolated piece of information; by definition it is a part of conceptual knowledge only if the holder recognizes its relationship to other pieces of information. (p3-4)

In contrast, procedural knowledge is described in the following terms:

> Procedural knowledge […] is made up of two distinct parts. One part is composed of the formal language, or symbol representation system of mathematics. The other part consists of the algorithms, or rules, for completing mathematical tasks. (p6)

The idea of ‘order’ or ‘sequence’ is viewed as a central feature of the algorithmic component of procedural knowledge:

> The second part of procedural knowledge consists of rules, algorithms or procedures used to solve mathematical tasks. They are step-by-step instructions that prescribe how to complete tasks. A key feature of procedures is that they are executed in a predetermined linear sequence. It is the clearly sequential nature of procedures that probably sets them most apart from other forms of knowledge. (p6)

Hiebert & Lefevre further distinguish between procedures based on the types of mathematical objects that they operate on – standard symbolic objects (numbers/expressions) which relate to procedures described as ‘essentially syntactic manoeuvres on symbols’ (p7); and concrete objects/visual diagrams/mental images or other objects that are not standard mathematical symbols which relate to problem-solving strategies. The objects presented in this paper by the teacher within her data handling lesson tended to fall into this latter category of operations on a range of visual diagrams – and thus lent themselves to problem-solving oriented strategies.
These descriptions provided some initial handles – in relation to procedural and conceptual knowledge that could be examined via a focus on the sequence of objects derived within the lesson that was observed.

The methodology that was used to identify what the teacher presented as her sequence of mathematical objects across the lesson is delineated in the next section detailing the data sources and methodological tools used.

**Data sources and analytical tools**

The data presented in this paper are drawn from the wider doctoral study of the second author focused on examining the implementation of the new Further Education and Training (FET) mathematics curriculum across a range of Johannesburg schools. The focal lesson occurred in a disadvantaged school and involved a teacher with nine years experience of teaching mathematics at secondary level. All lessons within this study were videotaped with additional field notes taken. In this case, a verbatim transcription of the talk and a record of the teacher’s accompanying board work in the classroom were produced to support the analysis. Anonymity and confidentiality of the school, the teacher and learners have been maintained within our reporting in this paper.

The focal lesson dealt with the topic of displaying and interpreting information in bar charts. The problem that the teacher focused on was located in the context of understanding and displaying the information presented in Table 1 below – which the teacher wrote on the board following a preamble discussion on displaying and organising data and incorporating the idea that information such as this would have been collected through a survey. This table therefore represented the ‘object’ that launched subsequent work within this lesson.

**Table 1.** Data about number of children in different families

<table>
<thead>
<tr>
<th>Number of children in the family</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
</tr>
</tbody>
</table>

Given our interest in the presentation and sequencing of mathematical ideas, and the ways in which teachers worked with operations and objects, we borrowed an analytical tool (‘evaluative events’) devised by Adler & Davis (2006) to focus on the ways in which teachers constituted and sequenced mathematical objects within lessons. Drawing from Bernsteinian theory on pedagogic discourse, Adler & Davis (ibid) proposed the use of ‘evaluative events’ as units of analysis that focused on the ways in which teachers constituted a range of mathematical objects as the focus of pedagogy and therefore, of learning, within lessons. An evaluative event is defined as a teaching-learning sequence that can be recognised as focused on the acquisition/constitution of particular mathematical content or objects (Adler, 2009). In technical terms, this methodology breaks teacher-led working in mathematics classrooms into sections based on what teacher actions and talk tell us about the object they are leading towards. In analytical terms, Adler (2009) has noted that this tool allows for a focus on
mathematical ideas as enacted in classrooms. Whilst Adler (ibid) has used the notion of evaluative events to understand the nature of the resources that teachers draw upon within their constitution of mathematical objects, we use this unit of analysis to think about the entailments of particular sequencing of objects for the nature of teacher understandings of both the operations and objects they are working with.

Before detailing the ways in which we used the evaluative events tool, we point out that ‘objects’ as viewed within the mathematical objects focused on within evaluative events are different from ‘objects’ as viewed within the ‘objects/operations frame’. Within evaluative events, objects are the particular mathematical goals that the teacher appears to be driving towards in specific lesson segments. They are therefore ‘prospective’, and unfolded into being within an evaluative event. A teacher could focus on a mathematical concept or a procedure as the ‘object’ in an evaluative event. In contrast, within the objects/operations frame, objects are simply the entities that operations act upon, producing a transformed object as the outcome. This distinction needs to be borne in mind within the reading of the sections that follow.

We divided our lesson transcripts into distinct ‘evaluative event’ units. In some instances evaluative events were comprised by single sections; in others, they consisted of two or three sections, due to the teacher interjecting the flow with a different mathematical object, but then returning to an earlier object subsequently. Excerpts of talk in which the focus was not on mathematics per se were not classified within the evaluative event scheme.

Below, we provide an excerpt from the transcript of the focal Grade 11 lesson, noting alongside the ways in which this section was broken down into two distinct evaluative events.

<table>
<thead>
<tr>
<th>Teacher/Learner</th>
<th>Utterances</th>
<th>Evaluative event no</th>
<th>Object</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>Now to display data how can you display data?</td>
<td>EE2</td>
<td>How can data be displayed</td>
</tr>
<tr>
<td>L</td>
<td>In a graph</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>In a form of a graph and then, any other way you can display?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>Poster</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>Tally table</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>Tally table, and then, I heard someone saying something else</td>
<td>EE3</td>
<td>Are ‘displaying’ and ‘organising’ data the same</td>
</tr>
<tr>
<td>L</td>
<td>Poster</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>Pie chart</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>Pie chart</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>Ok now we are talking about displaying and organising. How do you organise data? Or is displaying and organising data – do they mean the same thing?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>Two different words, so what is to organise?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>To put in order</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Throughout the lesson transcripts the shift from one event to the next was marked by a change in the object focused on by the teacher, and we were able to identify such shifts through teacher utterances such as ‘Ok before we move on somebody talked about a tally. Does anyone know how to tally the number 8?’

Below, we present an overview of the lesson in terms of the sequence of mathematical objects that the teacher focused on within the lesson. This provided us with a sense of the range and sequence of presentation of mathematical ideas within which the breakdowns that we saw were nested. We follow this overview with an analysis that hones in on the detail of three events presented within the lesson. Each event was selected because it represented an episode
with some kind of breakdown, which helped us to understand better and to expand the range of the domain-related phenomena that we saw in prior writing. Importantly, our analysis of the lesson overview allowed us to confirm that these breakdowns were not tempered or ameliorated in any way by discussions in other evaluative events. Following a presentation of excerpts associated with each of these three evaluative events, we analyse the link between the operation and the object it is focused upon, and conclude from this analysis on what these links can tell us about the nature of this teacher’s conceptual/procedural knowledge related to the topic in focus.

**Findings – an overview of the sequence of mathematical objects presented**

In this section we provide an overview of the sequence of objects that the teacher appeared to focus on across the lesson. Our analysis indicated a sequence of fourteen objects identified through the methodology defined within the evaluative events frame. In most instances, objects occurred as single episodes, but in some cases, a particular object was returned to following a shift into a different intermediate focus. The sequence of objects across this lesson is detailed below in summary format, with the ‘events’ that we are focusing on for analysis highlighted:

<table>
<thead>
<tr>
<th>Event Description</th>
<th>Event Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is data? (teacher states that it is ‘information but in a numerical form’)</td>
<td>EE1</td>
</tr>
<tr>
<td>How can data be displayed?</td>
<td>EE2</td>
</tr>
<tr>
<td>Are 'displaying' and 'organising' data the same?</td>
<td>EE3</td>
</tr>
<tr>
<td>What is organizing data? (&quot;put it in order&quot;)</td>
<td>EE4</td>
</tr>
<tr>
<td>That organizing and displaying data depends on the type of data and the type of graph.</td>
<td>EE5</td>
</tr>
<tr>
<td>Collecting data to seek information on an issue or problem which then needs interpretation</td>
<td>EE6</td>
</tr>
<tr>
<td>Interpreting the context of data (based on the data in Table 1)</td>
<td>EE7</td>
</tr>
<tr>
<td>Explaining frequency and its meaning in relation to information in Table 1.</td>
<td>EE8</td>
</tr>
<tr>
<td>How to tally</td>
<td>EE9</td>
</tr>
<tr>
<td>Return to 'interpreting the context of data'</td>
<td>EE10</td>
</tr>
<tr>
<td>Calculating the total no of households</td>
<td>EE10</td>
</tr>
<tr>
<td>Return to 'how can THIS data be displayed’ – note that this links to EE2, but now refers to specific data, rather than general focus on data display</td>
<td>EE11</td>
</tr>
<tr>
<td>Drawing a bar chart to represent the given data.</td>
<td>EE12</td>
</tr>
<tr>
<td>Unclear object, - ‘reading’/ ‘interpreting’ graphs – is possible, but the emergent instructions suggest that ‘labelling axes’ is the object</td>
<td>EE13</td>
</tr>
<tr>
<td>Comparing bar charts based on categorical data</td>
<td>EE14</td>
</tr>
<tr>
<td>Return to ‘drawing a bar chart for the given data’</td>
<td>EE12</td>
</tr>
</tbody>
</table>

In the sequence of events presented above, EE12 - ‘drawing a bar chart to represent the given data’ – occupied the longest time slot across the two episodes. Given that it represented one of the focal breakdown episodes presented in this paper, it underscores evidence in the South African literature of problems relating to the use of time within mathematics classrooms (Ensor et al, 2009; Reeves & Muller, 2005). However, it is also important to note that this overview highlights that we did not see such breakdowns across all or even most of the events in the lesson. Across the majority of events, relations between objects and operations in the domain, and the sequencing of these events, were largely coherent although sometimes partial in their coverage – as in the definition of ‘data’ in EE1.

**Analysis**

The overview pointed us to potential problems at a broad level. For example, the initial object involving a table with frequencies was followed up with a focus on tallies. However, this overview level in itself does not provide conclusive evidence of an underlying problem – as teacher explanations may well have worked to point out an appropriate connection between
operations and objects, regardless of the order in which the objects were presented temporally in the lesson. We found it useful therefore, to look in more detail at the nature of the teacher’s questions and explanations at these key junctures. Detail from the transcript focused on ‘breakdown’ events is presented and discussed below.

**Evaluative Event 9 (EE9): Mathematical object – how to tally**

EE9 begins at a point in the lesson where the teacher has introduced and discussed the frequency table (see Table 1) on the board – its production via a survey, its context in terms of possible location in either urban or rural settings and explained the meaning of the word ‘frequency’. At this point, recalling that a student has earlier mentioned the term ‘tally table’ when asked about ways to ‘display data’, she asks the following question:

‘OK before we move on, somebody talked about tally ok. Does anyone know how to tally the number 8? […] Do you know or you want to try?’

Having asked the question, she then adds a further column to her frequency table and entitles it with the word ‘tallies’. She then shows the class how to tally the number ‘8’ – this being the first frequency value in her table. Then, pausing to ask the class if they have seen this (pointing to her tally) before, she explains further and demonstrates:

‘Ok so its one, its two, its three, its four and what happens to number five.[Indicates the diagonal line] And then it’s one, it’s two and it’s three Ok. Your tally and your frequencies must be of the same number.’

Her board work at this point reflected the production of the elaborated table shown in Figure 1:

**Figure 1.** Tallies column added on to the end of the original table

Several features of this event are interesting from the perspective of the procedural/conceptual knowledge dichotomy. Firstly, the tally is clearly presented with a strongly procedural orientation – an emphasis on ‘how’ to present it with a focus on its conventional form. There is also stress on the fact that the frequency and tally values should coincide. Skemp (1978, 1989) distinguishes between instrumental/procedural and relational approaches to mathematics teaching in the following ways: By instrumental knowledge, he refers to the rote performance of a procedure (knowing how to use it, but not necessarily knowing why). He defines ‘instrumental knowledge’ as the ability to use the ‘rules without understanding the
reasons’ (Skemp, 1978, p. 32). Instrumental understanding can be applied to very specific situations, and can be acquired through what Skemp referred to as “habit learning”.

We pointed out in our earlier discussion that ‘order of working’ was seen as a central pillar of procedural knowledge within Hiebert & Lefevre’s discussion. Within procedural working, the ‘step-by-step’ orientation is related in mathematics to the objects that operations act on. In this instance, the teacher’s actions suggest that frequencies are appropriate objects for the operation of tallying to act upon. This contrasts with the mathematical objects usually associated with tallying – raw data, which when acted upon by the operation of tallying produce frequencies as an outcome object.

In this instance, it would appear that the teacher does recognize the domain associated with frequency tables and the fact that this domain contains a range of objects: – she mentions ‘surveys’, ‘frequency’, ‘display data’ and ‘tally tables’. However, the notion that these objects might be ordered and connected in particular ways through the selection and use of operations is largely absent in the teacher’s constitution and sequencing of operations on objects related to frequency tables.

**EE12: Mathematical object - Drawing a bar chart to represent the given data**

In this event, the teacher began by asking the class how the data in the table could be displayed, and received ‘bar graph’ as a response from several pupils. The teacher then drew two axes on the board, elicited the words ‘x- and y-axes’ from the class and connected these to the words ‘horizontal’ and ‘vertical’ respectively. After explaining that the two axes needed to be linked to numbers of children and frequencies, she drew rough examples of bars on the side of the board and then added a ‘0’ at the origin. She also added in 1, 2, 3, etc on her horizontal axis and the numbers 5, 10, 15 and 20 on the vertical axis. The class was reminded that they must use scales when drawing a graph, and then, the following question was posed:

‘Now how are you going to display your 0 and 8?’ [referring to the first row of data in Table 1]

A pupil was asked to come up and draw in the first bar – which he drew as a vertical bar, approximately a quarter of a unit wide and starting at the 0, and 8 high. Observing this bar, the teacher initiated the following line of questioning:

T: Is he correct?
L1: Somehow
L2: Almost
L3: Maybe
L4: That bar shows a $\frac{1}{4}$ and 8 ma’am

T: It’s a quarter and 8. Ok so the 0 was supposed to be where? Here?

The teacher at this point adds another ‘0’ on the x-axis at the point where the right side bar edge meets the horizontal axis. The pupil’s bar therefore sits at this stage between two ‘0’s. She then asked whether the learner would have been correct if the 0 was in this second position. With no conclusive answer here, the teacher moves on to asking another learner to add in the bar for 1 and 14 (second row of data in Table 1). A learner adds a second bar, adjacent to the first and going across to the ‘1’ on the x-axis. Another learner is then invited to draw the third bar (to represent a frequency of 20 for families with 2 children. This bar is drawn, non-adjacent now to the second bar, but going across to the ‘2’ on the x-axis and 20 high. At this stage the screenshot below shows the bar graph’s appearance on the board (Figure 2):

**Figure 2.** Bar graph at this point
With some learners raising questions about the bar chart as it stands at this point, the teacher says the following:

‘Ok fine, alright fine, our example ok, I chose it because I wanted you to see something. If you have 0 [...] as a number included [...], don’t [...], this is the point of origin by the way, ok so don’t make 0 your point of origin. There are numbers before what, before 0 ok, so think this as a Cartesian Plane whereby the number before 0 will be what, a -1.’ ([…] represent pauses in teacher’s utterances)

Once again here, several issues of interest have arisen. The operation introduced in this case relates to the drawing and scaling of axes, acting on the initial frequency table object and aiming to produce a bar graph as the outcome transformed object. The operation of adding scales to the axes is produced in relation to an object where data is continuous rather than discrete and categorical which - as the extract shows - then causes problems for the drawing in of the bars. Further, the plane produced by the two axes that are drawn is related to the continuous Cartesian plane – a problematic link between objects from different domains (algebra/ analytic geometry and data display) that share some overt similarities in operational skills (scaling and locating positions on a plane) but are distinguished by important differences. The notion of ‘-1’ lying to the left of the plane shown in the screenshot is problematic here in relation to the meanings that underlie the object where x-axis values relate to the ‘number of children’. Here, essentially, the slippage between the operation and the object it acts upon suggests a fragile understanding of the differences between mathematical objects that share overt similarities, and of the differing constraints that these pose for operations acting upon the different objects.

**EE14: Mathematical object – Comparing bar charts based on categorical data**

At the start of this evaluative event, a completed version of the bar graph for the information in Table 1 has been produced, with all bars indicating continuous rather than discrete data – see Figure 3:

**Figure 3.** Completed bar graph (Note removal of 0 at origin and equal width bars here but ongoing continuous, rather than discrete data representation)
Having added labels following a pupil’s request that this be done, the teacher asks the class to compare their graph with an example of a bar graph that is up on the classroom wall (Figure 4):

**Figure 4.** Bar graph up on the classroom wall

In the responses, the following aspects are brought up by the learners:

The spaces’ ‘It’s decorated’ ‘It’s neatly displayed’

Summarising pupils’ responses the teacher comments as follows:

‘It was well organised, well displayed ok, as compared to our graph. Ours can be confusing ok, but it does not make it, what, wrong. So now you remember like what [first learner] has done, that is wrong. […] Remember you are drawing this to scale and if you talk of 0 and 8 the bar must be between -1 and 0.’

In this event, the activity again opens up potential for useful mathematical insights. The graph that learners have been asked to make comparisons with also represents discrete data – year labels. The pupil offering of the word ‘spaces’ can allow from an everyday or a mathematical standpoint for some re-consideration of the meanings underlying the class’s bar graph and the data it purports to represent, but the interaction is not taken up in this way. Further, the teacher operational response is to suggest that if 0 is one of the labels in the data set, then a ‘-1’ should be either imagined or inserted at the origin (she does not write -1 in). Through this operational suggestion, she entrenches the idea that the outcome object of the bar chart is working with continuous data and leaves in place the link made earlier with the Cartesian grid representation.

**Discussion**

Across the three episodes presented in this paper, there are incidents that represent breakdowns between the operations suggested and the objects that they act upon. In the first
episode, we analysed the object selected for the operation of tallying to act upon – frequency values – and noted the ways in which this is produced an ‘inversion’ of the mathematical purpose of tallying, in which frequency values are produced as an outcome object of the operation. This reversal of ‘order’ presents ‘tallying’ as an operation that figures within the domain of displaying data, as one where the importance of ‘match’ between tally and frequency is stressed, but not as an operation which solves any ‘problem’ or serves any purpose in relation to the object. The directionality that is an inherent part of mathematical problem solving is absent. Tallying appears simply as one of the many operations and objects that figure within the domain of displaying data. The domain appears to consist of a ‘collection’ of such objects and operations, but not as an ‘ordered’ or connected set of objects and operations. A metaphor that helps us to think about this phenomenon is of a box labelled ‘displaying data’ filled with a jumble of clothes which can be taken out and put on in any order, with no sense of some items needing to be worn underneath other items. The notion of ‘order’ or ‘sequence’ that Hiebert & Lefevre describe as central to procedural knowledge is strikingly absent: the ‘domain order’ is disrupted.

The second and third episodes present somewhat different examples of breakdowns between operations and objects. In the second and third episodes, we analysed the ways in which the operations of inserting scales onto the axes and the drawing of bars ‘violated’ the meanings underlying the frequency table as the object upon which this operation acts. This example sheds light on Hiebert & Lefevre’s delineation of procedural approaches linked to non-symbolic objects where ‘problem-solving’ operations are required. In this case, the object ‘constrains’ or ‘structures’ the operations that can legitimately be brought to bear upon it. The teacher’s subsequent explanations suggest that her notion of the operation of inserting scales on the bar graph is borrowed from the domain of algebraic graphs, where overtly similar grids figure. In this sense, these episodes represent to a partial degree the ‘lack of domain recognition’ that was seen in Venkat’s (2010) paper. However in that instance, the teacher’s actions indicated an overall misrecognition of the fact that the task was intended to work within the number patterns domain. The teacher in the data presented in this paper does appear strongly aware of the domain of data display that the initial object is located within. Her subsequent operational actions suggest a misunderstanding of the ways in which this domain and the specific objects within it ‘structure’ the range of operational possibilities: ‘domain structure’ is disrupted.

Conclusions

In summary, the empirical data presented in this paper suggests that the categories of ‘domain shift’ and ‘lack of domain recognition’ might be expanded to include a new category: ‘lack of domain order/structure’. Like its predecessors, this category also involves teachers working within a predominantly procedural orientation. However, the focus on differences in the nature of relationship between objects and operations across a range of examples of mathematics teaching is starting to provide a more nuanced understanding of the ways in which teachers understand mathematical domains and the various objects and operations located within them. As we analyse the minutiae of mathematics teachers’ work with objects and operations across an expanded range of examples, we expect that these categories may well have to be further refined.

References


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Promoting critical thinking – are we asking the right questions?

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This paper reports on a study to explore if and how technology teachers provided opportunities for learners to develop critical thinking skills in the technology classrooms. Problem-solving skills, creativity and critical thinking skills are essential skills that must be developed in Technology Education. Specific methodological approaches are recommended to promote problem solving, and in the process critical and creative thinking. Critical thinking is a purposeful, self-regulatory judgement that results in interpretation, analysis, evaluation and conclusions. Pupils should be provided with opportunities to apply critical thinking in the process of identifying problems or needs, developing solutions while investigating and researching, creating solutions, evaluating processes and communicating their ideas and results. The research consisted of semi-structured interviews followed by a Likert-type questionnaire and follow-up interviews, focusing on the way teachers promoted critical thinking and their questioning techniques. Results showed that pupils were seldom encouraged to ask enquiring or critical questions and limited opportunities for critical reflection were provided. Opportunities where pupils can collaborate, and discuss ideas and problems, or get feedback from their peers and teachers were not evident. The questioning style used by teachers was seldom the “what if” or “how could we improve”, but rather closed, one-word response questions. A reason for this lack of opportunity for critical thinking may be the teachers’ own lack of knowledge, preventing them from feeling comfortable in situations where learners question and query what they are learning. These findings emphasize the need for teachers to become Technology specialists.

Theoretical framework
The subject Technology in South Africa is defined by three learning outcomes - the technological process (also known as the design process), the knowledge areas (structures, systems and control and processing) and technology and society (including indigenous technology, impact of technology and bias in technology). The learning outcomes are integrated and teachers are expected to deliver them that way, using Learning Outcome 1 (the design process) as the backbone of the subject to integrate Learning Outcomes 2 and 3.

Problem-solving skills, critical thinking and creativity are listed as essential skills that must be developed in pupils as part of technological capability (DoE, 2003; Webster, Campbell & Jane, 2006; Jones & Moreland, 2004). The design process as described by the Department of Education encourages the development of critical and creative thinking skills (DoE, 2002). Guideline documents for teachers (DoE, 2003) state that pupils should be encouraged to think creatively and critically as they design and make artefacts. Critical thinking is described as a purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based (Facione, 2009).
The teaching of technology in the South African classroom should involve the application of the design process where pupils are provided with opportunities to apply and integrate their knowledge and skills in the development of relevant practical solutions. This design process should take place with the integration of the knowledge areas described in Learning Outcome 2. The proposed integrated process approach to doing technology provides the recommended methodology for facilitating learning up to the General Education and Training Certificate level (Grade 9). Pupils must be given opportunities to develop expertise in the process of identifying problems or needs, developing solutions while investigating and researching, creating a solution to meet the problem or need, evaluating the process and the solution in terms of criteria, and communicating the course of action as it proceeded (DoE, 2003). These activities all involve critical thinking in some or other way, but it will only be encouraged when teachers follow appropriate methodologies in their classes. The teacher’s role in facilitating learning and thinking in Technology Education classrooms is crucial to creating an environment conducive to the promotion and development of thinking (Ankiewicz, Adam, De Swardt, & Gross, 2001).

Wilson and Harris, (2003: 233-236) summarised the findings of various studies in the UK in which the teaching methods of Design and Technology teachers were described. They concluded that effective teaching of Design and Technology requires a wide range of teaching methods, and that the interaction of teachers with individuals, groups and whole class activities is crucial in developing pupils’ technological capability. Thinking skills will not develop in pupils merely when they produce technological products (Ankiewics, et al., 2001) but activities that promote the solving of problems, generation of own ideas, critical questioning and decision making should form part of the learning process. Teachers need to apply questioning techniques that will promote critical thinking. The questioning style used during lessons is essential in challenging the pupils to think just that little bit further, thus encouraging higher-order thinking. Ankiewics, et al., (2001) found in their study of technology teaching that the questioning style used by the teachers did not result in higher-order thinking, but promoted closed-ended, one-word responses. It is thus essential that probing questions from both pupils and teachers should be encouraged to involve pupils in thinking and reasoning. Fatt and Joo (2001) explain that the question “what if...?” can stimulate analysis and reasoning and does not expect a one-solution type answer.

Critical and creative thinking may be promoted further by including learning opportunities where pupils need to collaborate and discuss ideas and problems, and get feedback from their peers as well as their teachers. Fox-Turnbull (2006) stated that it is very important that teachers allow children the opportunity to discuss their planning and justify their decision-making. This was supported by Ankiewics, et al (2001), who wrote that pupils should be taught to defend their choices and reflect on their activities. Feedback during and after the implementation of the design process must form a natural aspect of problem solving. Pupils need feedback in order to improve their ideas and artefacts. Methodological tools such as questioning techniques, controversy and co-operative learning to challenge pupils’ perceptions and conceptions are suggested by Ankiewics, et al (2001). According to Turner (2006), some of the most effective feedback is self-generated. Questions such as “How could we improve?” lead to innovation and continual improvement. The “how could we improve” and “what if...” type of question should be encouraged in the technology classroom to provide pupils with opportunities to engage in critical evaluation, constructive feedback and innovative improvement of technological ideas, as they solve problems.

The way in which pupils are guided through the design process should also challenge them to be creative and critical during the solving of problems. The extent of guidance provided by the teachers may influence the development of critical thinking and must be carefully considered. Ginestie (2002) cautions that guided approaches may allow students to experience success by choosing a teacher’s predetermined solution, but their learning may be inadequate compared to learning through engagement in more open-ended approaches where their ideas are developed as possible solutions to a problem. They need opportunities where they can question their own processes and thinking, constantly interrogating themselves on their performance and progress.
The methodologies applied by teachers during technology activities are determined by their knowledge and experience. Fox-Turnbull (2006) states that in order to plan a quality unit of work in technology, teachers must have a sound knowledge of relevant technological practice. Technology teachers in South Africa were provided with information regarding the content and expected outcomes for Technology in the Revised National Curriculum Statement documents (Policy Documents, Learning Programme Guidelines, Assessment Guidelines). Some teachers had access to the Department of Education documents, DoE’s website and in-service training workshops. However, limited guidance was provided on how to teach this content in a way that will promote the development of problem-solving skills, encourage critical thinking and creativity. It is irresponsible of policy makers and educationalists to expect teachers to know how to teach Technology without adequate guidance, taking into consideration that very few teachers received training for this subject (Reitsma & Mentz, 2009).

Problem Statement

The question being asked is: do technology teachers facilitate the prescribed content of Technology in a manner that promotes the development of critical thinking skills? The aim of this paper is to report on a study that determined if and how teachers provide opportunities for critical thinking, and what type of questions are asked in the technology classroom and how they do just that.

Research Design and Methodology

This study was conducted from a post-positivistic research paradigm (Hatch, 2002). A multi-method research methodology involving standard procedures of qualitative and quantitative research methods was used. A Qual-Quant-Qual approach in three phases was applied, allowing the researcher to enrich and verify the data from the interviews and questionnaires, thus satisfying the criteria for triangulation. Ethical considerations such as informed consent, anonymous participation and availability of results were applied.

Phase 1: Qualitative method

In the first phase, individual semi-structured interviews with technology teachers from different schools were conducted. These technology teachers were selected because they were experienced teachers who had been responsible for technology education since it was implemented in their schools. Interviews were conducted by the researcher in a setting chosen by the interviewee. The interviews took approximately one hour. The teachers were asked how they promoted critical thinking and creativity in their lessons. The interviews were taped, transcribed and analysed using constant comparative analysis. Themes were identified, categorised and described to provide a structured and comprehensive description of the results (Merriam, 1998). Data saturation was achieved after six interviews, when no new information or concepts were found.

Phase 2: Quantitative method

In the second phase, results from these interviews were used to structure a Likert-type questionnaire regarding technology teaching and learning practices focusing on problem solving, creativity, and critical thinking. Prior to mailing the questionnaire, a pilot study was conducted to identify any unclear instructions, to make sure that the items in the questionnaire were clear and unambiguous, and to identify potential problematic answers. The questionnaire was mailed to a random sample of 550 technology teachers (26%) from the 2085 schools in the North West Province in South Africa. Leedy and Ormrod (2005) recommend a sample size of at least 20%. One hundred questionnaires were received back, resulting in a response rate of 18%. Due to the low response rate, only descriptive analysis was conducted, by calculating the frequency distribution of each item. This sample did not include the technology teachers who participated in the first qualitative phase. Respondents had to indicate on a 0 to 5 scale to what extent they agreed with statements on teaching practices. The data were simplified by combining four of the five response categories into two nominal categories. The 0 was not taken into account during analysis. The categories were as follows: 1= not at all or sometimes; 2= mostly or always.
Phase 3: Qualitative method

In the final qualitative phase, follow-up individual semi-structured interviews were conducted with technology teachers from different schools to clarify and explain the data collected from the questionnaires. These were not the same teachers who participated in phase 1, but were selected from the returned questionnaires from phase 2. The same procedures for these interviews as with the first interviews were followed. Data saturation was achieved after four interviews.

Findings

The results of the study are presented according to the themes that emerged from the data. Comments from the interviewed teachers are presented as direct quotations, and results from the questionnaires regarding teaching and learning activities are presented in Table 1.

Critical thinking and creativity

The results from the first interviews showed that although creativity and critical thinking were sometimes encouraged, it would seem as if pupils were restricted during the design process. Pupils were given an assignment to make a product, predetermined by the teacher, to demonstrate some or other concept learned about in the theoretical part of the lesson. The teachers showed pupils examples before the time, ensuring that the pupils knew what to make.

Teacher B: I tell the pupils – it (the product) must be able to move and it must look like this and this is the function.

Teacher C: But if I show them examples, then they can visualise what I want. So I try with most of the things to show them examples, to give them ideas. So the design that they make should at least look like this end product.

Only one of the teachers did not do so, stating the pupils will just reproduce what they see, and not really bring in their own ideas or creative work.

Teacher A: I did not want to show them examples, because then they make your example. They make what they saw.

It would seem as if the teachers were careful not to expect too much of their pupils in terms of putting them in challenging situations where creativity and critical thinking can be developed.

Teacher C: Because it does not help to give a child a task that is way above his abilities.

Teacher D: With our pupils, you have to do less work, and they must really understand it before they can apply it.

Teacher B: But the pupil who is unsure about his abilities is very dependent on you and what you tell them what to do.

The results from the questionnaires (Table 1) confirm most of the findings from the first interviews regarding critical thinking and creativity.

Table 1: Questionnaire responses on statements regarding critical thinking and creativity

262
<table>
<thead>
<tr>
<th>Questionnaire statements</th>
<th>% of response per category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Missing data or not applicable</td>
</tr>
<tr>
<td>1. When we do practical work, it sometimes is just to design and make something.</td>
<td>4</td>
</tr>
<tr>
<td>2. I criticize or evaluate the pupils’ ideas in terms of implementability or sustainability.</td>
<td>5</td>
</tr>
<tr>
<td>3. I give the pupils challenging problems that they can only solve with extra effort.</td>
<td>3</td>
</tr>
<tr>
<td>4. The type of assignments that I use asks for innovative thought from the pupils.</td>
<td>3</td>
</tr>
<tr>
<td>5. Although pupils can suggest their own ideas, we end up with the final idea that I present.</td>
<td>7</td>
</tr>
<tr>
<td>6. It is necessary to show examples to the pupils before the time.</td>
<td>1</td>
</tr>
<tr>
<td>7. I show the pupils examples before the time.</td>
<td>5</td>
</tr>
<tr>
<td>8. Pupils must complete tasks according to specific examples.</td>
<td>6</td>
</tr>
<tr>
<td>9. I demonstrate before hand to pupils what and how they should make something, and then they do it themselves.</td>
<td>2</td>
</tr>
<tr>
<td>10. I allow pupils to try alternatives when they design or make something.</td>
<td>2</td>
</tr>
<tr>
<td>11. My pupils must include their own ideas in the practical work.</td>
<td>4</td>
</tr>
<tr>
<td>12. Pupils all make the same products or models.</td>
<td>7</td>
</tr>
<tr>
<td>13. I encourage pupils to ask questions.</td>
<td>0</td>
</tr>
<tr>
<td>14. The pupils do not necessarily need to motivate or explain their ideas.</td>
<td>6</td>
</tr>
<tr>
<td>15. Pupils are encouraged to make something even if they are not sure whether it is going to work.</td>
<td>6</td>
</tr>
<tr>
<td>16. I give pupils the chance to improve their projects.</td>
<td>3</td>
</tr>
<tr>
<td>17. The pupils get an opportunity to adapt or improve their ideas.</td>
<td>4</td>
</tr>
</tbody>
</table>

Less than half of the teachers (46%) allowed for pupils to simply design and make an artefact, not linking it to a specific design brief for a problem that needed to be solved. When evaluating ideas, less than half the teachers (45%) were critical in terms of feasibility or sustainability of the ideas.

It would seem that teachers do not expect pupils to be very innovative or creative when they do get the opportunity to design and make an artefact. Teachers tend to think that they need to show the pupils
examples before the time. This may inhibit creativity, because pupils tend to follow the example instead of exploring their own ideas. However, 89% of the teachers did allow pupils to try alternatives when they design or make something, and 81% expected the pupils to include their own ideas in the practical work, but it does not necessarily happen. In the end, 57% indicated that pupils all made the same products or models, showing a lack of creativity and diversity in ideas.

During the follow-up interviews, the teachers explained why they were not positive about the creativity of the pupils. According to their experience, pupils showed a lack of creativity in their work. They tend to copy the examples provided by the teachers and did not include innovative ideas.

Teacher G: Only a small percentage will think out of the box, the majority will only copy the example that you showed them.

Teacher E: They all draw the same picture, and they cannot use space (on the paper). Space does not exist, it (the drawings) is small little things, and then they always draw the same pattern. It is very difficult to get them to try something new.

Teacher F: I never get creative things from the pupils. Look, for the practical thing that they make, I allowed them to design their own thing, but they only copy what I do. So there is very little creative thinking.

According to one of the teachers, she did promote creativity and regarded her success in teaching due to the fact that she encouraged and supported pupils to design and make their own things.

Teacher H: I give them space to come with their own ideas. That is the only way that the children will enjoy my class. I am strict, but I do not restrict the child. I think the main thing is the encouragement from teachers, because a lot of pupils have talent that they don’t know about.

The type of questions asked can be indicative of the critical thinking that happens in classrooms. In the questionnaire, 94% of teachers encourage pupils to ask questions, although the type of questions may not necessarily be indicative of critical thinking, as the qualitative data will show. It is interesting to note that nearly 30% of the teachers did not expect their pupils to motivate or explain their ideas. This is in line with question 2 where only 45% of the teachers criticized their pupils’ ideas in terms of feasibility of sustainability. However, the results from the questionnaire indicated that pupils were encouraged to ask questions, but the follow-up interviews showed that it was seldom the “What if..” question indicative of critical thinking.

Teacher G: I allow pupils to ask questions, but they never ask what if type of questions, rather just to explain again or so.

Teacher F: No, it is never a question of what if. It is more typical of I don’t understand.

Two-thirds of the teachers (66%) did encourage pupils to make something even if they were not sure that it was going to work, with 73% providing opportunity to improve on their projects. This can enhance critical thinking and problem solving throughout the design and manufacturing phases. In contrast with the results from the questionnaires, the follow-up interview data showed that pupils are not always provided with opportunities to discuss ideas or to improve on their ideas or products.

Teacher G: No, not really (opportunities for discussions), I allow time for questions if they want to ask questions, but no, no discussion.

Teacher F: There is not time for that (improving on designs).

Teacher H: I have never thought about it, I have never thought of giving it back to them to go and improve on it.

Teachers in the first interviews were of the opinion that they did include problem solving in their teaching, but it was not evident from the interviews that the questioning approach used encouraged the development of problem solving skills associated with the design process. The solving of problems was the answering of once-off questions during lessons when explaining the theoretical content of
technology.

Teacher C: Then I say, what is the problem, why does it (the wheel) not turn?

**Teachers’ training and experience**

The teachers who took part in the first interviews had substantial experience in teaching, but very limited training in technology.

Teacher A: I was trained in Consumer studies, but no training in Technology. Natural Science was one of my majors, so that helps.

Teacher D: I had senior primary school training; you know that was 27 years ago, so we did not have this specific training. But I say, if you can read, you can teach any subject.

The results from the questionnaire supported this data (Table 2).

**Table 2: Experience and training of teachers**

<table>
<thead>
<tr>
<th></th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>43</td>
</tr>
<tr>
<td>Female</td>
<td>44</td>
</tr>
<tr>
<td>Not indicated</td>
<td>17</td>
</tr>
<tr>
<td>Total number of years experience in the teaching of the learning area Technology</td>
<td></td>
</tr>
<tr>
<td>0 response or missing data</td>
<td>5</td>
</tr>
<tr>
<td>Less than a year</td>
<td>7</td>
</tr>
<tr>
<td>1-2 years</td>
<td>11</td>
</tr>
<tr>
<td>3-5 years</td>
<td>33</td>
</tr>
<tr>
<td>6-10 years</td>
<td>32</td>
</tr>
<tr>
<td>Longer than 10 years</td>
<td>12</td>
</tr>
<tr>
<td>Description of their own training in the learning area Technology</td>
<td></td>
</tr>
<tr>
<td>Missing data</td>
<td>5</td>
</tr>
<tr>
<td>Intensive</td>
<td>7</td>
</tr>
<tr>
<td>Satisfactory</td>
<td>38</td>
</tr>
<tr>
<td>Unsatisfactory</td>
<td>21</td>
</tr>
<tr>
<td>No training</td>
<td>29</td>
</tr>
</tbody>
</table>

Of the 100 teachers who responded, only 7% indicated that they had intensive training and 38% stated that they had satisfactory training in Technology. Fifty percent of the teachers indicated that they had unsatisfactory training or no training at all.

The teachers, with whom the follow-up interviews were conducted, explained the situation regarding their training. Most of them were not trained technology teachers, although they have been teaching technology for a few years. They admitted their lack of training and lack of in-depth knowledge of technology was a problem and they were unsure about their own pedagogy.

Teacher G: I did not have any technical drawing training, so for me, it is ... it is without purpose to expect it from the children. I cannot teach it to them because I cannot draw like that.

Teacher G: You must know about LEDs and transistors, the basic principles, how a circuit board works, that information is not in all the books, and they expect that you
already know everything.

Teacher H: I must admit, it is only after the student teacher explained the technological process that my mind opened up.

Discussion

The content of Technology Education in South Africa is clearly defined in Education policy documents, but not enough guidance is provided to teachers regarding the pedagogical approaches that should be used in order to attain the outcomes specified for Technology. Pedagogical approaches should focus on the integration of the three learning outcomes of technology, providing opportunities for pupils to apply and integrate the content of technology in the solving of technological problems. Through qualitative and quantitative research methods, the pedagogical approaches of technology teachers were investigated, in order to determine how critical thinking is encouraged in their classes.

The results from this study indicated that critical thinking, which is seen as one of the important thinking skills that should be developed in technology education, did not figure strongly. Activities done in technology classrooms did not always require the learners to think critically.

If pupils did get the opportunity to make an artefact, it seldom included critical reflection or creativity. Artefacts were mostly copies of examples shown by the teachers, and not necessarily solutions to technological problems. Even when allowed, pupils seldom included their own ideas in their products. Some of the teachers were of the opinion that pupils were not able to be creative or to think “out-of-the-box”. One teacher did, however, state that she taught her pupils to be creative by encouraging and supporting them. This supports the viewpoint that the way in which technology is taught plays an important role in the development of creativity.

Pupils were seldom encouraged to ask enquiring and critical questions that could lead to discussions and reflection. Critical thinking was thus limited in the classroom. Although pupils were allowed to ask questions, as the questionnaire indicated, these questions were seldom indicative of critical enquiry. The “what if” question was seldom asked, thus limiting opportunities for thinking about and discussing technological issues. Pupils had limited opportunity to discuss their ideas, with only less than a third of the teachers expecting their pupils to explain or motivate their ideas. The questionnaire showed that 73% of the teachers provided opportunities for pupils to improve on their projects, but this was not confirmed by the interviews. In fact, from the interviews, teachers stated that there was either not enough time to improve their designs or they simply hadn’t thought of doing it.

One of the reasons for the lack of technology activities that requires critical thinking may be the knowledge and experience of the teachers. Few of the teachers had specialised training in technology, although they had a number of years experience as teachers. This could have resulted in a lack of in-depth conceptual and procedural knowledge of technology. Teachers were not immersed in the content and processes of technology and this may have resulted in their not being aware of the pedagogy appropriate for technology education, nor ways of encouraging critical thinking in their classes.

Conclusion

For technology education to survive in South African schools, researchers, policy makers and educational institutions will have to re-look at how technology is presented in schools and take note of the realities faced by teachers. Current practices in technology classrooms do not provide enough opportunities to develop critical thinking skills in pupils. In order to change this situation, teachers should be supported to become technology specialists. They should become comfortable with the content and processes of Technology, thus allowing the learners to investigate, question and query what they are learning. They should attain in-depth knowledge of the curriculum and get opportunities to develop appropriate pedagogical content knowledge for technology. Further research on how this should be achieved are needed so that sustainable and effective support for teachers can be made available.
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Indigenous Technology and Culture in the Curriculum: Starting the conversation. A Case Study.

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Part of the transformation of education in South Africa since the first democratic elections of 1994 was the development of a new curriculum known as Curriculum 2005 (C2005), in which Technology was introduced as a new learning area. This study is based on the inclusion of ‘indigenous technology and culture’, an aspect introduced in a revision of this curriculum. The broad goal of the study was to examine and explore pedagogic practice in relation to this inclusion. The study was informed by an examination of literature pertaining to philosophy of technology, indigenous knowledge systems and technology education. The review of the literature highlighted the contested nature of ‘indigenous knowledge’. Philosophies on the nature of technological knowledge were reviewed in order to explore the meaning of ‘technology’, and the issue of what constitutes technological literacy was explored. This study presented an attempt to determine the rationale for the inclusion of ‘indigenous technology and culture’ in the curriculum and to explore and examine teachers’ practices in this regard. It also examined a process of participatory co-engagement with a focus group of teachers. A case study approach using an in-depth, interpretive design was used.

Introduction

One of the key strategic and symbolic changes since South Africa’s first democratic elections in 1994 was the transformation of the education system. The new curriculum, known as C2005 and developed in 1997, was the first single curriculum for all South Africans and it was the pedagogical route out of apartheid education. Technology was introduced as a new learning area in the General Education and Training band, which was compulsory for all learners from Grade R – Grade 9. However, schools responded to C2005 in very uneven ways and there was a disjunction between policy and practice. A review of the curriculum in 2000 resulted in a revised National Curriculum Statement (NCS) that set out to streamline and strengthen the original curriculum. It was in the revised NCS that the assessment standard of ‘indigenous technology and culture’ appeared in the curriculum for the first time. This curriculum is for every student from Grade 4 to Grade 9 in South Africa. This study set out to determine the rationale for the inclusion of ‘indigenous technology and culture’ and how teachers were dealing with this aspect.

Purpose of the study

This study set out to examine and explore what selected teachers were making of the inclusion of ‘indigenous technology and culture’ in the curriculum. The overall goal of the research was to examine and explore, through a process of participatory co-engagement, pedagogic practice in relation to ‘indigenous technology and culture’ in the technology curriculum of the National Curriculum Statements (NCS) for South Africa. The research attempted to answer the following questions:

- How is the aspect of ‘indigenous technology and culture’ being proposed for Technology Education processes in policy documents?
- What is the existing pedagogical practice in regard to this aspect of the curriculum?
- Does a process of participatory co-engagement with selected teachers, with reference to ‘indigenous technology and culture’ in the technology curriculum, impact on teaching practice?

Theoretical framework

Pedagogical implications for technology education arise from the epistemological debate about the nature of technological knowledge (Rowell, Gustafson, & Guilbert, 1999). The
ways in which technology is conceptualised by teachers will have a direct bearing on the shaping of technology as a subject. Teachers’ conceptualisation of ‘technology’ and ‘indigenous technology and culture’ will influence the way in which they deal with ‘indigenous technology and culture’ in their classrooms. However, curriculum and classroom practice can also affect teacher’s beliefs about technology. It was necessary therefore to explore the different theories of technology. Philosophical and sociological perspectives have prompted an extensive debate about the nature of technology (Hansen, 1997). The debate seems to run along two continuums: the extent to which technology is viewed as autonomous or human-controlled, in other words technology’s relation to human powers; and the extent to which technology is viewed as neutral or value-laden (Feenberg, 1999). This study used Feenberg’s (2006) table to explore this nature (see Figure 1).

Figure 1: Theories of technology (adapted from Feenberg(2006))

According to Keirl (2006), disciplines such as economics, sociology, anthropology and politics offer perspectives on technology but they fail to locate potential for real understanding of technology. He suggested, however, that the complexity of the concept does not make it impenetrable and it is possible to identify some key attributes. Some of these key attributes are that technologies are central to our lives and cultures; all technologies are created by a manufacturing process resulting from human intention and design; and technology cannot ‘be’ in any functional sense without a relational human engagement. Burkitt (2002) gave the following definition of technology: ‘Technology is a means through which humans produce not only products and works, but also themselves as human selves in both their reflexive and non-reflexive aspects. It is through various technologies that humans develop the habits, capacities, skills, identity, and knowledge that mark them out as individual members of a social and cultural group’ (p. 224). There is thus consensus that technology is irreducibly social, an aspect important to this study. The definitions given in technology education documents focus on the practical nature of technology and the relationship between technology and humans is viewed as one in which technology is there to satisfy humans’ needs and wants (International Technology Education Association, 2002; South Africa. Department of Education, 2002).

In the past, many theorists took a dichotomous view focusing on either the social impact of technology or the social shaping of technology. Technological determinism developed out of social impact theories where, after it has been introduced into society, technology takes on a life of its own (Marx & Roe Smith, 1994). But this does not provide the full picture of technological development. Studying the impact of technology on society places the emphasis on a restricted point of the sequence of technological development (Pannabecker, 1991) and it ignores the role of human agency. The implications for technology education are that the focus on studying the impact of technology on society leads to a domination of dichotomies, such as ‘advantages and disadvantages’ or ‘uses and abuses’ (Hansen, 1997), and oversimplifies the human-technology relationship. The neutrality thesis to which the
instrumentalists and the determinists subscribe admits that technology embodies a value, but this is a merely formal value: that of efficiency (Feenberg, 2007). Hansen (1997), in his criticism of technological determinism stated: ‘An ontology directed towards the technological artefact tends to be reductionist, it excludes the complex dialectic of individual and cultural meanings. The historicity of technology is neglected, leaving ontological interpretations to reflect technological determinism rather than the possibility of human choice’ (p. 52). This criticism also applies to instrumentalism. Theorists such as Feenberg (1999) and Ihde (1990) claim that technology can never be removed from a context and therefore can never be neutral. Theories based on a neutrality thesis ignore the influence of contexts, including indigenous knowledge practices (Vandeleur & Schäfer, in press). In attempting to situate indigenous knowledge practices within this framework, a dilemma arises in using a western discourse (see Figure 1).

The inclusion of ‘indigenous technology and culture’ in the South African National Curriculum Statement: Technology (South Africa. Department of Education, 2002) is noteworthy. It comes at a time when questions are being asked on the formation of knowledge production, the gap between formal institutions and society, and the vacuum in theorisation (Odora Hoppers, 2002). Defining the term ‘indigenous’ is a complex but important issue, as the term is increasingly associated with new laws and rights (Niezen, 2003) as well as being used in education policy documents in countries such as South Africa, Canada and New Zealand (Phiri, 2008). There are, however, issues with the defining of ‘indigenous’, ‘indigenous knowledge systems’ and ‘indigenous peoples’. The word ‘indigenous’ refers to the root, something natural or innate (Odora Hoppers, 2002). According to Arce and Fisher (2003), the plethora of terms surrounding the knowledge that people hold, such as ‘local knowledge’, ‘traditional knowledge’, ‘indigenous knowledge’, ‘indigenous knowledge systems’ and ‘rural people’s knowledge’, reflects the different interest groups that use these terms, such as those with research interests, those with certain theoretical stances and those interested in the practical applications of knowledge. It also reflects the influence of disciplines like ecology, anthropology and sociology. ‘Indigenous knowledge’ is a term which, in recent years, has become value laden, and has gained meaning beyond its mere semantics (Rouse, 1999).

Battiste (2002) stated that ‘Indigenous knowledge comprises the complex set of technologies developed and sustained by Indigenous civilizations. Often oral and symbolic, it is transmitted through the structure of Indigenous languages and passed on to the next generation through modeling, practice and animation, rather than through the written word’ (p. 2). Flavier, de Jesus and Mavarro (1995) stated that indigenous knowledge systems are dynamic and are being continuously influenced by experimentation, internal creativity and contact with external systems. Battiste also emphasised the dynamic nature of indigenous knowledge and pointed out that using the taxonomic approach to analyse indigenous knowledge is therefore not justified. According to Woodley (2003), indigenous knowledge systems should be studied in terms of space and time, emphasising the importance of context. He further stated that the spatial dimension of indigenous knowledge is the embedded, holistic or ‘place-based’ aspect of knowledge at any one point in time, and that to understand knowledge as embedded in place needs an understanding of the social norms, values, belief systems, institutions and ecological conditions that provide the basis for the ‘place’ where knowledge is derived.

The whole area of ‘indigenous knowledge’ is a contentious and political one and issues from what constitutes ‘indigenous’ to whose interests are being served by the documentation of such knowledge arise. As Nakata (2002) suggested ‘there lies a string of contradictions, of
sectorial interests, of local and global politics, of ignorance, and of hope for the future’ (p. 281) all of which add to the contentious nature of indigenous knowledge. Another issue is the false dichotomy created in the defining of ‘indigenous knowledge’. Most definitions compare ‘indigenous knowledge’ to ‘western knowledge’, and in doing so, separate them. This separation is important in some fields, such as horticulture, where the difference between indigenous, endemic and exotic plants is significant (Fiorotto, 2008). It is important as it impacts on aspects such as biodiversity, sustaining ecologically sensitive areas and positive use of land. It is my view, however, that in other fields such as technology studies, this separation creates an artificial boundary. In agreement with this view is Rack’s statement that ‘the terms ‘indigenous’ and ‘local’ imply a discontinuity with other forms of knowledge, such as state, official or scientific knowledge. This implicit dichotomy highlights the power differentials that exist’ (2003, p. 171). She suggested that these terms oversimplify the different ways of knowing. Aikenhead and Ogawa (2007) agreed with this notion when they write about a ‘false dichotomy’. They suggested that the labelling of ‘indigenous knowledge’ and ‘science’ belies the great diversity found within each of these categories but it also hides the similarities such as empiricism, rationality and dynamic evolution. The comparison of western scientific knowledge and indigenous knowledge usually creates a dialectical opposition (Shava, 2006). However, indigenous knowledge proponents can also create an oppositional logic of ‘us’ and ‘them’ – the subjugated ‘us’ and privileged ‘them’ (Dei cited in Shava, 2006).

The attention is moving away from the dichotomous approach to a process by which different discourses, values and practices associated with the notions of ‘modernity’ and ‘tradition’ intersect and are intertwined in the everyday encounters and experiences of people from diverse socio-cultural backgrounds (Arce & Long, 2000, pp. 2-3). Interfaces of knowledge are not found between the scientific, official and local knowledges. A consensus has emerged in the development field, that knowledge production is rather a continuous, boundless, seamless process between many different forms of knowledge. This consensus emerged due to the postmodern challenge that ‘bounded’ needed to be replaced by ‘relational’, ontological categories (Arce & Fisher, 2003). Local knowledge does not exist in isolation but rather interacts with a variety of ways of knowing, so it is being continually shaped and re-shaped. Local knowledge is therefore not unquestioningly endogenous as local people interact with exogenous elements to strengthen their own ways of knowing. The binary ‘endogenous/exogenous’, ‘us/them’ view of knowledge does not apply much to everyday reality (Pottier, 2003). Agrawal (1995) suggested that it makes sense to talk about multiple domains and types of knowledge with differing logics and epistemologies rather than creating distinctions between these domains and Nakata (2002) stated ‘that the very separation of the domains – cultural and Western – or traditional and formal – lead to simplifications that obscure the very complexities of cultural practices in both domains’ (p. 285). However, the inclusion of ‘indigenous technology and culture’ in the South African curriculum should make educators aware of different knowledge systems. Dei (2000) stated that it is now necessary ‘to address the emerging call for academic knowledge to speak to the diversity of histories, events, experiences and ideas that have shaped human growth and development’ (p. 113).

Technology education is a relatively new subject in schools and has been implemented in countries such as the United Stated of America, New Zealand, Australia, England, Finland, Israel and South Africa. Most of these countries have been through a process of curriculum revision. One of the goals of technology education stated in most curricula is to develop students that are technologically literate (O'Riley, 1996; Rasinen, 2003), and in the USA, it is
the intended outcome (Petrina, 2000). It is also the aim of the New Zealand technology curriculum (Ministry of Education, 1995). However, defining technological literacy is a contested area. Petrina (2000) stated that so-called literacies, although they are constructs that are nebulous by design, ‘are not impotent or meaningless. These constructs serve as links between action and ideology – they serve to govern some economic, political or social course of action. They are socially distributed and shared ideologically across groups with contradictory articulations and meanings. They help to diffuse a range of motives with popular appeal. This is to say that these constructs are ‘always already’ political’ (p. 181). For most technology educators, however, the construct of technological literacy is neutral (Petrina, 2000), and for the ‘Technology for all Americans’ project, technological literacy is simply ‘the ability to use, manage and understand technology’ (International Technology Education Association, 2002, p. 7). Dakers, Dow and de Vries (2007) conflate technological literacy and technological capability. Yet Petrina (2000) suggested that technological capability is ‘simply the potential for efficient, practical, quality work in design’ (p. 181). The New Zealand Curriculum Draft for Consultation (as quoted by Gawith, O'Sullivan, & Grigg, 2007) claimed that a ‘broad, technological literacy’ is encompassed by the three strands in their curriculum – Technological Practice, Nature of Technology and Technological Knowledge.

According to Dakers (2006b), a genealogy for technology education shows roots firmly embedded within an industrial and vocationally orientated past. As a result, much of what happens in technology classrooms today addresses only the operational dimension of technology, with the focus on ‘designing and producing for ‘fitness for purpose’ with an overemphasis on skills and competencies’ (Michael, 2006, p. 49). This instrumental approach to technology education has led to much criticism by technology educationists, such as Williams (1996), Michael (2006), Dakers (2006a) and Compton and France (2007), as the focus on materialist, artifactual knowledge is restrictive and develops a technological literacy in our students that is narrow. It reduces the concept of technology to that of artefacts necessary for our needs and wants. One of the problems, as Hansen (1997) suggested, is that ‘an ontology directed towards the technological artefact tends to be reductionist, it excludes the complex dialectic of individual and cultural meanings’ (p. 52).

Another issue in technology education is the ‘taken-for-granted’ phenomenon of technology. Michael (2006) asserted that it is the nature of our ‘mundane technologies’ and their ‘embroilment in sociotechnical ensembles’ that make them difficult to see and understand. This ‘taken-for-granted’ phenomenon is perhaps why our pupils do not engage critically with the technologically-pervasive world that surrounds them. Technology education cannot ignore this. According to Dakers (2006a), there is a lack of discourse in the technology classroom. This lack of discourse is symptomatic of the emphasis in technology education on in-depth manipulative competencies rather than cognitive and attitudinal competencies (Michael, 2006).

I would like to suggest that much can be learnt from the critical literacy work associated with Shor (1999), Luke (2000), Lankshear (1993) and Willinsky (2007). Their work openly acknowledged the educational influences of critical theory. The larger educational influence of critical theory extends to the broader critical pedagogy field that informed the work of Giroux, Simon and others (Kinchehlo, 2004). Shor (1999) stated ‘When we are critically literate, we examine our ongoing development, to reveal the subjective positions from which we make sense of the world and act in it’ (n.p.). Petrina gave the following as having a critical literacy towards technology:
(a) a critical orientation to representations of technological literacy;
(b) the sensibility or critical intention to engage politically with technological practices such as those that sustain high rates of capital, consumption, inequities, and unegalitarian distributions of profit and waste; and
(c) the political or critical agency to mobilise and produce actions and ‘texts’ that work against or ‘jam’ the discourses and works of culturally and ecologically destructive technologies. (pp. 200 – 201)

Methods
The research was conducted in three phases. The first phase dealt with how and why ‘indigenous technology and culture’ was proposed for Technology education purposes. In other words, according to Lindblad and Popkewitz’s (2000) notion of narrative, the argument put forward was explored. The purpose of the second part of Phase 1 was to examine how ‘indigenous technology and culture’ was being proposed in policy documents and learning materials. This part of the phase involved the analysis of texts that related specifically to the pedagogy of Technology that included ‘indigenous technology and culture’. The issue that was being explored here was in what way was the argument put into a context (Lindblad & Popkewitz, 2000).

The purpose of Phase 2 of the research was to analyse existing pedagogical practices in terms of ‘indigenous technology and culture’ as an assessment standard. The inclusion of ‘indigenous technology and culture’ as an assessment standard first appeared in 2002 in the revision of the curriculum. Technology teachers had to deal with what knowledge to teach and how to recontextualise this knowledge. Phase 3 of the study consisted of analysing a process of participatory co-engagement around an area of shared concern, namely the meaningful implementation of ‘indigenous technology and culture’. The best way to examine the subjective experiences of the focus group of teachers was through an in-depth, interpretive design using the case study method.

Data sources
Phase 1 of the research used data gathered by a questionnaire sent to the curriculum developers. It also analysed policy documents and learning materials to establish how this assessment standard was being recontextualised. The data source for Phase 2 and Phase 3 of the research were a selected group of five teachers. The focus group method was of particular value to this study as it allowed me to examine ‘how people engage in collective sense-making’ (Wibeck, Dahlgren, & Öberg, 2007, p. 249).

Results
The revisioning of ‘nation’ and ‘citizen’ in the National Curriculum Statement is a result of South Africa’s historical and political past, and the inclusion of ‘indigenous technology and culture’ emerged from this revisioning. The inclusion of ‘indigenous technology and culture’ is part of this political vision, and perhaps due to this, there was unanimous support for it from the focus group of teachers. The study revealed that authors and teachers are slow to adopt the more phenomenological theories which would bring the social and cultural aspects of technology into the classroom. In Technology education there is an overemphasis on skills and competencies without much critical engagement concerning technological development. However, designing learning activities to get students to question assumptions is difficult as environments in which a technology is developed and used are complex and dynamic (Michael, 2006), so this remains a substantial challenge for authors of learning materials.
At the start of the study, most teachers in the focus group did not implement ‘indigenous technology and culture’. The reasons for this were mainly lack of clarity around the term ‘indigenous’, very little in the way of learning materials on this topic, the teachers were not qualified Technology teachers and did not feel competent to teach this aspect, and most schools did not allocate the correct time to this subject so teachers focused mostly on ‘design and make’ tasks. In Phase 3 of the study the focus group of teachers were asked to implement ‘indigenous technology and culture’. It was found that most of the teachers used learning material from text books and did not develop their own material. It is therefore imperative that textbooks develop tasks that require learners to develop a critical stance of technology and to engage with ‘indigenous technology and culture’ in a meaningful way. A questionnaire, document analysis, interviews and focus group discussions were used to conduct the investigation. What emerged from the data analysis was that there was unanimous support for the inclusion of ‘indigenous technology and culture’ in the technology curriculum, but implementation had been problematic. This was partly due to difficulties with the interpretation of this aspect in the curriculum as well as a lack of meaningful teaching and learning for various reasons.

**Significance of the study**

The purpose of this study is to contribute to a deeper understanding of ‘indigenous technology and culture’ so as to enable a more meaningful implementation by technology teachers in their classrooms. The value of this exploratory study is that it can act as a platform so that other researchers can further explore and test issues around implementation of the technology curriculum. This study is, however, significant in its own right as it has generated tentative explanations and interpretations around the implementation of ‘indigenous technology and culture’. The results of this study will hopefully impact positively on teachers’ practices and contribute to a better quality of teaching and learning in technology. The next step would be to engage more fully with teachers who are located within an indigenous context.

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**Effects of dialogical argumentation-based workshops on primary and secondary school teachers’ ability to co-construct the concept of solubility**

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**Abstract**

This article presents a case for equipping science teachers with the necessary skills needed to enact dialogical argumentation-based classroom discourses. Even though teachers are required to scaffold knowledge construction in the classroom, it appears that not much prominence has been dedicated to exploring alternative or novel approaches to teaching. Hence, this research seeks to evaluate the effectiveness of dialogical argumentation-based pedagogic framework as essential tools for enhancing teachers’ ability to co-construct solubility concepts in the classroom. The workshop sessions employed for this study involved primary and secondary school teachers. The results reinforces the belief that dialogical argumentation-based model is a plausible pedagogic approach which augments teachers’ ability to co-construct scientific knowledge and also improves their quality of argument during discursive classroom environment. In addition, frequent epistemic interactions during dialogue could enable the teachers to synthesis and critically evaluate scientific concepts as well as exhibiting keen interest in problem solving discourses.

**Introduction**

It is a well known fact that science teachers’ conceptions of the Nature of Science (NOS) are anything but adequate (e.g. Arkerson & Abd-El-Khalick, 2003; Schwartz, Lederman & Crawford, 2004). In this regard, teachers tend to present scientific knowledge as a ready-made product to be transmitted verbatim to students without making any serious attempt to reveal the heated debates and
controversies involved in generating such knowledge. As Ziman (2000) has succinctly put it, “Scientific biographies are deeply scarred by private episodes of vitriolic personal jealousy between individuals...The frontiers of knowledge are partitioned into a thousand special territories” (p.29). Kittleson and Southerland (2004) add that in order to understand how scientific knowledge is constructed one needs to know how that knowledge “is negotiated or co-constructed in social settings” (p. 268).

Co-construction of knowledge is a joint and collective endeavour undertaken to build an understanding of a given phenomenon. It is a collaborative experience shared by a group of people in the act of performing a task. Although much has been revealed in the last few decades about the nature of contestations and vibrant social interactions among scientists in the process of knowledge construction through the works of Popper, Kuhn, Hempel, Lakatos, Merton and others, not much has been done to help science teachers reflect that critical aspect of the Nature of Science (NOS) in their classrooms. Also, not much has been done to examine the effectiveness or otherwise of teachers’ pedagogic training programmes aimed at equipping them with necessary knowledge and pedagogic skills to facilitate meaningful discourses in their classrooms (e.g. Driver et al, 2000; Kittleson & Southerland, 2004). Hence, this study aims at contributing towards efforts made to fill this gap. It is an attempt to train a group of teachers on how to make co-construction of knowledge an important aspect of their instructional practice. The new South African curriculum popularly known as Curriculum 2005 (C2005) emphasizes the need for students to develop critical process skills. However the same curriculum does not explicitly state how such skills can be developed among students.

Theoretical Framework

Argumentation is a statement advanced to justify or refute a claim in order to attain the approbation of an audience (Van Eemeren, et al, 1987). Argumentation has been used as a rhetorical and instructional tool since time immemorial. It was a common rhetorical tool used by pre-Socratic natural philosophers before 500 BC as well as by succeeding generations of scholars up to the present day scientists in their attempts to unravel the nature of matter and the universe as a whole (Popper, 2001). As Fraser, et al (1994) have contended, 20th century physics (using arguments and counter arguments backed by scientific evidence) depict two major voyages in science of discovery namely, looking “outwards through telescopes toward the edge of the universe” and probing the micro-cosmos, namely, “the minuscule world of atoms and sub-atomic particles” (p.13). The underlying assumption of the study therefore was that training teachers explicitly on how to co-construct concepts (like scientists do) might be an effective way to develop process skills among their students. It was for the same reason that argumentation was used as the organizing framework for the development of Argumentation-Based (A-B) workshops discussed later in the paper.

An argumentation model that has featured prominently in the science education literature in recent years has been Toulmin’s (1958) Argumentation Pattern (TAP). The TAP consists of a claim-an assertion, declarative statement or belief about a phenomenon; data-evidential or supportive statements of that assertion; warrants-statements which seek to justify or show a relationship between the data and the claim; backings-implicit or underlying assumptions of the claim; qualifier-the contingent conditions on which the claim is based; and rebuttals or contrary statements to the claims. Some criticisms that have been levelled against the TAP include: the inconsistent way in which it presents the validity of an argument; its use in certain cases of formal logical meaning of “soundness” and so on (Van Eemeren, et al, 1987). However, despite the criticisms that been levelled against the TAP, its great contribution lies perhaps in its rejection of a universally applicable argumentation model as well as serving as a useful guide in assessing arguments in a given context. For instance, a number of studies have shown that there is no common pattern in the way teachers use even the same form arguments in their classrooms. In other words, the use of arguments appears to be teacher dependent (Erduran, Simon & Osborne, 2004). To avoid the usual overlaps among the elements of the
TAP this study has adopted a modified version of the TAP by considering data, warrants and backing simply as grounds (Erduran, Simon and Osborne, 2004). It is this modified version of TAP that we adopted for this study.

**Purpose of the Study**

The aim of the study was to examine the effect of Dialogical Argumentation Instructional Model (DAIM) on teachers’ understanding of selected science concepts. The DAIM was used as exemplary model of instruction which science teachers could use to facilitate the co-construction of science concepts with their learners. We also chose the approach to provide the needed intellectual space for teachers and learners to discuss and argue more freely in the classroom. We also hoped that unlike the typical teacher-where teachers tend to dominate a discursive classroom environment might help learners to clear their doubts, revise their conceptions and even change their attitudes as a result of listening to the views of others (Erduran, Simon & Osborne, 2004; Ogunniyi, 2006). More specifically, the study sought to determine possible effects of an activity-based DAIM in enhancing the concept of solubility among a cohort of teachers who attended a series of workshops for a period of six months. In pursuance of this aim we sought answers to the following questions:

1. How effective is the DAIM in enhancing the teachers’ ability to co-construct with their peers the concept of solubility?
2. What levels of the TAP are evident in the teachers’ dialogic argumentation as they work on solubility of two unknown substances?

**Method**

**Dialogical Argumentation Instructional Model**

The main study involved 13 primary and secondary science teachers with varied content and pedagogic content knowledge-an issue not presented for lack of space in this proposal. The teachers attended three-hour per week workshops underpinned the TAP for a period of six months. In addition they were assigned selected readings based on the works of scholars (e.g. Ziman, Medawar, Popper, Hempel, Kuhn, Merton, Driver, Akerson, Abd-El-Khalick, McComas, Lederman and others) reflecting the socio-cultural dynamics of the Nature of Science (NOS). The first session began with a brief lecture on the fascinating story of what Hungarian physician Semmelweis did to find out the cause(s) of childbed fever. They were also introduced to the controversies that ensued among pre-Socratic philosophers and scientists in the early 20th century regarding the nature of the atom as lucidly espoused in a book titled, “The Search for Infinity” (Fraser, Lilelotstol & Sellevag, 1994). The purpose of the reading assignments was to create the teachers’ awareness about how scientists go about constructing knowledge in their various fields and to show teachers how to reflect same in their instructional practices. As an example we provide an abridged version of one of the workshops on NOS as follows:

**Workshop 1 on the Nature of Science**

These workshops will introduce you to various aspects of the Nature of Science (NOS). You will learn about the scientific assumptions, hypotheses, laws, theories and the type of reasoning used in science such as: deduction, induction, and practical reasoning and so on. Specifically, you will learn about a form of argument proposed by a British philosopher called Toulmin. Toulmin (1958) proposed an argumentation model popularly known as the Toulmin Argumentation Pattern (PAT). It consists of a claim, evidence (data), warrant, backing and rebuttals. A claim is a statement or belief about a phenomenon whose merits are in question. Data are the facts or evidence used for supporting a claim. Warrants are the statements used to establish or justify the relationship between the data and the claim. Backings are the implicit assumptions underpinning the claim. Qualifiers are conditions governing the claim, while rebuttals are statements which show the claim to be invalid.
A good example that we shall consider in today’s workshop is the historical case of Ignaz Semmelweis and his research team. Ignaz Semmelweis was a Hungarian doctor who between 1844 and 1848 attempted to find out the causes of childbed fever which resulted in the deaths of several women who came to deliver their babies at a particular hospital and so on (see the full story in the Appendix 1). As scientists normally do Semmelweis proposed a number of hypotheses (a wise and informed guess) to find the cause(s) of childbed fever. Despite several trial experiments carried out to test the validity of these hypothesis he found to his dismay that nothing seem to change as the women continued to die! In other words, the results of his experiments did not provide solid valid evidence (data) or warrant (justification) for the claim implied by the hypotheses. He resolved to make more careful observations to obtain more reliable evidence. But despite his effort, the women continued to die at child birth. He had no option than to revise his hypotheses until the causes of the disease were known… In your groups you are expected to discuss and argue about Ignaz Semmelweis and his research team went about co-constructing knowledge until they resolved the mystery surrounding child-bed fever. But in your discussion remember the emphasis is not to win an argument but to reach consensus on the basis of solid and justifiable claim.

Wrap-up questions:
The two wrap-up questions for this morning session which you need to work upon in your take home assignment for the next workshop are:

1. Based on the story of Semmelweis, what have you learned about the NOS? “What role does a hypothesis play in a scientific investigation?” Based on the story of Semmelweis, what have you learned about the NOS?
2. What role does a hypothesis or theory play in scientific investigation?

Assignment 1:
(a) You are to submit 1-3 page reflective essay on what you have learnt about the NOS in the first workshop (please cite relevant references) and how this would impart your instructional practice.
(b) To benefit from the workshops it is critical to read handouts provide on the NOS.
(c) Select a partner with whom you would debate a topic from the list below in the next workshop.

The workshops on Solubility
The solubility tasks were carried out by four groups of participating teachers in two separate workshop sessions. The first session consisting of activities 1 and 2 asked the teachers to identify the two unknown substances on their tables. DAIM based-activities involved the specification of the intended outcomes, the materials to perform the tasks and following the protocols which entailed: individual brainstorming or “intra-dialogical argumentation level,” group or inter-dialogical argumentation level and whole class or “trans-dialogical argumentation level.” For example activity 1 involved the following:

Intended outcomes: Solubility of solutes in solutions depends on the relationship between their chemical and physical properties and these are affected by: temperature; polar or non-polar properties; intra and inter molecular forces; likeness (polar dissolves in polar and non polar dissolves in non polar); amount of solutes in solution (saturated, unsaturated and supersaturated); acidity or alkalinity; crystal size of solutes and so on. Next was the sequence of activities: prediction; argumentation and dialogues; experimentation; observation; and reinforcement and consolidation of knowledge at the intra-, inter- and trans- dialogical argumentation levels. The two unknown substances were: distilled water (substance A) and 20g sodium acetate (substance B). The apparatuses included: 300/250 ml beaker; hot plate; water bath; conical flask; stirring rods; small measuring cylinders; tongue holders;
eye protection goggles; filter strip to test to test alkalinity; bottle stoppers; and funnels to dispense water. To make the investigation interesting as well as intensify the discussions certain material detractors were deliberately put among the items on the tables.

Methodology and activity worksheet for Activity A
Individual Task-You have been given the above apparatus and chemicals: 1. Brainstorm (intra-argument or self-conversation) and predict the types of experiments to be done. 2. State your predictions as your **claims**. 3. State your reasons as your **data or evidence**. 4. How did you arrive at your claims and evidence? 5. How can you justify your claims? 6. Is there a relationship between your claim and evidence? Yes or No. 7. If yes, then state these relationships as **warrants**. 8. Assumptions are part of scientific reasoning. What assumptions did you make in order to arrive at your predictions? State these as your **backings or grounds**. 9. By looking at the equipment and chemicals again, identify any extra conditions which may have aided you in making your claims. 10. Record these conditions governing your claims as **qualifiers**. 11. Remember that at the intra-level no one challenged or opposed your claims. What level(s) of argumentation did you deploy out of the seven levels of TAP (modified from the five espoused by Erduran, et al, 2004) in filling the worksheet? You are now ready for small group activities: level 1 consists of a non-oppositional claim; level 2 consists of a claim versus another claim or counter claim; level 3 consists of a claim/counter claim with evidence, warrants, a backing/qualifier and but no rebuttal; 4. consists of a claim/counter claim with evidence, warrants, a backing/qualifier; and at least one rebuttal and so on. The seven level has an extended argument with two or more counter claims and rebuttals.

Small Groups Task- In order to justify your claim, discuss your arguments with other members of your group and then tabulate the arguments in terms:
- **Claims**
- **Evidence**
- **Warrants**
- **Backings/qualifiers**
- **Rebuttals**

In terms of these elements of TAP above, are there any competing or different claims to which the teachers were to express **Yes on No**. If yes, they would list these as **counter claims**. 2. If the claim was challenging other people’s claims, then must be provided as evidence. The evidence would be used to invalidate such claims. 3. If the evidence stated to support the dispute was valid then was regarded as the **rebuttal**. 4. By determining the various levels of argumentations the teachers might have used plus much reflection some consensus was then reached. 5. They were also to state the experiments that they had agreed upon or unanimously predicted. This experiment then served as the basis of their claims. 6. By stating the data, warrants and backing/qualifiers they might have used they were then ready for the whole class or trans-argumentation dialogues.

**Whole class discussions:** 1. The leader in each group would present their claims, evidence and warrants, backings/qualifiers to support their arguments. 2. Facilitators would then mediate whole class to identify counter claims and rebuttals. 3. The class agrees on the various levels of argumentations. 5. The class would reach a consensus on the type of experiment to be done.

In brief, activities 1 required the participating teachers to identify the two unknown substances on their tables. Activity 2 followed the same procedure on solubility tasks. The following workshop was used to complete activity 3. After the six-month workshops the teachers were introduced to DAIM through prototype lessons as exemplars. A lesson could be based on an inductive or deductive instructional model or hypothetical-deductive model of the NOS depending on the envisaged outcomes. This paper
is based on the latter. The teacher were confronted with tasks without suggesting to them the topic other than to brainstorm individually (i.e. at the intra-argumentation level) and collectively (i.e. at the inter-argumentation level) the topic and experiment and then co-construct the appropriate concept(s) from a collection of materials on their lab tables. My task and that of my two assistants during the first one and a half hours was mainly to facilitate collaborative dialogues among the teachers though thought-provoking questions. The next hour was used for group presentation followed by the whole class discussion and summary. The last 30 minutes of the session was used to identify collectively the levels of arguments used by the teachers. To reinforce their argumentation skills the teachers were then given some assignment for the next workshop. For example, based on the story of Semmelweis you read earlier and what you have done in the lab sessions today, what have you learned about the NOS? What role does a hypothesis play in a scientific investigation? All the lab sessions were recorded using both audio-video tapes. The transcribed materials were then analyzed in terms of qualitative descriptions. More details about the Dialogical-Argumentation Instructional Model (DAIM) used in the study have already been published (Ogunniyi, 2007a &b).

The NOS questionnaire consisting of 18 items was the outcome of a series of refinements of a 30-item earlier version based on scholarly critique and a pilot test involving 45 teachers. Validity checks involved average pair-wise ratings of items from 1 to 5 (1 being a poor item and 5, an excellent item) by four science educators on the final draft of the questionnaire. Using the Spearman Rank Difference formula, the correlation stood at 0.98 while an odd-even and a split-half correlation stood at 0.92 and 0.99 respectively. Likewise, the correlation of the categorizations of the teachers’ levels arguments in a Lab session by two independent experts stood at 0.94 using the same formula. These indices show a strong face, content and construct validity of the instrument. Further details about the development of the questionnaire have already been published elsewhere (Ogunniyi, 2007a &b). The preliminary findings on a selected lab session are presented in the section that follows. Because of space limitations we shall place our emphasis on only the leaders of each group who acted as the “voices” of their respective groups. We shall also attempt to show to what extent Toulmin’s Argumentation Pattern are manifested in the discussions of the groups and the whole class.

Results and Discussion

The preliminary results briefly summarized here are based on transcribed textual data extracted from the audio and video archives, and discursive worksheets designed for the purpose of this discussion. The worksheet was designed in such a way to allow the enactment of the discourses in intra-, inter- and trans-argumentation-based scenarios. The main tasks required of the teachers were: (1) the identification of the unlabelled chemical substances based on their physicochemical properties and (2) the suggestion of plausible potential laboratory experiments using the provided substances and laboratory apparatus. The argumentation-based instructional model developed in this research has been shown to create a positive learning environment, which enabled teachers to actively participate in the workshop activities. Teachers exhibited keen interest and positive attitude towards the problem solving science based discourses. In most instances teachers relied on their prior experiences and knowledge which emerged during the argumentations. Most of the claims which were made were supported with grounds pertaining to physicochemical properties of substances. It emerged that DAIM is an effective pedagogic tool for enhancing teachers’ ability to co-construct with their peers the concept of solubility. The teachers’ conceptual understanding of scientific knowledge as a whole appeared to have been reinforced. Before arriving at claims, the teachers sometimes did not base their arguments on scientific phenomena pertaining to solubility alone but also integrated other relevant scientific concepts. It was evident that the teachers developed high level argumentation skills since there was an increase in the levels of argumentation during the DAIM discourse. A trend seems to have emerged where increased epistemic interactions leads to higher incidences of rebuttals with the potential to augment argumentation skills.

Evaluating the quality of argumentation

In seeking answers to our first research question we critically examined the obtained textual data for...
instances of dialogical argumentation in the discourses. In most instances the participants were able to support any inference made with grounds (see Erduran, et al, 2004) such as evidence, warrants, backings and qualifiers. Even though some of the grounds assigned may not be entirely scientifically reasonable or valid to some extent, these attempts buttress the fact that the teachers interrogated and critically analyzed their scientific thoughts. Semantic evaluation of the textual data also showed that the discussions are characterized with the terminology “if”. This terminology could highlight instances of argumentation in textual data. High frequency occurrence of “if” could also correlate to enrichment of dialogical argumentation discourses. In this work, the frequent usage of words such words such as claims, warrants and qualifiers pinpoint teachers’ conceptual understanding of DAIM. The results presented below are indicative of how the discourses were enriched with features pertaining to Toulmin’s Argumentation Pattern (TAP).

Individual and intra-group discussions

Example 1 (Group 1)

T1 also the team leader of group 1, contended that, “If a substance boils at a certain temperature, the identity of the substance can be determined... assuming that the substance is pure.” To posit his claim he first argued that knowing the physicochemical properties of substances was a way to identify the actual substances.

T2 on the other hand claimed that, “If an impurity B is added to A, the boiling point of A will increase.” Although he did not explain why he thought B was an impurity he buttressed his claim by suggesting first to: “Determine the boiling point of A alone. Thereafter add B and determine the boiling point.” He argued further that, “If the temperature of A is increased, the solubility of B in A will increase.” To him, “If A and B are pure substances, their identities can be determined by finding their fixed points [fixed points could be boiling or melting points].”

T3 argues that, “If the temperature is increased, the solubility of B in A will increase. If the temperature is increased, the solubility is also increased.”

Interestingly, while the focus of T1 was on identification of the unknown substances A (liquid) and B (solute), T2 was already hypothesizing that the task was concerned with determining the solubility of solute B in solvent A in different temperatures. T3 agreed with T1 and T2 regarding the effect of temperature on the solubility of substances. T1, T2 and T3 used physicochemical properties such as boiling points and physical appearances of the liquids and solids as grounds to buttress the espoused claims. By carefully linking the physicochemical properties of substances (evidence) to their claims, the group has thus established a relationship or warrant between the claim and the evidence. In summary, T1, T2 & T3 made a claim of identification of substances which was supported to certain extent with grounds. T2 went further to provide evidence for two extra counterclaims: (a) effects of impurities on the boiling point of liquids and (b) effect of temperature on solubility. By evaluating the above arguments in the context of TAP the individual/group’s argument was primarily at level 2.

Example 2 (Group 2)

T4 also the team leader of group 2, predicted that the materials on the table were concerned with “an experiment on solubility, identifying types or classes of compounds” and that “substance B was salt.” However, he was not sure if substance A was pure water because of its slight adhesion to the sides of the test tube. He supported his claims with the evidence that: substance B was in form of “white crystals shape … was colourless and odourless.”

Like T4, T5 predicted that the experiment was concerned with testing the type of salt provided and whether B would dissolve in A. T4 & T5 went further by claiming that “B was NaCl [while] substance A could be water, acid, base or alkaline…flaky, damped, white and shiny in colour.”
In summary, T4 & T5 made a claim of identification of substances which was supported to certain degree with grounds. T4 & T5 went further to provide some data for another counterclaim: solubility experiment. The teachers in group 2 like those in group 1 predicted reasonably the correct experiments and identified substances A and B basing their claims on physicochemical characteristics of A and B as evidence even before carrying out the experiment. In terms of the TAP their level of argument was also 2. With few exceptions the arguments used by groups 3 and 4 represented by T7-10 and T10-13 respectively were also at level 2 of the modified TAP.

**Example 3 Whole class or trans-group discussions**

After group activities, the leaders of the four groups made short presentations on how they arrived on what the experiment was all about and how they reached their conclusions regarding the unknown substances on their tables. All the four groups after individual and group brainstorming and discussions concluded that that the items on their tables were concerned with carrying out an experiment to identify substances A and B; and the solubility of B in A. Whatever evidence emerged from the experiment (not yet conducted at the time) would then serve as grounds for their claims about the two unknown substances. For example, at the class discussion level there were a few claims, counterclaims and rebuttals on the grounds that:

Group 3 made an extra claim: effects of solutes on the boiling points of liquids. T4 rebutted this claim by questioning the evidence used to substantiate the claim. According to T4, both A and B were unknown substances and that the available apparatus and their supposed usage were not enough to predict the above claim. In furtherance of his rebuttal, T4 asserted that in the absence of actual heating, boiling, weighing or mixing the substances it was presumptuous of T11 to corroborate the claim with assertion that: the boiling point of A is 100 or that its density is 1.0. By evaluating the above discussions, the teachers made various claims and counterclaims with a single rebuttal which was directed at the evidence substantiating one of the counterclaims, in the context of the modified TAP, the whole class discussions attained level 3. The discourses above seem to support the effectiveness of DAIM framework for mediating co-construction of concepts.

**Evaluating the levels of argumentation**

In seeking answers to our second research question we examined the argumentation processes and scenarios to elucidate the various levels of argumentation attained. The various levels of argumentation were used as analytical framework to evaluate the quality of the arguments since they could determine whether the teachers are developing high-level argumentations skills. Higher incidences of rebuttal of claims and grounds by colleagues involved in the argumentation discourses could lead to the attainment of high level of argumentation (e.g. Simon et al., 2006; Ogunniyi, 2007a &b). It is clearly evident that during self-construction of solubility concepts at the intra-argumentation level, the teachers were able to come up with various degrees of evidence to substantiate their respective claims. This fortifies the notion that actively engaging in self explanations improves understanding (Chi et al, 1994). This conscious effort on the part of each individual teacher culminated in the attainment of level 2 of the modified TAP. In spite of the fact that this dialogue was done alone, the teachers explored, interrogated and critically evaluated whatever assertions they made. Since there were no concrete rebuttals or opposition of claims or grounds, level 2 of argumentation was also attained by all the groups during the discussions at the inter-argumentation level.

Even though there were no concrete rebuttals the teachers engaged in interactive discussions. The group leaders enhanced the articulation of discourse by mediating the small group discussions in order to arrive at sets of agreed claims and grounds. These were attained largely by the group members via co-constructing the various solubility concepts. As evident, the teachers used extensive explanations as part of the argumentation process to elaborate and co-construct solubility concepts. This is in agreement with previous postulation that explanatory and argumentative interactions are epistemic interactions that play a role in the co-construction of scientific notions (Baker et al, 2001). Baker et al
(2001) further intimated that it may be ambitious to use argumentation dialogue as the primary medium for co-construction of scientific notions. Nevertheless, they considered argumentation dialogue as a potential means for encouraging critical thinking and awareness about the task in order to enhance understanding of the nature of the problem. In this paper, a three-tier discourse approach comprising of individual, small group and whole class discussions model was used to augment the dialogical argumentation pedagogy. Group leaders and workshop facilitators mediated the epistemic interactions to enhance efficient implementation of the argumentation. The scaffolding of knowledge co-construction ensured that dialogical argumentation was not merely used as a vehicle to enact the discourses.

During the whole class discussions, the level of argumentation attained was 3. This was an improvement upon the small group discussions which was at level 2. The teachers appeared to have reinforced their understanding of the various levels of argumentation, since the whole class unanimously agreed on the correct level of argumentation attained (i.e. level 3). The ability of the teachers to engage in dialogical argumentation was enhanced considerably since other assertions were also challenged. For example, in the course of the whole class discussions, T4 had the following arguments rebutted: B would release or absorb energy when dissolving in polar liquids; sugars would produce a viscous solution in polar liquids; salt solutions is not viscous; and that all sugars are opaque, very white while some are fine powders. These incidences of rebuttals in the whole class discussion seem to suggest that the teachers are not only critically analyzing scientific concepts but are also enhancing their levels of argumentation. What is evident from this snapshot report is that the teachers have begun to appreciate the value of argumentation not only as an instructional tool but also as a means for scaffolding knowledge co-construction. Further, as in an earlier study (Ogunniyi, 2007b) observation and interviews data (not reported for lack of space in this paper) showed the teachers increased in knowledge and practical argumentation skills in the workshops.

Conclusion

From the foregoing, have shown how dialogical argumentation-based instructional model when integrated with knowledge scaffolding could enhance school teachers’ ability to co-construct the concept of solubility with peers. We believe that the discursive worksheets and the three-tier discussion model employed in this work could be adapted as an exemplar for modeling other classroom based discourses. We have also demonstrated how increased epistemic interactions during dialogical argumentation-based discourses could has enhanced the quality argumentation and analytic skills the teachers used. Although total evaluation of this ongoing project awaits future findings, it could serve as a useful indicator for assessing the effectiveness of DAIM. Nevertheless, the reported preliminary findings have shown DAIM to be a useful and an effective pedagogical framework for modeling scientific discourses for teaching and learning.

References


Matric Students’ Understanding Of Equations And Competence In Using Them

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Abstract
Equations are an important part of all quantitative sciences. Competence in them will simplify
learning and problem solving. This study tested final year matric students’ competence in the various types of intellectual skills and strategies needed for the effective use of equations as frameworks for storing and applying knowledge. The study method used was the analysis of students’ answers to questions that tested ability to: deduce the information organized in equations; transform information given in statements into equations; rearrange and combine equations; use equations for calculations and deductions and correlate information in equations and linear graphs. The results showed that about 70% of students (average performance in all questions used for testing) had difficulty in answering correctly the questions given. This lack of competence will seriously handicap effective learning of physical science and hence there is a need for training students in the intellectual skills and strategies needed not only for using equations but also for studying science effectively.

Keywords
Intellectual skills, intellectual strategies; usefulness of equations; problem solving; students’ difficulties; knowledge organization

Introduction
Equations are an integral and important part of physical science and all quantitative sciences. They organize knowledge in a concise and unambiguous manner. They show quantitatively the various types of relationships (e.g. directly proportional, inversely proportional, exponential, and logarithmic) that exist between the variables (variable physical quantities) in the equation. There are many types of equations: linear equations; exponential equations and logarithmic equations. In addition to these, which are integrated equations, there are also many types of differential equations. This study deals only with the simplest type of equations; linear equations.

The organization of knowledge as equations has many advantages over other ways of organizing knowledge such as verbal statements, tables, graphs and models. This is mainly because equations are concise and hence are easier to remember, store and recall from memory than statements. They are also easier to handle, manipulate and use and they simplify learning and problem solving. Furthermore, information provided by them is sharp, clear and unambiguous. Because of these advantages, equations should be used, whenever possible, as frameworks for learning, organizing and storing knowledge, and also for applying knowledge.

Perhaps the most important use of equations is for calculations and deductions. Calculations and deductions using equations are sharper, easier, less cumbersome and less error-prone than calculations and deductions using verbal reasoning. Another advantage is that when equations are combined, the principles organized in the equations (e.g. direct proportion and inverse proportion relationships between quantities) are also automatically combined. This corresponds to ‘reasoning’ using the principles organized in the equations. The combined equation will then have more information (principles) than those in the non-combined equations. For example, when equations \( V = k_1/p \) and \( V = k_2T \) are combined, the equation obtained, \( V = k_3T/p \), has the additional information, over that present in the equations \( V = k_1/p \) and \( V = k_2T \), that \( p \) is directly proportional to \( T \).

To organize knowledge as equations and then use them, for example to solve problems, needs competence in some intellectual skills and strategies. The main purpose of this study is to test whether matric students have this competence. Equations are needed for the solution of most quantitative problems. Extensive research has been done on quantitative problem solving and many of the difficulties in quantitative problem solving and due to incompetence in dealing with equations. Some research studies have already been done in this field in South Africa, on first year university students and
matric physical science teachers'. These studies, however, were a small part of a broad study on many types of intellectual abilities and therefore tested only a few aspects of equations. The present study, which was done as a BSc Hons research project, dealt only with equations. It is a comprehensive study that attempts to test all basic aspects of equations that are important for the effective study of matriculation physical science.

Objectives and method of study
The main objectives of this study were:
(a) to test final year matric students to find out their competence in the basic intellectual skills and strategies that are needed for dealing with equations in their physical science courses;
(b) to identify the nature and extent of their difficulties;
(c) to make suggestions for rectifying the difficulties

Main aspects tested were students’ ability to do the following:
- identify and state verbally the information organized in equations;
- transform quantitative information in statements into equations;
- correlate information provided by equations with the equation for a linear graph (∵ mx + c);
- manipulate (rearrange) equations;
- combine different equations;
- calculate using an equation, when the equation has to be applied twice;
- use equations for qualitative deductions

The study method used was the analysis of learners’ answers to questions that were carefully designed to test their understanding of equations and their competence in using them.

Subjects of study and administration of question paper
Learners tested were final year matric physical science students from three schools in the Molopo district of North-West province: Letsatsing High school (in Mafikeng; urban school); Regolotswe High school (in Itsoseng; semi-rural school) and Tswelopele High school (in Itsoseng; semi-rural school). All these are well-resourced Dinaledi schools. National Department of Education provides special facilities to these schools for the teaching of science and maths.

60 learners were tested; 20 learners being randomly selected from the matric class in each school. The test was conducted like a normal examination. No time limit was set for answering the question paper. Most of the learners submitted their answers scripts before one and a half hours.

The question paper
The question paper had eight questions which tested various aspects of competence associated with equations. Students wrote the answers in the question paper itself: ample space was provided for this below each question. Space was also provided along the margin to the questions for doing “rough work”. Five instructions were given in the title page of the question paper of which three are particularly relevant to this paper. These are:
1. Some questions may appear to be difficult but they are not. If you reason logically you will be able to answer them quickly. Note also that some information given may not be necessary to answer the question.
2. Show all the steps in your reasoning. Also do all the rough work in the space provided adjoining each question because the main objective of this test is to probe into how you think.
3. If you do not understand any words or phrases in a question, underline these words and phrases.
The questions used for testing are shown in Table 1.

**Table 1: Questions used for testing understanding of equations and competence in using them.**

The last three columns in the table show, under the heading “% correct”, the percentages of students who correctly answered each question.

<table>
<thead>
<tr>
<th>1. Use the defining equation for density ((d)), which is (d=m/V) where (m = )</th>
<th>% correct</th>
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<tr>
<td>(R+T)</td>
<td>(R+T+L)</td>
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mass and \( V = \text{volume} \), to deduce answers to the following questions:

(a)

(b) The density of 1 gram of a solid substance is \( x \). Which one of the following will be the density of 2 grams of this substance?

(i) \( 0.5x \)  
(ii) \( x \)  
(iii) \( 2x \)  
(iv) \( x^2 \)

(c) State whether the density of a liquid will increase, decrease or remain unchanged if its temperature is increased, given that the volume of a liquid always increases when its temperature is increased. State how you deduced the answer

(d) Which one of the following states the relationship between \( d \) and \( V \)? (\( m \) is kept constant)

(i) directly proportional  
(ii) inversely proportional  
(iii) linear  
(iv) logarithmic  
(v) exponential

(e) The density of a gas is \( x \) at a temperature \( T \). Which one of the following will be the density of this gas if the temperature is doubled to \( 2T \), when volume is kept constant?

(i) \( x \)  
(ii) \( 4x \)  
(iii) \( 2x \)  
(iv) \( x^2 \)

2. For a non-ideal gas, the variables (variable quantities) \( V, T \) and \( p \) are related by the equation \( V=kT^2/p^{1/2} \), where \( k \) is a constant. Use this equation to answer the following questions. State also how you deduced the answers.

(a) At constant \( T \), will \( pV \) be a constant?

(b) If \( T \) is increased, will \( k \) increase, decrease or remain unchanged?

(c) At constant \( T \), deduce whether \( V \) will increase, decrease or remain unchanged if \( p \) is increased

(d) The volume \( V \) of this gas is \( x \) at a temperature \( T \). Which one of the following will be its volume if the temperature is doubled to \( 2T \), when pressure \( p \) is kept constant?

(i) \( 0.5x \)  
(ii) \( x \)  
(iii) \( 2x \)  
(iv) \( 4x \)  
(v) \( x^2 \)

(e) Complete the following sentences

(i) At constant \( p \), \( V \) is directly proportional to ……

(ii) At constant \( T \), \( V \) is inversely proportional to ……

3. The questions below concern the time \( t \) needed by a car moving at a speed \( s \) to travel some fixed distance \( d \).

(a) Name the variables (variable physical quantities) in the above statement.

(b) Which one of the following states the relationship between \( t \) and \( s \)?

(i) directly proportional  
(ii) inversely proportional  
(iii) linear  
(iv) logarithmic  
(v) exponential

(c) Which one of the following is the correct equation that relates the time \( t \) needed for the travel and the average speed \( s \) of the car? (\( k \) is constant).

(i) \( t=ks \)  
(ii) \( t=k/s \)  
(iii) \( t=s/k \)  
(iv) \( t= ks^2 \)  
(v) \( t=1/s \)

4. The questions below test understanding of the equation for a linear graph (straight-line graph), \( y=mx+c \), where \( y \) and \( x \) are variables and \( m \) (gradient) and \( c \) (intercept) are constants.
(a) Draw the graph for the equation \( y = mx + c \), when \( c = 2 \) and \( m = 0 \)
(b) For the equation \( V = kT^2/p \), state whether a linear graph will be obtained if (note: \( V,T \) and \( p \) are variable quantities and \( k \) is a constant). \( V \) is plotted vs \( p \) (when \( T \) is kept constant).

5. The equation for the statement “The mass of an object A (symbol, \( m_A \)) is larger than the mass of an object B (symbol, \( m_B \)) by 4g” is \( m_A = m_B + 4g \).
   Similarly, write the equations for the following statements.
   (a) The mass of an object A (symbol, \( m_A \)) is smaller than the mass of another object B (symbol, \( m_B \)) by 8g.
   (b) The difference between the selling price (\( S \)) and the cost price (\( C \)) of an item is equal to its profit (\( P \)).
   (c) Moles of nitrogen (\( n_{N_2} \)) and moles of hydrogen (\( n_{H_2} \)) react in the ratio 1:3
   (d) The time (\( t \)) needed by a car to travel a fixed distance is inversely proportional to the average speed (\( s \)) of the car.
   (e) Write the equation that relates the time \( t \) needed to perform some task and the number of men \( N \) employed to do the task.

6. The equation that relates the time \( t \) needed to travel some fixed distance and the average speed \( s \) of a car is \( t = k/s \), where \( k \) is a constant. Use this equation \((t = k/s)\) to calculate the time that will be needed by a car moving at an average speed of 120 km h\(^{-1}\) (kilometers per hour) to travel from Mafikeng to Pretoria, given the information that 4 hours are needed for this travel when the cars average speed is 90 km h\(^{-1}\)

7. Eight (8) hours are needed by a car moving at an average speed of 75 km h\(^{-1}\) to travel some fixed distance. Calculate the time that will be needed to travel the same distance if the cars average speed is 100 km h\(^{-1}\)

8. A gas obeys the equation \( pV = kT \), where \( p \) = pressure, \( V \) = volume, \( T \) = temperature and \( k \) is a constant. Combine this equation with the defining equation for density \( d \), which is \( d = m/V \), so as to obtain an equation that shows how \( d \) is related to \( p \) and \( T \).
Results and Discussion

Learners’ performance in each of the questions used for testing is shown in Table 1. The last three columns show, under the heading “% correct”, the percentages of learners who correctly answered each question. Column 2 (labelled R+T) shows performance of the 40 learners from two schools (Regolotswe and Tswelopele high schools) in a semi-rural area. Most learners in these two schools are from a poor socio-economic background. Column 3 (labelled L) shows performance of learners at Letsatsing high school, an urban school situated in Mafikeng which is the capital city of North-West province, and column 4 (labeled R+T+L) shows the performance of all the 60 students in the three schools (20 from each school). The average correct performance in all the questions used for testing was 29% for learners in the semi-rural schools, 35% for learners in the urban school and 31% for all learners. The results in Table 1, which show that learners’ performance is poor, will be discussed below for each question. The performance considered for discussion will be the overall performance shown in the last column of Table 1.

Question 1 mainly tests ability to deduce the information organized in a simple equation, \( d = \frac{m}{V} \). The solutions to all parts of the question depend mainly on the ability to deduce the information organized in this equation. It is therefore necessary to focus on this equation and use it for deducing the answer. This is not done by most students.

The correct answer to part (a) of the question is \( x \). This is because when the mass \( (m) \) of a solid is increased its volume \( (V) \) too will increase in the same proportion. Hence \( \frac{m}{V} \), which is the density \( (d) \), will remain unchanged. About 75% of the students tested did not answer this question correctly. Most of them (about 65%) thought that density will be doubled when mass is doubled. They implicitly made the assumption, probably by using some sort of qualitative reasoning, that density is directly proportional to mass. It may appear from the equation \( d = \frac{m}{V} \) that \( d \) is directly proportional to \( m \). This however is not true unless \( V \) is kept constant. In the problem given \( V \) is not kept constant and hence \( d \) cannot be considered to be directly proportional to \( m \).

To solve question 1(b) too, it is necessary to focus sharply on the equation \( d = \frac{m}{V} \). In addition, it is necessary to recognize, because \( V \) appears in the denominator of the equation, that \( d \) will decrease when \( V \) increases (provided \( m \) is kept constant). Since an increase in temperature \( (T) \) will increase the volume \( V \) of a liquid (this was stated in the question), it follows from the equation \( d = \frac{m}{V} \) that an increase in \( T \), because it increases \( V \), will decrease \( d \). About 60% of students could not answer this question correctly. Most of them (about 30%) thought that density will increase when temperature is increased and about 20% did not attempt its solution. Students’ difficulty in answering this question may be due to two reasons: (a) to their not recognizing, because \( V \) is in the denominator of the equation \( d = \frac{m}{V} \), that \( d \) will decrease when \( V \) increases; (b) to their not correlating the information given (that \( V \) increases when \( T \) increases) with the equation \( d = \frac{m}{V} \).

Question 1(c) tests basic concepts associated with the inverse proportion relationship between \( d \) and \( V \) in the equation \( d = \frac{m}{V} \). This equation shows (provided that \( m \) is kept constant) that an increase in \( V \) will decrease \( m/V \) and hence decrease \( d \) in the same proportion. \( d \) is then said to be inversely proportional to \( V \). About 75% of the students did not know this. Direct and inverse proportion relationships, and direct and inverse proportion reasoning, are important not only in the study of the sciences but also in daily life. It is important, therefore, that students are trained to become competent in these two types of reasoning.

Question 1(d) also tests whether we focus sharply on the given defining equation \( d = \frac{m}{V} \) and use it to deduce the answer. Since it is stated in the problem that \( V \) is kept constant (and \( m \) also does not change), we can conclude that \( m/V \), and hence \( d \), will remain unchanged at \( x \). Its
value will not change when \( T \) is changed. About 75\% of students did not answer this question correctly. Most of them thought that \( d \) will be doubled when \( T \) is doubled. The error of these students may be attributed to their not recognizing that they must use the equation \( d = m/V \) to deduce the answer. They probably tried to deduce the answer by using some sort of qualitative reasoning.

Students’ poor performance in question 1 may be attributed mainly to their not recognizing an important use of equations: their use for making deductions. Equations are storehouses of knowledge and they should therefore about relationships between physical quantities and they should therefore be used not only for doing calculations but also for making deductions (both qualitative and quantitative deductions), as illustrated in the answers to the various parts of question 1.

**Question 2**, like question 1, mainly tests ability to deduce the information provided by an equation. An unfamiliar equation \((V = kT^2/p^{1/2})\) was used to prevent the possibility of recall of correct answers from a familiar equation.

**Question 2 (a)** tests the ability to deduce information from the equation \( V = kT^2/p^{1/2} \): to deduce whether, at constant \( T \), \( pV \) will be constant. It will be easier to do this if the given equation is first rearranged to \( p^{1/2}V = kT^2 \). This equation shows, since \( kT^2 \) will be constant at constant \( T \), that \( p^{1/2}V \) (and not \( pV \)) will be constant. About 65\% of students, however, thought incorrectly that \( pV \) will be constant. These students did not know how to deduce the answer from the given equation.

For **question 2 (b)**, it was stated that \( k \) is a *constant*. This means that the value of \( k \) will not change when any of the variable physical quantities \((V, T, p)\) are changed. An increase in \( T \) will therefore not change \( k \). About 40\% of the students tested, however, thought incorrectly that \( k \) will change when \( T \) is changed. These students either did not understand clearly the meaning of the word constant or did not give sufficient thought to clarifying the problem before attempting its solution.

**Question 2 (c)**, like questions 1(b) and 1(d), mainly tests whether an equation is used for deducing the required answer. The equation in this question, \( V = kT^2/p^{1/2} \), shows that if \( p \) is increased \( V \) will decrease. About 55\% of students, however, were unable to make this deduction.

**Question 2 (d)** tests ability to simplify a given equation and then do a calculation. When \( p \) is kept constant, the given equation \( V = kT^2/p^{1/2} \) can be simplified to \( V = k_1T^2 \) where \( k_1 \) is a constant. That is, \( V \) is directly proportional to \( T^2 \) (and not to \( T \)), and hence if \( T \) is doubled (i.e. increased by the factor 2) \( V \) will increase by the factor \( 2^2 \) (which is 4). \( V \) will therefore increase from \( x \) to \( 4x \) when temperature is doubled from \( T \) to \( 2T \). Since many students have difficulty with the factor \( 2^2 \), the steps in the calculation will be elaborated. The equation \( V = k_1T^2 \) has to be applied twice to do the needed calculation: first at temperature \( T \) when we get \( V_1 = k_1 T^2 \) and then at temperature \( 2T \) when we get \( V_2 = k_1 (2T)^2 = 4 k_1 T^2 \). Therefore 

\[
V_2/V_1 = 4 k_1 T^2 / k_1 T^2 = 4
\]

Since \( V_1 \) is given in the question as \( x \), it should be clear from the above equation that \( V_2 \) is \( 4x \). Students’ performance in this question was very poor. About 75\% of them (see Table 1) were unable to answer it.

**Question 2 (e)** tests ability to state verbally the information organized in the equation \( V = k T^2 / p^{1/2} \). This equation shows that \( V \) is directly proportional to \( T^2 \) and is inversely proportional to \( p^{1/2} \). The data in Table 1 shows that most students (about 65\%) thought incorrectly that \( V \) is directly proportional to \( T \) and inversely proportional to \( p \). These students, therefore, were unable to deduce and state correctly the information organized in the given equation.
Question 3 tests understanding of the basic concepts associated with the relationship between the time (t) needed by a car to travel a fixed distance and the speed (s) of the car. This is a familiar type of relationship. From experience we know that when the speed of a car increases the time needed to travel a fixed distance will decrease in the same proportion. The relationship between t and s is said to be inversely proportional and the equation relating t and s is \( t = \frac{k}{s} \), where k is a constant. The results in Table 1 show that about 75% of the students did not know that the phrase “inversely proportional” is used to state the relationship between t and s and that the equation for the relationship between t and s is \( t = \frac{k}{s} \). Inverse proportion relationships and inverse proportion reasoning, along with direct proportion relationships and reasoning, are very important not only in the study of the sciences but also in our daily lives. Students should therefore be trained in them until they become competent.

Question 4 tests ability to correlate linear graphs with the general equation \( y = mx + c \). Part (a) of the question should be easier to solve than part (b) because it deals only with the equation \( y = mx + c \). Part (b) is more difficult because its solution also needs, in addition to the understanding of the equation \( y = mx + c \), the correlation between a given equation (\( V = \frac{kt^2}{p} \)) and the equation \( y = mx + c \). Students’ performance was poor in part (a) and very poor in part (b). About 70% of them were not able to answer part (a) of the question with about 20% of them not even attempting to solve it. Concerning part (b), about 80% were unable to answer it with about 30% not even attempting its solution.

Question 5 tests ability to transform information provided in statements into equations. This skill is very useful because it aids problem solving. Many of us have difficulties with the use of statements for reasoning (verbal reasoning) and this is probably associated with the difficulty in processing information in statements because it is lengthy. There is research evidence that many people find it difficult to simultaneously process many items of information because of limitations in working (short-term) memory. Without using statements and verbal reasoning for calculations, a better method would be to first transform the lengthy information given in statements into equations (which are always concise) and then use the equations for calculations and deductions. Students’ performance in question 5 was poor. Table 1 show that only about 35% (average performance in all parts of the question) of them were able to answer correctly. Lack of competence in this skill will handicap students’ problem solving abilities.

Questions 6 and 7 are similar in that both deal with the same type of calculation involving speed (s) and time (t). The equation needed for the calculation was given in question 6 but not in question 7. It is our experience that most people try to answer question 7 by verbal reasoning; inverse proportion reasoning has then to be used. For question 6, to calculate t, using the equation \( t = \frac{k}{s} \) when \( s = 120 \text{ km h}^{-1} \), the value of the constant k is needed. Since this is not known, it has to be first calculated by substituting the data (\( t = 4 \text{ h} \) when \( s = 90 \text{ km h}^{-1} \)) into the given equation: \( k = t s = 4 \text{ h} \times 90 \text{ km h}^{-1} = 360 \text{ km} \). By using this value of k, the required time t can then be calculated: \( t = \frac{k}{s} = 300 \text{ km} / 120 \text{ km h}^{-1} = 3 \text{ h} \). The main objective of testing students with these two questions was to compare their performance in them so as to find out whether they are better at using equations or verbal reasoning for calculations. Unfortunately, students’ performance in both questions was very poor (only 14% and 19% answered questions 6 and 7 correctly) and therefore significant conclusions cannot be drawn from the results. The results show, however, that a large majority of the students tested have difficulty both in using equations and in using verbal reasoning for calculations.
Question 8 tests ability to combine two simple equations: \( pV = kT \) and \( d = m/V \). To combine two equations, it is necessary that both equations have a common physical quantity. The common quantity in the two equations given is \( V \), and \( V \) in the equation \( d = m/V \) can be replaced by \( kT/p \) (rearrangement of \( pV = kT \) gives \( V = kT/p \)), to obtain the required equation that shows how \( d \) is related to \( p \) and \( T \).

\[
d = \frac{m}{V} = \frac{m}{kT/p} = \frac{mp}{kT}
\]

Learners’ performance in this question was poor. Only about 35% answered correctly and about 20% did not even attempt to answer the question. Since ability to combine equations is needed for the effective solution of quantitative problems, lack of competence in this skill will seriously hinder students’ ability to solve problems in their courses.

**Conclusion**

The main objective of this study was to test matric physical science students to find out whether they recognize the importance of equations and are competent in the basic intellectual skills and strategies needed for effectively using equations in their physical science courses. All important aspects of equations were studied and they included the ability to do the following: to deduce information organized in equations; to transform information given in statements into equations; to rearrange, manipulate and combine equations; to use equations for calculations and deductions and to correlate the information in equations and linear graphs.

The study method used was the analysis of students’ answers to carefully designed questions. The results showed that students’ performance was poor. About 70% of them (this is the average performance in all the questions used for testing) were unable to answer the questions correctly.

The intellectual skills and strategies needed for the effective use of equations are not particularly difficult to learn and use. Students’ lack of competence in them is, in our view, not due to difficulty in learning them but to insufficient emphasis being placed on them during their courses. Their importance is not well recognized. This is despite the strong emphasis placed in the matric Curriculum on the development of higher order thinking skills of students. Lack of competence in intellectual skills and strategies can be expected to reduce self-confidence and foster negative attitudes towards learning and problem solving. This lack of competence may be an important reason for the rote memorization of knowledge by many students and also for the high failure rate of students in their science courses.

Since the usefulness of equations for the effective storage of knowledge in memory, and also for the recall of this stored knowledge and its applications is not well recognized, some explanatory comments may be helpful. Consider the organization and storage of quantitative knowledge. Three common ways for organizing quantitative knowledge are as statements, equations and graphs. These are alternative ways of representing an item of knowledge. Storing knowledge as equations (and not as statements) has many advantages. Since they are concise, equations can be more easily stored in our memory, and also more easily recalled, than statements. Furthermore, information provided by them is unambiguous. Many students try to remember knowledge items (e.g. Boyles law, Charles’ law) in all these three forms. This is not only an unnecessary waste of time and effort but also disadvantageous because it would hinder the retrieval of required knowledge items since a larger amount of knowledge items stored in our memory have then to be scanned. Statements and graphs should not generally be consciously memorized because they could be deduced from equations. This,
however, needs competence in intellectual skills and strategies.

Since a clear understanding of equations is of fundamental importance for the effective learning of all quantitative sciences, it is important that students are trained so that they become competent in the intellectual skills and strategies needed to deal with equations. Research evidence suggests that such training should be integrated, throughout the courses, with the teaching of subject content.  

References

16. B.K. Beyer, Ref.15, p 275-282

The effectiveness of cluster groups as a bridge to the future: Developing Physical Sciences educators’ ability and confidence to deliver the NCS

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This study was conceptualised in order to explore research questions centred on issues related to Physical Sciences educators’ perceptions of working in cluster groups, the extent to which cluster meetings support educators, and how cluster groups could be improved so that they serve the purpose
for which they were intended. Data was collected by having participating educators complete questionnaires containing both multiple choices items and longer, open-ended questions. Main findings include that educators prefer working in clusters, where they support each other by sharing ideas and difficulties, which in turn, improves their confidence to deliver the National Curriculum Statement. Some the factors that impact negatively on their cluster experiences include poor cluster leadership, and having to travel to remote, unsafe locations for long hours to attend cluster meetings. Implications of these findings include that cluster leader training should be reconsidered, together with clustering schools that are physically close together.

**Purpose of the Research, and Justification of Importance**

At the time when this study was carried out, the first author was a Physical Sciences educator in the Further Education and Training (FET) phase (Grades 10-12) in a district falling under the Gauteng Department of Education (GDE), and as such belonged to cluster groups for the subject. The second author also has experience of GDE cluster groups, and specifically as a cluster leader.

The idea for this study initially arose from especially the first author’s contact and informal conversations with fellow educators in cluster groups. Educators’ informal conversations after cluster meetings were especially intriguing. It seemed as though educators did not really want to discuss their experiences during the formal cluster meetings, but rather preferred to re-group in smaller informal clutches to discuss their difficulties.

As educators reflect on their experiences, many view cluster group meetings as satisfying and helpful. However, others seem to be somewhat disinterested in cluster meetings and had little regard for them, taking the view that cluster meetings are a waste of time and effort. Many educators seem troubled by the sheer unpredictability of having to relate to a group of strangers, where “(d)istrict officials have clustered schools in subject groups” (GDE, 2006:3) without any consultation with the educators involved. Although the stated purpose of cluster groups is for educators to meet “to support one another” *(ibid)*, the very notion of working in a group to share ideas and support each other in a multi-racial environment is quite foreign to many educators.

The purpose of this study was thus to explore these observations, centred on issues related to:

- educators’ perceptions of working in cluster groups;
- the extent to which cluster meetings support educators; and
- how cluster groups could be improved so that they serve the purpose for which they were intended.

This study thus responds to the call by Jita and Ndlalane (2009:66) that “(f)urther work is needed to explore the possibilities and arrangements that are likely to support and sustain the ... operation of ... effective clusters.” It is hoped that results from this study can contribute towards encouraging Physical Sciences educators to work in cluster groups, so that they look forward to cluster meetings with enthusiasm, and contribute “to the efficacy of clusters” (Jita & Ndlalane, 2009:66), so that such effective cluster meetings will leave educators feeling revitalized and supercharged for the next time they make contact with their learners. Unlike in the past, where educators were left to their own devices to map their teaching techniques by themselves, the formation of cluster groups helps educators to share their workloads and thus reduce the stress associated with not knowing whether they are doing the right thing. If anything, cluster groups should provide the support and development that all educators need from time to time, as these were designed to empower educators to work together cooperatively, as they often have access to more information and teaching strategies than those working in isolation.
Carpenter and Matters (2003:1) point out that educator professional learning communities signify one of a number of initiatives available to educational leaders, which “are considered powerful contributors to staff development and ... effective strategies for stimulating school change” that could ultimately lead to the provision of quality instruction and improved learner performance. Fortunately, Swanepoel and Booyse (2006:189) report that “there was fairly strong support for the involvement of” educators from their schools in most processes that involve “school-change activities” amongst South African secondary school principals.

Literature Review

Jita and Ndlalane (2009) are of the opinion that teacher clusters represent a fairly new phenomenon in South Africa. However, in line with Carpenter and Matters (2003:1) pointing out that “(l)earning communities have been discussed with increasing vigour during the last decade”, a circular (GDE, 2001:3) states that “(s)chools have been clustered in subject groups in all Districts by District Officials.”

In their research, Bryk and Schneider (2002) show that educators’ commitment to create educator-educator networks can be driven by three possible reasons: they seek help to carry out the day-to-day routines of schooling, seek to advance their knowledge for the best interests of their learners, and/or they want to improve their own careers and self-worth.

Teaching networks, however, are poised to be a powerful source of educator learning and school improvement – especially if they are designed and actualized in the ways that respect the sharing and cultivation of best practice in the form of work samples, lesson plans and assessment instruments developed by other educators. Jita and Ndlalane (2009:66) support this by pointing out that “the success of the teacher clusters ... depends entirely on teachers’ strong sense of commitment to their collaborative learning and support in the cluster meetings as peers.”

Especially in the previous century, it was common for educators to work in isolation behind closed doors, in the isolated environment of their own classrooms. However, Achinstein (2002) explains that the development of professional communities could ease the isolation and uncertainty inherent in the teaching profession.

All across South Africa, and in Gauteng specifically, the formation of cluster groups (or educator community networks) have become popular tools to help schools reform and achieve higher pass rates, and support educators by developing their skills to deliver the National Curriculum Statement (NCS). Although thus far there has been limited success with cluster groups, the advantages these pose for all educators far outweigh the disadvantages. Isolation of an educator in the present environment is to the detriment of the learner and the development of educators’ professionalism. For this reason, cluster meetings must be an exciting and fruitful exercise for all educators who are part of them.

DuFour (2004:10,11) point out that “(e)ducators must stop working in isolation and hoarding their ideas, materials,” strategies, and talents - instead, they need to “begin to work together” so that all educators in e.g. an entire cluster have access to these. The GDE (2006:5) also emphasises that “(t)he importance of cluster meetings cannot be overstated”, as “(t)hey form an important link between the Department and schools as well as an inter-school link.”

Theoretical and Conceptual Framework

According to the Encarta Dictionary (2008) a cluster is “(a) group of people or things close together.” In line with this definition, cluster groups are schools grouped together, typically from the same area. With the introduction of the NCS, schools were clustered together in
groups to supply educators at grass root level “with a local professional network for exchanging ideas and sharing suggestions for better implementation” where “small discussion groups (engage with the) implications for their professional practice.” (Goosen, 2004:88). These also act as opportunities to report back and discuss ways to handle problems that they and their learners are having, as well as to guide and assist each other in delivering the new curriculum.

The most recent directive from the GDE requires that “(a)ll schools must be part of the cluster meeting system and must attend all meetings.” (GDE, 2006:3). Because attendance is thus compulsory for educators, there are seldom absences at cluster meetings. However, Jita and Ndlalane (2009:66) warn against such situations “where teachers come together as a bureaucratic requirement rather than for their own benefit and growth.”

In line with recommendations by DuFour (2004), the educators in each cluster group have frequent meetings on a quarterly basis throughout the school year.

In education districts, each subject facilitator is responsible for making recommendations to the District Director to appoint cluster leaders in his/her subject (GDE, 2006). One of the criteria on which these recommendations should be based includes that such educators should have a minimum of three years’ experience in teaching the subject at Grade 12 level, to ensure that an experienced and committed person, who is up-to-date with the requirements of the NCS, is appointed for an area in their immediate vicinity.

These cluster leaders oversee and coordinate the efforts of cluster groups using the “Critical Friends” concept. As “(c)luster leaders ... are responsible for the management of ... in their clusters (they) should be relieved of some of their extramural activities/duties”, to “enable them to plan, prepare for and attend cluster meetings.” (GDE, 2006:5). Goosen (2004) warns that if educators (especially cluster leaders) don’t receive release time for their participation in cluster groups and related activities, they will have to complete all this additional work on their own time, and they will feel that they don’t have sufficient time to teach the NCS properly. All cluster leaders are required to attend an information sharing meeting at the beginning of the year.

In the South African milieu where this study was undertaken, the term cluster group is used, similar to the term teacher cluster used by Jita and Ndlalane (2009:58) in their study, also located in South Africa. They indicate that “(i)n other countries and contexts, clusters are also referred to as ‘teacher communities of learning’ or ‘teacher networks’”, while Carpenter and Matters (2003:1) point out that the term that they refer to as learning communities has been used interchangeably with other designations such as teacher professional community (Achinstein, 2002) and professional learning communities (DuFour, 2004; Graham, 2007; Hughes & Kritsonis, 2006).

According to Jita and Ndlalane (2009:59, quoting Secada & Adajian) teacher clusters are a “form of professional community that provides a context within which members can come together and understand their practices”. Achinstein (2002: 422) defines a teacher professional community as a “group of people ... who are engaged in common work; share to a certain degree a set of values, norms and orientations towards teaching, students and schooling; and operate collaboratively with structures that foster interdependence.” Similarly, according to Carpenter and Matters (2003:1), “(i)n education cultures, the term learning community is most often used to describe a group of people from multiple areas and multiple levels who work together collaboratively and continually”.

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Graham (2007:2) indicates that the concept of professional learning communities “builds on a
variety of previous organizational models and theories”, while, according to DuFour (2004:6),
the model for professional learning communities “flows from the assumption that the core
mission of formal education is not simply to ensure that students are taught but to ensure that
they learn.” In this way, the model specifically provides “a powerful new way of working
together that profoundly affects the practices of schooling.” (DuFour, 2004:11). Some of the
attributes of a professional learning community described by Hughes and Kritsonis (2006:2)
include “leadership, ... shared values and vision, (and) supportive conditions”.

Research Methodology
The first author met with the respondents at a location that was convenient for the
respondents, to deliver the questionnaire to them. Participants were given a brief overview of
the aim of the research, and the possible benefits of the research were explained. He
highlighted the importance of the research, and that respondents’ contributions were highly
valued and vitally important for the success of the research. The first author reminded the
respondents of their right to withdraw from the research at any time if they wished to do so.
Respondents were informed that they did not need to complete or return the questionnaire if
they chose not to participate. However, he appealed to respondents to complete the
questionnaire for the sake of the study. Each participant signed a consent form for taking part
in the study when the questionnaire was handed to them.

Research design
The survey design was selected so that large amounts of tangible data could be obtained in a
relatively short space of time. This design was preferred, since many of the respondents lived
in different areas in and around Pretoria. The majority of the respondents were out of the city
centre and this posed a problem in terms of making contact with them.

Maree and Pieterson (2007:157) mention that using a questionnaire as data collection method
“is relatively cheap and easy to do” and “(r)espondents can complete the questionnaire at a”
time (and place) that is convenient. There is also “no interviewer” (ibid) present to influence
the respondent.

The researchers were aware of the limitations of the proposed design, and intended to address
these challenges to prevent them from affecting the quality of the study. For example, an
appeal was made to respondents to return the questionnaire on the agreed upon date, and also
not to give the questionnaire to somebody else to complete. Lastly, the researchers’ contact
details appeared on the questionnaire, and respondents were informed that they were free to
send a text message for a ‘call back’ if they had difficulty with the questionnaire.

Selection of respondents (Sampling)
According to McMillan and Schumacher (2001), in survey research, researchers select
samples of respondents before administering questionnaires to collect information about their
demographics, ideas, opinions and perceptions.

Potential participants included 20 Grade 12 Physical Sciences educators from schools in areas
including Atteridgeville, Saulsville, Lotus Gardens, Elandspoort, Laudium and inner-city
schools in Pretoria, belonging to a specific education district resorting under the GDE. The
learners in these schools are predominantly from previously disadvantaged communities.

In order to obtain reliable information about the functioning of cluster groups in the chosen
district, all respondents were selected from this district only. Respondents must have
belonged to a cluster group, must have been teaching Physical Sciences in the FET phase, and
needed to be able to speak, read and write English. Special effort was made to include some female educators in the sample.

**Data collection strategy**

Owing to the fact that the respondents for the study lived so far away from each other it was decided to use a questionnaire as the instrument to collect data for this study. The first section of the questionnaire asked respondents to complete a section on basic biographical information, while the remainder of the questionnaire consisted of questions that were designed to probe educators’ opinions on cluster groups. This part of the questionnaire allowed educators to reflect on their cluster groups and try to identify what some of the shortcomings of the group was, and/or why their cluster groups were not functioning as they should be. Some questions were also added to ensure consistency with the responses obtained in earlier questions.

The questionnaire was only issued once to the respondents (no follow-up questionnaire was administered), who were then allowed to take the questionnaire home. Respondents were contacted telephonically after a week, so that the completed questionnaires could be collected at a venue that was convenient for the respondents.

Although the data collection strategy was primarily quantitative, it was decided to add a qualitative dimension to the research, to add authenticity to the study, by exploring and gaining insight as to how cluster groups function. The qualitative element was in the form of longer questions where respondents were required to express their views, attitudes and perceptions about their cluster groups. Admittedly, although interviews would have been a much richer source to gather qualitative data, it was decided not to use this method, because of the additional expenses that this would involve, which was beyond the budget available.

**Response rate**

The initial survey register consisted of 20 educators (consisting of 17 seventeen Black, one White and two Asian), and the questionnaire was issued to all. Thirteen (65%) of the questionnaires were returned, of which one questionnaire (5%) was incomplete. Although most educators were cooperative and helpful, some of them were difficult to contact after they had been issued with the questionnaire.

**Discussion of Results**

Table 1 reflects that just more than two-thirds of respondents were male, and that the same number of them was between the ages of 36 and 40. The majority of respondents teach in classes with more than 40 learners per class. Although respondents’ education qualifications are spread fairly evenly across the various options, less than half of them have a degree as academic qualification, but most do seem to have a tertiary qualification in Science. The medium of instruction for all responding educators was English.

**Table 1. Biographical data.**

<table>
<thead>
<tr>
<th>Gender</th>
<th>Number of responses</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>4</td>
<td>31%</td>
</tr>
<tr>
<td>Male</td>
<td>9</td>
<td>69%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age</th>
<th>Number of responses</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 – 25</td>
<td>1</td>
<td>8%</td>
</tr>
<tr>
<td>26 – 30</td>
<td>1</td>
<td>8%</td>
</tr>
<tr>
<td>31 – 35</td>
<td>2</td>
<td>15%</td>
</tr>
<tr>
<td>36 – 40</td>
<td>9</td>
<td>69%</td>
</tr>
</tbody>
</table>
As seen in Table 2, more than three-quarters of educators rated their confidence in teaching Physical Sciences as ‘fair’. The fact that none of the educators in this study rated their confidence as ‘very high’ could indicate that they are not as confident as they would like to be with regards to delivering the NCS for Physical Sciences.

Table 2. Perceptions on educators’ confidence in NCS.

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of responses</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Fair</td>
<td>10</td>
<td>77%</td>
</tr>
<tr>
<td>Unsure</td>
<td>2</td>
<td>15%</td>
</tr>
<tr>
<td>Poor</td>
<td>1</td>
<td>8%</td>
</tr>
</tbody>
</table>

The results in Table 3 showed that almost three-quarters of educators feel that they work better with colleagues in their clusters, as compared to working alone.
Table 3. Perceptions on working alone rather than in a cluster.

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of responses</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>1</td>
<td>9%</td>
</tr>
<tr>
<td>Partly yes</td>
<td>2</td>
<td>18%</td>
</tr>
<tr>
<td>Partly no</td>
<td>8</td>
<td>73%</td>
</tr>
<tr>
<td>No</td>
<td>0</td>
<td>0%</td>
</tr>
</tbody>
</table>

Most educators’ perceptions of the reasons for educators/schools being grouped into clusters were to encourage cooperative learning and the sharing of ideas. Another point raised by some respondents related to advantaged schools helping disadvantaged schools.

Table 4. Perceptions on support from cluster groups.

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of responses</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>1</td>
<td>8%</td>
</tr>
<tr>
<td>Good</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Fair</td>
<td>9</td>
<td>69%</td>
</tr>
<tr>
<td>Poor</td>
<td>3</td>
<td>23%</td>
</tr>
</tbody>
</table>

More than two-thirds of educators indicated that they were not entirely satisfied with the support they received in their clusters - this does not agree well with the stated intent of the GDE (2006:3) for cluster groups “to support one another.”

Table 5. Should educators decide themselves on which clusters they would like to belong to?

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of responses</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly agree</td>
<td>8</td>
<td>61%</td>
</tr>
<tr>
<td>Agree</td>
<td>1</td>
<td>8%</td>
</tr>
<tr>
<td>Disagree</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Strongly disagree</td>
<td>4</td>
<td>31%</td>
</tr>
</tbody>
</table>

The fact that almost two-thirds of educators felt that they should decide on which cluster group they would like to belong to, could indicate that many of them are not completely satisfied with the clusters to which they belong.

If educators were given the opportunity to group schools into clusters, eleven (92%) of the respondents indicated that they would group schools that were close together into the same cluster. Travelling times and costs are some of the other factors that they would take into consideration to group the schools together. The perception also exists that clusters ought to be a mixture of schools that are high achieving, together with schools that achieve below average pass rates. The rationale behind that is that higher-achieving schools will share successful practices with under-performing schools.

Most educators described the qualities of a good cluster group by referring to ‘regular meetings’, ‘more relevant discussions’ and ‘better organisation’.

Table 6. Would you consider the cluster group that you belong to, to be a good cluster?

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of responses</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>7</td>
<td>54%</td>
</tr>
<tr>
<td>No</td>
<td>6</td>
<td>46%</td>
</tr>
</tbody>
</table>

Educators in this study are almost equally divided between those who feel that they belong to a good cluster, and those who don’t. These results seem to support the responses provided in Table 5.
When probed as to what about a particular cluster made it a good/poor cluster, we were unable to find many common reasons amongst those educators who had indicated that they belonged to a good cluster. However, there seemed to be a perception that good cluster groups involved educators sharing ideas, and met regularly. The perceptions of those educators who felt that they did not belong to a good cluster also varied a lot, but most quoted poor leadership and lack of commitment from cluster members.

Educators’ responses as to the factors that they thought would prevent a cluster group from reaching its desired objectives were similar to those mentioned at the end of the previous paragraph, including poor leadership, lack of commitment from the GDE, and lack of support for the local districts. Poor leadership was thus cited as both a characteristic of poor clusters, and as a factor that prevent cluster groups from reaching their objectives.

Table 7. Perceptions on whether cluster groups need leaders.

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of responses</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>12</td>
<td>92%</td>
</tr>
<tr>
<td>No</td>
<td>1</td>
<td>8%</td>
</tr>
</tbody>
</table>

Only one educator did not agree that a cluster should have a leader. In response to a question as to why they thought that a cluster group needed a leader, educators indicated that the purpose of the leader was to guide the activities and monitor the progress of the cluster group. They also believe that the leader is specifically tasked with calling meetings regularly.

When probed about their opinions on the qualities of a good cluster leader, common responses included ‘strong leader’, ‘good leadership’, ‘experienced’ and ‘reliable’. The following traits of an effective cluster leader were also mentioned:

- Be organized
- Focus the efforts of the group
- Be experienced with NCS
- Guide cluster members on what is required of them
- Be easy to reach
- Liaise with GDE regularly

The general feeling was that cluster leaders needed to have all these qualities for the group to be successful.

Table 8. Perceptions on whether educators think that cluster meetings are useful.

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of responses</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>8</td>
<td>62%</td>
</tr>
<tr>
<td>No</td>
<td>5</td>
<td>38%</td>
</tr>
</tbody>
</table>

Almost two-thirds of educators agree that cluster meetings are useful. When probed regarding their feelings about how they benefited from cluster meetings, educators indicated that cluster meetings provided the ideal opportunity for them to share ideas and to check if they were on the right track.

The combination of the majority of educators in this study indicating that they work better with colleagues in their clusters, as opposed to working alone, and believing that cluster meetings are useful, seems to confirm the assertions made by Achinstein (2002) regarding educators not wanting to work in isolation, and Goosen (2004) that these meetings help educators to feel that they do not stand alone. This could also imply that educators recognize the advantages of group work.
On the other hand, those educators who indicated that cluster meetings were not useful to them pointed out that cluster meetings were disorganised, since the leader seemed uncertain about what to do. Because concerns were raised about (a lack of) organisation, despite the fact that cluster leaders were supposed to have attended information sharing meetings at the beginning of the year, a return might have to be considered to something like the two days’ worth of training for cluster leaders initially conducted (GDE, 2001).

These educators also indicated that they had to travel to unsafe remote locations for long hours to attend cluster meetings. Some educators indicated that they handed over their work to other cluster members without receiving anything in return.

**Table 9.** Priority given to cluster meetings by educators’ schools.

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of responses</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top priority</td>
<td>11</td>
<td>92%</td>
</tr>
<tr>
<td>Not top priority</td>
<td>1</td>
<td>8%</td>
</tr>
<tr>
<td>Can be missed</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Not a priority at all</td>
<td>0</td>
<td>0%</td>
</tr>
</tbody>
</table>

Most educators indicated that cluster meetings were a top priority at their schools. It would then seem as though, as recommended by DuFour (2004:9), schools do seem to provide educators with “time (and opportunities) to analyze and discuss ... curriculum” related issues by allowing them to attend cluster meetings.

**Table 10.** Who takes responsibility to inform staff of cluster meetings?

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of responses</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>The secretary</td>
<td>3</td>
<td>25%</td>
</tr>
<tr>
<td>School principal</td>
<td>2</td>
<td>17%</td>
</tr>
<tr>
<td>Head of department</td>
<td>4</td>
<td>33%</td>
</tr>
<tr>
<td>A notice is left for educator</td>
<td>2</td>
<td>17%</td>
</tr>
</tbody>
</table>

The purpose of this question was to determine the priority given to cluster meetings in terms of communication. It is evident that cluster meetings are communicated to educators via many channels. No other options, apart from those provided on the questionnaire, were mentioned by respondents, and none of the educators cited poor communication as a hindrance to the functioning of cluster groups.

The main reasons cited for educators not attending cluster meetings combined factors already mentioned, again citing poor leadership, lack of support from the local district, long distances to travel and unsafe venues for cluster meetings.

**Table 11.** Which of the following applies when you need to attend a cluster meeting?

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of responses</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>You arrange your own transport.</td>
<td>12</td>
<td>92%</td>
</tr>
<tr>
<td>The school pays you for your transport.</td>
<td>12</td>
<td>92%</td>
</tr>
<tr>
<td>The school reimburses you if you need to make telephone calls, send faxes etc.</td>
<td>12</td>
<td>92%</td>
</tr>
</tbody>
</table>

It is quite evident from Table 11 that schools support educators when they need to go for cluster meetings. Financial issues do not prevent educators from attending cluster meetings, and it would seem that educators are allowed sufficient time to come together and plan collaboratively for implementation.
Educators indicated that they would be encouraged to attend cluster meetings if these meetings were more organized, more convenient to attend, and more supportive and informative. When explaining what discouraged them from attending cluster meetings, educators cited very similar reasons to those provided for not attending cluster meetings.

Interestingly, in an article by Hattingh, Aldous and Rogan (2007:83) the item ‘In my district teachers from different schools meet often so as to support and encourage one another’ was shown to significantly influence the quality and level of practical work in science classrooms – it would be interesting to investigate in a further study whether such opportunities, “where teachers collaborated with one another, both within and across schools” (ibid) in clusters also significantly influence the quality and level of other aspects, as well as specifically in Physical Sciences classes.

**Reflection, Implications and Recommendations**

It was pleasing to note that, despite the warning from Carpenter and Matters (2003:2) that collaboration across cultures “may create conflict”, as such educators could subscribe to different “norms and practices”, none of the educators in this study mentioned dissatisfaction with the fact that they had to work with different race groups.

The gender split for respondents in this study reflects the domination of males in Physical Sciences in the FET phase. The inclusion of more female educators in this study would probably have added greater depth, by indicating how women cope in cluster groups. Perhaps the attitudes of women belonging to cluster groups that are dominated by males would be an interesting concept to investigate in future studies.

Similar to what Jita and Ndlalane (2009) described, this study produced rich (and some unexpected) information about how cluster groups functioned. Much of the responses obtained were fairly simple to sort into themes, and to suggest recommendations. However, the relatively small number of respondents might lead to a situation where the findings of the study and these recommendations cannot necessarily be generalised to all cluster groups in Gauteng, or anywhere else for that matter.

The questionnaire used contained several questions that helped educators reflect on their experiences in their cluster groups. However, it was felt that the questionnaire could have been made shorter. Perhaps it would have been more suitable to include more multiple choice questions, as many of the respondents chose not to complete the longer questions - this posed a problem when it came to collating and interpreting the data. However, the reason for including longer explanation type question was to bring qualitative dimensions to this study, as such questions sought to gain a better understanding of educators’ perceptions.

The sample for this research involved educators from previously disadvantaged schools. Since previously disadvantaged schools are primarily from rural areas, it became very difficult for the researcher to make contact with some of the educators. This is not a reason to exclude these educators from future studies, but one need to take note of the fact that travelling to rural areas can be an expensive undertaking for a researcher.

One needs to keep in mind that the questionnaire was completed by the respondents at their homes. This allowed respondents to reflect on their experiences in their own time without the researcher influencing their judgment. However, even though the researchers’ contact details were made available to the respondents, if they needed to ask questions if they did not understand anything clearly, this would have meant that the respondents needed to have a cell phone or a land line to contact the researchers. This definitely impacted on the accuracy of the responses, and on whether respondents answered all the questions.
Perhaps a larger amount of data could have been obtained in a shorter space of time if all potential respondents answered the questionnaire at the same time (Maree & Pieterson, 2007:157). In this way the response rate could have been optimised, and the researcher could have assisted respondents with difficulties as these arose. Although it is highly unlikely that persons other than the intended respondents had completed the questionnaires, this possibility could have been eliminated altogether.

The analysis of the questionnaire was done on a question by question basis. The percentages for responses were calculated and, using these percentages, general statements and assumptions about educators’ perceptions were made. This represented the quantitative data and seemed the simplest method of processing the data obtained. An item analysis and factor analysis of questionnaire items could have given further credibility to the study and it would have made the findings more reliable.

**Conclusion**

This study explored issues related to educators’ perceptions of cluster groups, the extent to which cluster groups have supported educators, and how they think the operation of cluster groups can be improved.

In agreement with many other indications from literature, more than three-quarters of the educators in this study only rate their confidence with regard to teaching the NCS for Physical Sciences as ‘fair’.

Although almost three-quarters of educators indicate that they work better with their colleagues in their clusters, as compared to if they were working alone, they are about equally divided between those who feel that they belong to a good cluster, and those who don’t, and more than two-thirds of them are not entirely satisfied with the support they receive in their cluster groups.

Having established that educators prefer to work with each other in cluster groups, the focus is now placed on how cluster groups function. Educators perceive the sharing of ideas as one of the reasons for educators/schools being grouped into clusters, and believe that good clusters involved educators sharing ideas. Together with educators’ explanations that they benefit from cluster meetings as opportunities for them to share ideas and check whether they are on the right track, these could show some correlation to all three reasons cited by Bryk and Schneider (2002).

The notion of advantaged schools helping disadvantaged schools in the cluster milieu was also raised as a reason for educators/schools being grouped into clusters. Educators believe that schools which are located close together should be clustered, as to reduce travelling time and costs to attend cluster meetings.

Educators in this study believe that good clusters have regular, well-organised meetings. On the other hand, those educators who feel that they do not belong to a good cluster often refer to poor leadership. A lack of commitment from cluster members and the GDE, together with a lack of support for local districts, are some of the factors that educators think prevent cluster groups from reaching their desired objectives.

This study showed that educators agreed that cluster groups needed to have leaders, but that more training of such leaders is needed in order for them to effectively organise what goes on in the clusters.
It would seem that educators in this study have accepted that they benefit from participation in cluster groups in that the following advantages, as outlined by Goosen (2004), become available to them:

- Educators do not feel alone in their endeavours when they learn that their colleagues are also experiencing problems. Fellow educators not only understand their problems, but can also sympathise with many of the frustrations that they have also experienced;
- Not only do the social interactions appeal to educators, but these also provide a structure through which colleagues can collaborate to help one another. Educators get the feeling that there are others who would be willing to tell them what they think could work, as each person could contribute knowledge and skills to their mutual benefit. They are also able to bounce ideas off one another in an attempt to present material to learners in an interesting fashion and to make materials available, if other educators are interested; and
- They are very willing to share information and discuss with colleagues experiences and perceptions about instructional planning and problem solving activities employed by individual educators. Such discussions can lead to shared views and a shared sense of responsibility.

References


Are Natural Science teachers’ conceptual understanding of Astronomy developed through a module in an ACE programme?

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Abstract
Advanced Certificates in Education (ACE) have become a common vehicle for upgrading teachers’ qualifications. However, the question arises whether such courses contribute to the improvement of knowledge and skills. This research reports on an ACE course in science where data were collected to determine whether teachers benefited in terms of their conceptual understanding of Astronomy. The conceptual framework applied in the study is based on three constructs i.e. the social circumstances of cognitive activities; domain-specific processes and practices, as well as the importance of epistemological beliefs. A pre and post-module questionnaire, as well as interviews were the instruments used to collect data from a cohort of students registered for a module in the ACE programme. The data revealed that very little conceptual change occurred. Students still held misconceptions of basic astronomy concepts on completion of the section on Astronomy and most were unable to explain movements of the earth, sun and moon in relation to each other. Possible reasons for the lack of conceptual change are: Classroom environments and instructional strategies that are not conducive to conceptual change; an emphasis on declarative knowledge with little attention paid to procedural knowledge and lastly, students own epistemological beliefs of what constitutes science knowledge and learning.

Introduction
With the advent of democracy in South Africa, many changes were introduced. One of the most radical changes was the introduction of a new educational system. It was imperative that a democratically elected government be seen to eradicate the inequalities embedded in the apartheid education system. The introduction of Curriculum 2005 (DoE, 1995) as a single national curriculum for all citizens heralded not only a different approach in education in terms of an emphasis on the development of knowledge and skills, but also many changes with regard to the content of the curriculum.

Curriculum 2005 is a two-tiered system with the General Education and Training (GET) phase providing the basis for the Further Education and Training (FET) phase. The various disciplines in the GET phase are described as Learning Areas, with Natural Science as one of the designated Learning Areas. This Learning Area consists of 4 knowledge strands of which ‘Earth and Beyond’ is one. Most of the content of this knowledge strand was never included in the science curriculum of the most departments of education in the previous dispensation.
with the result that many science teachers have very little knowledge of Astronomy or Geomorphology.

**Background**

As science teachers are required to teach the above sections in the new curriculum, a number of workshops were initially organised by the Provincial and National Departments of Education in an attempt to re-skill teachers. However, this proved to be inadequate as the new curriculum provided access to more learners in the Natural Sciences and as a consequence many more teachers qualified to teach this Learning Area, were required.

This state of affairs prompted many tertiary institutions to offer qualifications that would ostensibly allow teachers to upgrade their qualifications in science or alternatively allow teachers who had no qualifications in science to be re-skilled and consequently qualify as science teachers in the GET phase. The institution where this research was conducted rose to the challenge and introduced an Advanced Certificate in education (ACE) specialising in Science Mathematics and Technology. The delivery mode of the module in this ACE was through seven contact sessions over one semester. Astronomy comprises one third of the module ‘Earth and Beyond’ and was taught at the start of the semester. The initial contact sessions were at the institution, while the remaining sessions were offered at centres across the province. All students registered for the course are practicing teachers.

Given our experience of previous ACE programmes we were interested in researching the efficacy of an ACE programme in promoting conceptual change. We decided to focus on Astronomy as this is an unfamiliar topic for many teachers. The purpose of this research therefore was to determine the impact on conceptual understanding as a result of engagement with a module in the ACE programme. The research questions underpinning the study are:

- How did teachers’ understanding of astronomy concepts and processes change after completing a module in an ACE programme?
- Why did their understanding of astronomy concepts and processes change in the way that it did?

**Conceptual Framework**

The cognitive framework for conceptual change applied in this study was adapted from a report by Duschl and Hamilton (1998) on conceptual change in Science and in the learning of Science. This framework provided us with an appropriate lens through which to analyse our data. The adapted framework covers three aspects that may have significant influence on conceptual change in science learning. These are:

- Social circumstances of cognitive activities
- Domain-specific processes and practices
- Importance of epistemological beliefs

While Duschl and Hamilton’s (ibid) report covers three subsections under each of the above areas, this research has focused on only one aspect ie implications for the teaching of science. As the research was about teachers’ learning astronomy concepts and processes, it is appropriate that we focus on how the above influence the learning of science teachers as students.

**Social circumstances of cognitive activities**

This theoretical construct is informed by a view of scientific knowledge as socially
constructed and by a perspective on the learning of science as knowledge construction involving both individual and social processes (Driver, Asoko & Leach, 1994). Learning improves when communication, and particular scientific discourse, between students and teacher is promoted. The kinds of communication required to promote conceptual change can be structured by the teacher (Pea, 1993, in Duschl and Hamilton). He (ibid) is of the opinion that conversations which embed meaning negotiation and appropriation processes are more likely to promote conceptual change. This process allows for the identification of shared, as well as divergent views with regard to a particular activity. This process requires the teacher to take a student’s meaning and reflect back the interpretation within the conversation. It also implies using a student’s meanings within a particular learning activity. In essence therefore, the aim is to not only to change the nature of what a student knows, but to help them to understand how they come to know what they know.

**Domain-specific processes and practices**
This aspect is concerned with the Nature of Science and the meaning of conceptual change within Science as well as within the individual. A number of philosophical models, such as those of Kuhn (1962) have been adopted by science researchers and has led to the categorisation of the mechanism of knowledge change into weak restructuring and radical restructuring models. Alternatives to this approach of categorising conceptual change have been offered as well and for the purpose of this study the generally agreed upon view that scientific thinking and problem-solving are grounded in a particular domain, will be applied (Glaser, 1984). This means that declarative knowledge related to principles, laws, theories and generalisations of science must be taught alongside the procedural and strategic knowledge of the domain (Duschl and Hamilton, 1998). Conceptual change therefore involves the restructuring of both declarative and procedural knowledge.

**Importance of epistemological beliefs**
This aspect acknowledges the importance of the learner’s epistemological beliefs. Sufficient evidence exists to suggest that a learner’s epistemological framework is a factor in effecting changes in knowledge representation (Duschl and Hamilton, 1998). Epistemological beliefs refer to the individual’s beliefs about the nature of knowledge and learning. Epistemological beliefs influence the degree to which individuals are actively involved in and in control of their learning.

**Literature Review**
A comprehensive body of research exists which has attempted to understand what facilitates or hampers conceptual change in science learning (Cobern & Aikenhead,1998; Driver, Squires, Rushworth & Wood-Robinson,1994; Duschl & Hamilton,1998; Hewson & Hewson, 2003). There is sufficient evidence in such research to suggest that conceptual change is facilitated when the science learnt is interesting and relevant and above all, grounded in practical application (Taylor, 2001). This has implications for the teaching of Astronomy as the topic is not easily grounded in practical application. Furthermore, Astronomy does not appear to be a topic that the general public views as particularly relevant to their everyday lives. This was revealed by a survey where only 55% of adults thought of the sun as a star. (Driver et al 1994). They are of the view that astronomy literacy is entwined with social institutions and values, as well as education. This has implications for disadvantaged communities where opportunities for improved conceptual understanding of astronomy may not be supported by social structures in the community.
Tests results are not always an indication of conceptual understanding as evidence suggests that most students retain correct conceptions long enough to pass tests, but in the long term revert to their previous misconceptions, if the misconceptions are not dealt with during instruction. Numerous studies with regard to student learning in Astronomy have revealed that the level of conceptual understanding achieved, is often overestimated. In reality, long term conceptual change is much lower than test results show (Prather, Slater, Adams, Bailey, Jones & Dostal, 2005). The explanation often given for this low student achievement is the mode of instruction. Appropriate instructional strategies are therefore essential (Diakidoy & Kendeou, 2001). Lectures are the most often–used instructional strategy where large classes are concerned. One of the challenges faced by any teacher of Astronomy is the prevalence of misconceptions that students hold and the impact of these misconceptions on learning (Zeilik & Bisard, 2000). Conceptions that learners bring to the learning situation should be explored by the teacher and used to build upon (Baxter, 1991). Comins (1999) suggests that teachers should ask misconception-based questions and expect students to write the answers- this gives the teachers an idea of what the misconceptions are as well as the students the opportunity to reflect on their answers. A key goal is to find common misconceptions so that instructional time can be focused on them (Zeilik, Schau & Mattern, 1998). Zeilik, Schau, Mattern, Hall, Teague, & Bisard, (1997) stress the importance of carefully designed instructional activities to promote improved understanding of astronomy concepts as an overwhelming body of evidence points to the fact that learners come with preconceived ideas which cannot be ignored. Teachers’ actions have a major effect on how students learn eg how the teachers explain ideas and organise information will influence the way students view science.

Frède (2008) adopted an approach where students were presented with misconceptions as well as given the opportunity to disprove the misconceptions through hands on activities. She found this to have a positive effect on their conceptual understanding (ibid). Unfortunately, some misconceptions are so deeply rooted that even intense instruction will not produce large gains over a semester. Barab, Hay, Barnett & Keating (2000) promote a participatory, project-based approach, based on constructivist principles to promote better understanding of astronomy concepts. This approach is advocated widely in research on conceptual development in Astronomy and this has implications for the way in which astronomy courses are designed. McGuiness (1993) supports the view that learning is strongly influenced by the social context in which it occurs, supporting socially shared cognition and situated cognition as new ways of understanding cognitive development.

Coll and France (2005) argue for the use of models and analogies within the pedagogy of science education in order to develop a better understanding of the Nature of Science and the scientific enterprise. In addition, recent research has shown that some pedagogical approaches to model use have enabled students to develop a meta-cognitive awareness as well as providing the tools to reflect on their own scientific understanding. This approach may indeed also benefit students in their learning of Astronomy (ibid). The results of a study by Keating, Barnett, Barab and Hay (2002) revealed that 3D computer modeling can be a powerful tool in supporting student conceptualisation of abstract scientific phenomena. This of course has implications for under-resourced learning environments. Schoultz, Säljö and Wyndham (2001) argue that the use of models as tools for thinking reduces the misconceptions that previous research has claimed most children have, while Shen and Confery (2007) support the view that models are important and describes how the design of models assisted their understanding and awareness. Yair, Mintz and Litvak, (2001) are of the view that Astronomy, more than any other field in science, requires models, both mental and physical, to facilitate
understanding of astronomical processes. Tayler, Barker and Jones (2003) argue for the use of mental models as essential tools when teaching Astronomy.

Research of student beliefs have revealed that children hold ‘non-science’ beliefs about scientific phenomena. Cobern and Aikenhead (1998) are of the view that a student’s culture can affect their learning science. This is especially true of non-western cultures (Freed, 2002). This has implications for science teaching as teachers need to ensure that they have some knowledge of the cultural beliefs of students in their classes, as well as the biases in the materials they may be using in the classroom (ibid). While research has established how preconceptions about science phenomena may affect learning, there is less consensus about the effect of epistemological and motivational factors on science learning. Epistemological factors refer to students beliefs about science learning (Hogan, 1999).

The literature review covers research conducted with a view to gaining some understanding of conceptual development in science learning. All the sources report on research conducted with children (primary and secondary). Very little research reports on how adult students come to develop their conceptual understanding of science, and specifically of Astronomy.

**Methods**

As the methodological paradigm applied in this research is interpretive, the study may be classified as a qualitative study, although a quantitative element is a feature of this research. The study focused on an interpretation of participants responses in interviews, while parts of the questionnaire were analysed quantitatively.

The participants were selected purposefully as we wished to investigate a particular group of students who were registered for a module called ‘Earth and Beyond’ in an ACE programme. Thirty three out of 36 students registered for the course agreed to participate in the study.

**Data collection**

Data were collected in the following ways:

*Questionnaires*

A questionnaire was administered to all participants. This questionnaire was administered twice: once at the start of the module –the pre-module questionnaire and secondly, on completion of the section on Astronomy, before examinations were written- the post-module questionnaire. The decision was taken to administer the post-module questionnaire before students wrote the examination as we wanted to assess their conceptual development over the course of the module and not short term gains in knowledge as a result of examination preparation.

The questionnaire consisted of three sections: Section A required students to provide biographical information; Section B assessed knowledge and understanding of astronomy concepts requiring students to answer whether statements were True, False or whether they were uncertain. Section C contained three questions where students had to demonstrate an understanding of phenomena by giving written explanations supported with relevant drawings.

*Interviews*

Section B of the pre-and post-module questionnaires were analysed to determine which students would be most suitable to be interviewed. We particularly wanted to interview
students who demonstrated minimal conceptual development. Our analysis showed that a large number of the participants fell into this category and we therefore decided to visit the two teaching centres and randomly interview students who were willing to be interviewed. Two researchers visited one centre and the third researcher visited the second centre. Nine participants were interviewed; four from one centre and five from the second. The purpose of the interview was threefold: to probe students’ reasons for registering for the ACE and to find out how they came to teach Natural Science; to develop understanding of why students changed their responses between answering the questionnaires and to probe certain persistent misconceptions more deeply.

**Results**

**Questionnaire**

The first step in the analysis of the data was an analysis of Section B of the questionnaire to determine students’ collective responses to each question. The table shows the percentage of students who gave a correct response to a question on completion of the section on Astronomy (Column A), as well as the percentage of students who still held misconceptions (Column C). However, pertinent to this study was Column B, the percentage of students whose conceptual understanding improved in that they were able to give a correct response in the second questionnaire.

<table>
<thead>
<tr>
<th>Table 1: Analysis of total responses to each question</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Section B</strong></td>
</tr>
<tr>
<td><strong>Question</strong></td>
</tr>
<tr>
<td><strong>Total percentage of correct responses on completion of the module</strong></td>
</tr>
<tr>
<td>----------------------------------------------------</td>
</tr>
<tr>
<td>1 In the Northern hemisphere the sun rises in the west.</td>
</tr>
<tr>
<td>2 In the Southern hemisphere the sun rises in the east.</td>
</tr>
<tr>
<td>3 The position of the Sun at midday in Summer and Winter is the same.</td>
</tr>
<tr>
<td>4 The Moon can sometimes be seen during the day.</td>
</tr>
<tr>
<td>Question</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td>5. The sun goes around the Earth.</td>
</tr>
<tr>
<td>6. The Earth goes around the sun.</td>
</tr>
<tr>
<td>7. The Earth spins on its own axis</td>
</tr>
<tr>
<td>8. The Moon moves around the Earth and the Sun.</td>
</tr>
<tr>
<td>9. We see the Moon because it gives off its own light.</td>
</tr>
<tr>
<td>10. As the sun sets the Moon rises.</td>
</tr>
<tr>
<td>11. The shape of the Moon as seen from earth depends on where the Sun and Moon are relative to each other.</td>
</tr>
<tr>
<td>12. The portion of the Moon that is not seen is in the earth’s shadow.</td>
</tr>
<tr>
<td>13. The Earth is the centre of the Solar system</td>
</tr>
<tr>
<td>14. The Sun is a star.</td>
</tr>
<tr>
<td>15. Our daily lives are determined by the positions of the sun, moon and the earth.</td>
</tr>
</tbody>
</table>

The questions in which the students scored highly are based on primary school Astronomy and are therefore the very basic concepts of an astronomy course. However, questions based on the movements of the sun, earth and moon, produced low scores. The low score for question 12 gave us some indication of the level of understanding of Astronomy of the cohort. A further interesting response was question 15. We did not expect so many students to believe that this statement is true.

While students produced correct answers for a number of questions, they appear to have had a correct understanding of these phenomena to start with. For instance in question 6, there was no improvement in conceptual understanding. In fact, initially all students gave a correct response, but 6.1% changed their minds during the course of the module. Very little improvement in conceptual understanding seems to have occurred during the teaching of the module.

The second step involved analysing students’ responses to the questionnaire based on the number of years they have been teaching Natural Science. The reason for this was to determine if teachers with more experience of teaching Natural Science had acquired more
knowledge of Astronomy than their colleagues with less experience.

Table 2: Analysis of student’s responses by categories of experience (n=33)

<table>
<thead>
<tr>
<th>Section A</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of students</td>
<td>19</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Number of years teaching Natural Science</td>
<td>0 to 5 years</td>
<td>6 to 10</td>
<td>10 to 20</td>
</tr>
<tr>
<td>Total teaching experience</td>
<td>9: under 10 years</td>
<td>4: 6 to 10 years</td>
<td>5: 10 to 20 years</td>
</tr>
<tr>
<td>10: more than 10 years</td>
<td>4: 10 to 25 years</td>
<td>1: 25 years</td>
<td></td>
</tr>
<tr>
<td>Key topics taught</td>
<td>All have taught seasons</td>
<td>All have taught seasons as well as ‘day and night’</td>
<td>All have taught seasons as well as ‘day and night’</td>
</tr>
<tr>
<td>15 have taught ‘day and night’</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Highest score Out of 15</td>
<td>11</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Lowest Score out of 15</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Section C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Question 1</td>
<td>Write a short paragraph to explain how we get day and night. Draw diagrams to illustrate your explanation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>5 (26.3%)</td>
<td>2 (25%)</td>
<td>3 (50%)</td>
</tr>
<tr>
<td>Incorrect</td>
<td>12 (63.2%)</td>
<td>4 (50%)</td>
<td>1 (16.7%)</td>
</tr>
<tr>
<td>Partially correct</td>
<td>2 (10.5%)</td>
<td>2 (25%)</td>
<td>2 (33.3%)</td>
</tr>
<tr>
<td>Question 2-</td>
<td>In space we get moons, planets and stars. What is the difference between these three things?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct statements</td>
<td>Moon are satellites of planets</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Planets orbit the sun</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Misconceptions</td>
<td>Stars are tiny particles</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stars are smaller than moons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Question 3</td>
<td>Explain why it is warm in Summer and cold in winter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>1 (5.3%)</td>
<td>0 (0%)</td>
<td>1 (16.7%)</td>
</tr>
<tr>
<td>Incorrect</td>
<td>17 (89.4%)</td>
<td>5 (62.5%)</td>
<td>2 (33.3%)</td>
</tr>
<tr>
<td>Partially correct</td>
<td>1 (5.3%)</td>
<td>3 (37.5%)</td>
<td>3 (50%)</td>
</tr>
</tbody>
</table>

**Group 1**

While 10 out of the 19 students in group 1 have been teaching for more than 10 years, they have limited experience of teaching science. These students registered for this ACE programme with the intention of improving their existing knowledge of science. As these teachers presumably belong to the cohort of teachers who have changed direction and therefore require re-skilling, we decided to analyse their responses as a group. It is important to mention that 15 out of 19 of these teachers have taught the topics ‘day and night’ and the seasons, as well as other astronomy topics. The four teachers out of 19 who have not taught both topics, all taught the seasons.

For section B of the questionnaire, not one student scored more than 11 out of 15, with the
lowest score being 5 out of 15. Table 1 provides information as to which questions were generally answered correctly.

For section C of the questionnaire the following results were obtained:
Question 1: Five students were able to give a scientifically correct explanation as to how day and night come about, while 14 could not. Two of the fourteen could give a partial explanation. It is interesting to note that three of the 14 students initially gave a partially correct explanation in the pre-questionnaire, but incorrect explanations in the post-questionnaire. The most often given incorrect response was that the earth revolves around the sun, causing day when the earth faces the sun and night when it is turned away from the sun.

Question 2: This question produced a diversity of answers. The reason for this is that the question did not ask students to distinguish between the different celestial bodies with regard to specific criteria eg differences in gravity, whether they generated light and heat or differences in size. This is a flaw in the question and resulted in a plethora of answers, many of which were correct statements about the particular objects. One of the most common misconceptions that emerged from the questionnaire was that students did not see the connection between stars and the sun of our solar system, as well as the misconception of size- many believed the moon was much larger than any star.

Question 3: Eighteen of the 19 students were unable to give an accurate explanation why it’s hot in summer and cold in winter. This means that they are unable to explain how seasons come about. One of these students gave a partially correct answer in the pre-questionnaire, but a wrong explanation in the post-questionnaire. Three other students mentioned the angle of the sunlight as it strikes the earth, but could not explain what the significance of this is. The misconception that students have is that the distance from the sun causes Summer and Winter. This means they are either not aware of or have not considered that both seasons occur simultaneously on earth.

**Group 2**
These students have been teaching Natural Science between 6 and 10 years. Half of them have been teaching for this period of time as well, which means they have always been Natural Science teachers. The other half have been teaching between 10 and 25 years which means they changed direction during the course of their teaching career. All of these teachers have taught the topics ‘day and night’ and the seasons.

For section B of the questionnaire, no score was higher than 12 out of 15, with the lowest score being 6 out of 15. Students in this group generally had higher scores than the first group.

Section C: Question 1: Two students were able to give a scientifically correct explanation as to how day and night come about, while two gave partially correct answers in that they referred to the rotation of the earth, but could not give a complete answer. Four students still had misconceptions regarding the causes of day and night, confusing it with the earth revolving around the sun, as in the previous group.

Question 2: As in the previous group, this question produced a diversity of answers. Similar responses were given by this group, with the most misconceptions occurring around stars.
Question 3: Five of the 8 students were unable to give an accurate explanation of why it’s hot in summer and cold in winter, referring to the distance of the earth from the sun instead. The remaining three students mentioned the angle at which sunlight strikes the earth but clearly did not understand why this caused differences in temperature.

**Group 3**

This group has experience of teaching Natural Science that ranges between 11 and 20 years. Five of the six students have been teachers of Natural Science throughout their teaching careers, while one who had between 11 and 15 years experience of teaching Natural Science, has been teaching for more than 20 years.

Section B: The marks ranged from between 7 out of 15 to 12 out of 15. Three students scored below 9 out of 15, which is relatively lower than the other groups and surprising as these are the students with the most experience in teaching Natural Science.

Section C: Question 1: Half the responses are incorrect; 1 correct and two mention rotation but give partial answers.

Question 2: Two responses have correct statements, while four responses contain inaccuracies. As in the previous two groups, most of the responses are incomplete with very little said about stars.

Question 3: Two responses are completely inaccurate; one is correct and two mention the angle at which the sunlight strikes the earth, but cannot explain the significance. One of the last mentioned responses was completely incorrect in the pre-questionnaire, but progressed to partial understanding in the post-questionnaire.

**Interviews**

Three males and five females were interviewed. Three teach Grades 8 and 9, while the other six teach Natural Science in the primary school. Qualifications include Primary Teachers Diploma (PTD), Secondary Teachers Diploma (STD), ACE in Management and a B.Ed. However, none of these qualifications include Natural Science. None of them had ever attended a short course or a workshop on Astronomy. All the interviewees expressed the desire to improve their knowledge to enable them to be more effective Science teachers. It is interesting to note that some have been teaching Science for more than 10 years, and have never before attempted to improve their scientific knowledge. When questioned how they managed to cope until then without formal qualifications in science, they replied that they either avoided teaching Astronomy or asked another teacher to teach it for them.

With regards to their learning of Astronomy in the module they admitted that all this was new to them. They found the reading difficult and thought it was too much work. They agreed that the Astronomy concepts were difficult. It became obvious from the interviews that these students had no previous knowledge of Astronomy and mentioned basic concepts such as the fact that there were other planets as important information.

Four of the nine students felt that their cultural beliefs clashed with what they learnt in Astronomy with regards to stars, moons and planets. When they were questioned about their response to question 15 in Section B of the questionnaire, 8 students thought that celestial bodies determined our lives, while one student did not.
All students were confident that they had acquired important knowledge of Astronomy from the module, but when their responses to the questionnaire were explored it was clear that they were not confident at all about their knowledge. While a discussion of a question seemed to facilitate a better understanding of a concept when asked about their responses they had great difficulty explaining why they answered as they did and often reverted to the incorrect answer.

With regards to the solar system:

R: Is the earth the centre of our solar system?
N: Earth?
R: The earth, yes
N: Yes I think so
R: What is the centre of our solar system?
N: The sun
R: So you are not clear about that
N: I am confused

On the question where the sun rises:

L: The sun rises on the east
R: Does it matter where I am on earth?
L: Yes
R: If I am in England, watching the sun rise, from which direction?
L: I don’t know

On the phases of the moon:

R: If we see a full moon—what do you understand by a full moon?
L: Full moon- I am not understanding that

With regards to the moon’s movement:

Researcher: OK, the question here was if the moon moves around the earth and the sun
P: It’s the earth that moves
R: OK, and the moon, does the moon move?
P: No
R: What is your understanding of what the moon is doing?
P: It revolves around the earth

When questioned about the teaching strategies employed in the module and how this assisted their learning as well as providing them with ideas in their own teaching, a common response emerged. Their tutors made use of diagrams, but these diagrams were simple diagrams drawn on the blackboard. Pictures from books were also used. They were emphatic that no models were ever used, but one student recalled that the tutor had mentioned that they could use a globe and a torch to teach day and night. An assignment required them to make a model of a sundial.

All interviewees agreed that they did group work, but on closer questioning it became clear that group work entailed preparation of the group to do a presentation on a particular topic. These topics generally meant an explanation of what meteorites or asteroids were. The information was obtained from their course materials.

The interviewees thought that they were better equipped to teach Astronomy than they were before, although they were still apprehensive about a number of concepts and processes in
Astronomy.

**Discussion and conclusion**
Analysis of the questionnaire revealed that very little conceptual change had occurred. Students still held misconceptions of how night and day occurred and only one could give an accurate explanation of the seasons. The question arises why it was so difficult for students to develop adequate knowledge of basic astronomy concepts, given that the concepts and processes they engaged with in the module were at a level more or less similar to the GET curriculum.

The interviews revealed that the mode of instruction in the course was mostly that of transmission with students suffering from an overload of new terminology. If we hold the view that knowledge is socially constructed, for conceptual change to occur, communication and negotiation between learners are essential. There is no evidence that students had the opportunity to discuss and argue about their misconceptions. If learning is socially constructed, the classroom environment was not conducive for such learning to occur.

Interviews further revealed that students were given numerous facts that had to be memorised and processes were explained by the tutor who then expected students to be able to repeat the given explanations. Instead of students engaging in scientific thinking and problem-solving activities pertaining astronomy processes, they only engaged in attempting to explain what certain concepts meant. The lack of models as instructional tools had a significant effect on the fact that so few of them were able to correctly explain how night and day as well as the seasons came about. Students never had the opportunity to interrogate models and argue about processes, neither did they have the opportunity to construct their own models depicting the movement of the earth, and moon. Conceptual change was limited by the fact that students did not appear to engage in the restructuring of procedural knowledge, but focused instead on declarative knowledge.

Finally, probing of student motivation to enroll for this ACE programme revealed something of their epistemological beliefs with regard to the nature of knowledge and learning. Students believed the way to gain more knowledge of science was to be told about scientific phenomena and have scientific processes explained to them. The fact that many of them taught for many years and never made the effort to develop some understanding of primary school astronomy reveals what their beliefs are of what it means to learn science. These are mature adults and the Astronomy they are expected to master is that contained in the Natural Science Learning Area and yet they were unable to master these concepts to the degree that would enable them to teach Astronomy effectively.

In conclusion, this research has shown that this module had limited success in preparing teachers to teach Astronomy. The mode of instruction in this programme needs to be reconsidered, with more thought being given to creating environments for social constructivist learning. Instructional strategies need to include both declarative and procedural knowledge. Finally an effort should be made to address students’ views of how they learn and acquire knowledge, especially in the light of the fact that most of the students who enroll for ACE courses are mature adults whose epistemological beliefs about knowledge and learning are firmly entrenched.

**References**


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Learners’ choices of a favourite subject – implications for creation of a sustainable empowering learning environment

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Abstract
Teaching explanations play an important role in creating sustainable empowering learning environment (Mdunge & Wasserman, 2009) and helping learners to acquire insightful understanding of science concept but few recognize their value in a classroom situation. The purpose of this study was to identify and categorise reasons provided by learners for their choice of a favourite subject. The study was conducted with learners who also have physical science as one of their subjects. Data collection and the analysis were based on the responses of 25 Year 11 and 67 Grades 11 and 12 Australian and South African learners respectively. Seven broad categories emerged from the responses and were used for classification of individual responses from Australian and South Africa learners. Approximately 40% of the Australian students and 20% of the South African students chose science subject because they enjoyed it. Almost 20% of South African students, compared to only 4% of Australian students, chose science because of career aspirations. Studies of this type hopefully can assist science teachers in understanding aspects that may need to be taken into consideration when planning the explanations that may contribute towards the creation of sustainable empowering learning environment in a classroom situation.

1.1.1.1 Introduction
Common reference to the concept of explanation is found in the literature where it is used interchangeably with other terms such as description, interpretation and clarification (Brosnan
& Reynolds, 2001; Chemero, 2001; Lehrer & Schauble, 2010). Its potential and value in a teaching and learning situation has been underestimated. Horwood (1981) has highlighted that for the purpose of understanding scientific explanations compared to other forms of explanations it should be noted that the “Why?” question needs to be addressed; Horwood further indicated that elaborating the physical structure of a phenomenon is viewed as description but an inclusion of “Why? and How?” questions will elevate it to an explanation. This implies that various components of an explanation need to be considered in order for it to be regarded as an explanation, namely, explanatory knowledge, explanatory artefacts and explanatory behaviour.

![Figure 1: Components of an explanation](image)

The components in Figure 1 may be regarded as pillars of any explanatory situation. How these pillars are positioned with respect to the explainer and explainee are as shown. The first pillar, explanatory knowledge, refers to the topic/concepts that are to be explained by the teacher. Explanatory artefacts refer to the things that a teacher uses during explanation of the topic/concept. The third pillar, explanatory behaviour, refers to how the teacher is going to conduct the explanation, including the extent to which he/she uses different types of explanations.

Robert (1991) also refers to these pillars when elaborating upon the three elements that are expected to be present in an explanation. From a teaching perspective, Robert (1991) viewed an explanation as “having at least three elements - crafts, intent and uptake” (p. 72); he outlined how each of these elements apply to explanations within the context of classroom teaching. The explainer (teacher) makes use of various aspects of the three pillars in order to produce teaching explanations that are understandable and acceptable by the students because at the end what constitutes an explanation is dependent on “… joint construction between teachers and students …” (Yackel, 1997 p. 1).

Various sources provide different versions on the concept explanation. According to Brown (1993), explanation is viewed as “… a statement … which makes clear or accounts for something ...” (p. 888). Similarly, Wilkes and Krebs (1991) refer to explanation as “… the act or process of explaining … ” (p. 546) and regard the word explain “as making something comprehensible, that is, giving a clear and detailed account or justify by reasons …” (p. 392). Process, reasons, clarification, justification and accountability are some of the terms that are associated with the concept explanation ( Assaraf & Orion, 2010; Robinson & Davidson, 1996; Rooney, 1999; Simpson & Weiner, 1989). From the various perspectives on
explanations mentioned, what becomes apparent is the presence of three components in any explanatory situation, namely, the explainer, the explainee and the thing to be explained. The last component manifests itself in a form of a problem that an explainer needs to explain to the explainee by the use of “a set of linked statements each of which are understood by the explainees and which together lead to a solution of the problem. The set of linked statements constitutes the explanation” (Brown & Hatton, 1982, p. 5). The linked statements are the ones that facilitate understanding. Treagust and Harrison (1999) also have emphasised the need for teachers to use effective pedagogical content explanations in their teaching, that is, the kind of explanations that will link scientific content explanations with everyday explanations. The following sections elaborate further on explanation, providing a historical background on the concept and how it is used in teaching and learning of school science.

The role and effect of explanations in science education and school science (Metz, 1991) has gained recognition and the attention has now been directed to explanations within the context of teaching and learning (Knowles, 1990; Ruben, 1993). Studies of scientific explanations from various perspectives have resulted in investigations on how these scientific explanations may be transformed into effective teaching explanations. Studies that provided an insightful understanding on the nature and types of explanation and their impact on students’ learning are reported by Ogborn et al. (1996). Other studies highlighted the need for teachers to use types of explanations that are learner-friendly in order to enhance students’ understanding of school science (Brown & Hatton, 1982; Cole & Chan, 1987; Treagust & Harrison, 1999).

Studies related to the effective use of explanations in teaching and learning to improve students’ performance in school chemistry emphasise the role of explanatory artefacts such as models in helping learners make sense of science concepts (Treagust et al., 2004). Some studies have shown that although students have a limited understanding of the role of these explanatory artefacts in school chemistry, teaching and learning that has been based on these artefacts has had a positive impact in students’ learning (Chittleborough et al., 1999). Recognition of the dynamics related to the creation of sustainable empowering learning environment is essential for creation of a meaningful learning environment (Brown, 2010; Mahlomaholo, 2009; Nkoane, 2009). In the next section, there is further elaboration on the three concepts - explanatory knowledge, explanatory artefacts and explanatory behaviour.

There are studies that focused on the use of explanation to enhance learning of school science (Chinn, 1995; Gilbert et al., 1998; Lehavi & Galili, 2003) and some that elaborated on the structure of a scientific explanation in a classroom situation (Treagust & Harrison, 1999). Whilst these studies have addressed important aspects related to explanations in school science, none has focused on the extent to which learners view explanations as having an influence in their choice of a favourite subject/learning area. Other likely influences of choice of science subjects are related to careers (Katcher, 2004), enjoyment (Fagan et al., 2004) and interest (Hidi & Renninger, 2006). Understanding of these dynamics related to learners’ choices may contribute to teachers’ planning of activities and explanations that may contribute towards the creation of sustainable empowering learning environment (Brown, 2010; Mahlomaholo, 2009; Nkoane, 2009). The paper focuses on this aspect: Reasons that science learners provide for their choice of a favourite subject – implication to creation of sustainable empowering learning environment.
1.1.1.2 Methodology
The paper reports on an aspect that was part of a larger study on teachers’, textbooks’ and learners’ perceptions of how explanations are used in classroom situations and school textbooks (Mamiala, 2001). Questionnaires were administered on 29 Year 11 and 67 Grades 11 and 12 Australian and South African learners respectively and interviews also were conducted. Twelve pairs of students participated in the interviews, six from Australia and the other six from South Africa. Questions asked in the interviews, were based on the frameworks described by Ogborn et al. (1996), Child and McNicholl (2007) and Chi, (1997). Student pairs were randomly selected and based on their responses to the questions, broad categories emerged. Another researcher, who was not involved in the study, was given the students’ responses and asked to classify them under the same categories: there was a high percentage of agreement between the classification of the two researchers (Altheide & Johnson, 1994). This procedure helped in enhancing the interpretive validity of the study (Cohen et al., 2000; Gall et al., 1996), so that the researcher could establish whether or not there was any consistency in the manner in which the responses are categorized.

1.1.1.3 Results
Students’ responses for the reasons why they chose their favourite subject or learning area resulted in the following seven categories: explanation-related, career-oriented, acquisition of knowledge, affective factors, teaching style, application to real life experiences and degree of difficulty. In Australia, out of 29 students six chose Physical Science as their favourite subject with five students choosing Physics and one choosing Chemistry; other subjects such as Human Biology and Economics also were chosen. In South Africa students’ favourite subjects were Biology (n=27), Physical Science (n=18) and Mathematics (n=22), none chose languages. Analyses of the reasons given for these responses are as shown under various categories in Table 1. A brief outline of each reason type as expressed in the categories is provided, followed by the actual statement said by the respondents during the interview for further elaboration.

Explanation-related
In this category the researcher was interested in whether or not the students themselves regarded explanations as being a factor in their choices of their favourite subjects. In Australia, none of the students indicated explanations by the teacher as a contributing aspect in their choice of a favourite subject. Out of 67 written responses in South Africa, only five (7.5%) mentioned explanations by the teachers as an influence in their choices. In Mr Kole’s class, only three out of 41 students mentioned explanations by the teacher as playing a role in their choice. Their responses were:

Because the teacher explains well, we get to do things which are practical, and I am satisfied with the way he answers our questions. (ssq7)
When the teacher is explaining science to me, I think hard. (ssq35)
Because I found out that I have an ability to work on challenges in Mathematics and have a teacher who could explain so that I understand. (ssq25)

In Mr Leka’s class, out of 26 students only two mentioned explanations, as a decisive factor. According to them:

When the teacher explains, she [Student refers to another teacher] explains properly
and she deals with our questions very well so that we can understand. (ssq56)
In studies about Human Physiology, I understand it well because of the way the teacher explains it to us. (ssq68)

These comments indicate that some students, although very few, recognised the role of the teachers’ explanations in their understanding of subjects, including chemistry concepts.

**Career-oriented**
The focus in this category was to do with whether or not the choice is influenced by the intended career of the student. In the Australian sample, only one student (4.0%) had a choice associated with a career. The reason that he/she gave for the choice of Chemistry was that “I understand them [chemistry concepts] and they are related to my ambition. Also the way of teaching of my teachers is very helpful and understandable” (asq11).

In South Africa 17 (25,4 %) of the students chose their favourite subject because it was related to their career (see Table 1). For instance, some of these students gave the following reasons:

I do like Physical Science because I want to become a chemical engineer, so Science will help me to reach my goal. (ssq8)
I like Science and Mathematics because of I want to be a pilot or a fireman in an airport. These two subjects will help me to succeed in my career. (ssq13)

<table>
<thead>
<tr>
<th>Table 1: Categories of reasons for choosing favourite subjects</th>
</tr>
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<tbody>
<tr>
<td><strong>Category</strong></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Explanation-related</td>
</tr>
<tr>
<td>Career-oriented</td>
</tr>
<tr>
<td>Acquisition of knowledge</td>
</tr>
<tr>
<td>Affective factors</td>
</tr>
<tr>
<td>Teaching style</td>
</tr>
<tr>
<td>Application in real life</td>
</tr>
<tr>
<td>Degree of difficulty</td>
</tr>
<tr>
<td><strong>Total</strong></td>
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</tbody>
</table>

* Four students did not complete this section
South African students who had their choices based on their future career made up more than a quarter of the responses, which is a higher percentage compared to other categories (refer to Table 1).

**Acquisition of knowledge**

In this category, the focus was on those students who made choices based on their intentions or desires to enhance their understanding of the subject. Unlike the previous category, where students chose a favourite subject specifically for its importance in their intended careers, in this category the choice was based on the potential of the subject to improve the student’s understanding of the nature or field of study and in some cases because it was related to their career. In Australia, this category had the third highest frequency with five students (20.0%) providing reasons to support their choices as follows:

- Because we learn how to use software in computers. (asq24)
- It’s interesting to learn about the ways a business runs. (asq19)

In South Africa, this category had the third highest percentage of responses (17.9%) (see Table 1). Some of the reasons that students presented for their choices were as follows:

- It teaches about nature, which is always around us and to explore it because we know something about it and about ourselves. (ssq45)
- I learn about people, plants, and animals. Biology is so interesting and practical. I have to know all about human physiology because I am going to study Physiotherapy, which I know a lot about. (ssq53)
- It is so interesting, because I learn a lot about nature and many things that we did not know about our environment. (ssq59)

The above quotes show that some of these South African students view the importance of a subject as related to the knowledge that may be acquired through it. These students are able to appreciate the value of the subject in terms of the bigger picture of their education.

**Affective factors**

In this category, the focus is on the attitudes or feelings that students exhibit towards the subject. Most of the Australian respondents (48.0%) have indicated that their choice is more to do with their attitude to the subject rather than with its importance or relevance with the intended career or acquisition of knowledge. The students have highlighted that “they have fun in what they are doing” (asq2), “find the subject interesting” (asq29) and “love the subject of their choice” (asq20).

In South Africa, this category consisted of 11.9% of the students and included the following comments:
Because I like calculating. (ssq57)

I enjoy maths very much and don’t see myself doing Physical Science without the knowledge of Mathematics. (ssq66)

In the affective category most of the students’ reasons are preceded by expressions like “I enjoy…” “I like It …” “It is interesting…” “I am pretty good at …”. These expressions indicated the students’ attitudes or feelings that might have contributed towards the choice of their favourite subject.

**Teaching style**

From the researcher’s experience and observations as a student, as a researcher and from the literature review on explanations (Dagher & Cossman, 1992; Ogborn et al., 1996; Treagust & Harrison, 1999), a teacher plays an important role in that her or his teaching styles promote or make scientific explanations understandable to students. However, the findings in this stage of the study indicated that very few students associated their choices of favourite subjects with the teachers’ style of teaching or explaining. For instance, none of the Australian students mentioned teaching style as contributing towards their choice of a favourite subject. The only student whose response included the teacher’s way of teaching was classified under Career-oriented and therefore could not be classified a second time. According to the student, her choice of Chemistry and Introductory Calculus as favourite subjects was associated with the teachers’ way of teaching. The student said, “… also the way of teaching of my teachers is very helpful and understandable”. (ssq11)

In South Africa, out of 67 students only two indicated that their teachers’ teaching role has an influence in their choices of subjects. One student gave the following reason for choosing Biology as her favourite subject:

> Because the teacher makes me understand everything about it. She always moves with a good pace when she teaches. She does not discriminate. So far, I know a lot about myself and about plants and animals. Biology is so funny and good. You can understand each and every process about your being. (ssq61)

As noted, there was a low percentage (1.5%) of South African students recognising the influence of the teacher’s teaching style on their choice of favourite.

**Application in real life**

In this category, students have highlighted that their choices of favourite subjects are based on how this may be applicable to their real life experiences. In Australia, two of the three students’ (12.0%) responses were:

> The theories and ideas in class can be seen to be physically happening around you at all times. (as25)
> Because I love taking photos as art, I like producing photos which I have done.
In South Africa, some students (16.4%) viewed their choices as influenced by this aspect of application to real life experiences and expressed their reasons as follows:

Maybe if we can understand the genetic structure of a human, we may be able to change the genetic structure (DNA) to make a human, or the body will not allow any sickness or make a perfect human. (ssq6)

Because I like to know more about what is really happening in the body. And knowing about what is happening during pregnancy and more about the brain. (ssq23)

Because it helps me to know about the human’s body and shows me how can I keep myself clean. (ssq42)

The reasons provided by these South African students may give one an idea about the approach used by the Biology teacher whose emphasis is on how the subject can be useful in the daily lives of the students. This may be closely related to what Treagust and Harrison (1997) referred to as learner-friendly type of explanations, that will result in students acquiring relational understanding (Skemp, 1976) of the school science concepts.

**Degree of difficulty (Easiness)**

To “like” the subject, to perceive it as being “interesting” or to be “pretty good” at the subject does not tell anything about its degree of difficulty and as such in this category, the researcher grouped those students (18.0%) who specifically indicated that their choice of the subject was based on it being easy to do. In Australia, this category had the second highest frequency (24.0%). According to some of the students:

Non-TEE course, less pressure. (asq8)

Because there is not much to do, and not much calculations to do. (asq17)

It is the easiest subject that I have and I enjoy it as it takes place in a relaxed atmosphere. (asq27)

In South Africa, the category had the third highest frequency (16.3%) and some of the responses were:

Because I get high marks and it keeps me busy. It will help me to get what I want in my future. (ssq26)

Because the maths is the subject, which I can do better than the other subject at school and I like it, it is the easy one. (ssq27)

Because I understand Biology faster than the other subjects, when compared with Physics and Mathematics (ssq54).

Most students’ responses in this category have indicated that their choice of favourite subjects is the result of them being easy to understand. In Australia, students’ choices of favourite
subjects appear to be influenced by affective factors; in South Africa, the influence is by the intended careers of the respondents.

1.1.1.4 Conclusion

This paper sought to identify and categorise the reasons that students provide for their choice of a favourite subject. The results indicate that few students regarded science as their favourite subject and of those who did, few students (none in Australia and 7.5% in South Africa) considered teachers’ explanations of concepts as an influence of interest. This implies that if teachers’ explanation of science concepts are to gain some recognition by learners in a classroom situation it is suggested that issues mentioned in the categories are taken into consideration during the preparation of the intended school science explanations. Use of explanations that are compatible with students’ interests, understanding and experiences will contribute towards improving the effectiveness and significance of teacher’s explanation in a classroom situation. Teachers need to be reflective of their explanations in a learning situation. The key outcome of any explanatory situation is the creation of a sustainable empowering learning environment. Teachers’ insightful understanding of explanatory situations for creation of sustainable empowering learning environment has the potential to promote meaningful learning and explanations that are learner friendly.

1.1.1.5 Reference


Teachers’ deconstruction of the image of science through contiguity argumentation theory - Paving the way for IKS in school curriculum

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“Our challenge is to devise a system of education for all people that respects the epistemological and pedagogical foundations provided by Indigenous as well as Western cultural traditions” (Barnhardt and Kawagley, p. 10).

Introduction
In some African countries the curriculum has been undergoing major changes in regard to what to include as content to be taught at school. In fact countries like South Africa, Mozambique and Lesotho have formulated in their new policy objectives issues relating to Indigenous knowledge system (IKS). However, curricula that have attempted to implement an inclusive education and to counteract excessive scientism so much abroad face enormous challenges with respect to teacher training and material development. A few years ago, the School of Science and Mathematics Education University of Western Cape, initiated a project aimed at equipping teachers with knowledge and skills to implement an inclusive science and IKS curriculum. The programme is based on a series of workshops in which teachers are introduced to the Contiguity Argumentation theory (CAT) as a philosophical/psychological ground to explore the Nature of Science (NOS) and the Nature of Indigenous Knowledge System (NOIKS). This paper will look at the effect of the workshops on teachers’ views of the image of science.

The Contiguity Argumentation Theory (CAT)
In view of the socio-political change in South Africa coupled with the emergence of multicultural classrooms, there is a general agreement with the aims of a new curriculum to teach IKS along school science. The area of contention however has been how educators
(teachers) can integrate the two distinctly different systems of thought in their classrooms. One of the challenges is that a naïve view that IKS can tempt teachers to simply extract the content of IKS from various sources without any ontological consideration of its nature and without teachers and pupils’ axiological consideration may lead to poor understanding of science and decadence of IKS.

A plethora of studies have shown how pupils own ontological (their worldviews) and axiological (their system of values) interfere with their learning in science. For example Aikenhead (2000) uses the term border crossing to explain difficulties that learners encounter while crossing from their everyday life world into the science classroom. Ogbu (1992) referred also to this process as “boundary crossing”. Jegede suggests the theory of “collateral learning” according to which “a learner in a non-western classroom constructs, side by side and with minimal interference and interaction, Western and traditional meanings of a simple concept” (Jegede, p.130,1999). Fakudze introduced the “African Learners Model” that encompasses theories of border crossing, collateral learning and contiguity (Ogunniyi, 1995). George (1999) identified four categories of interactions that could occur between learners’ IKS and school science knowledge. There is also reference to science educators using postcolonial theories such as Bhabha’s notion of third hybrid space (Bhabha, 1994) to reflect on classroom context. Shumar (2010) says hybridization is a process that “denies the binary reality and power of colonizer/colonized but also sets up possibilities for new social spaces for new discourses and new forms of subjectivities that potentially can be liberatory” (p. 498).

In the context of a country that had been under colonialism and apartheid the need to consider ontological and axiological issues becomes even more important. The process of including IKS in school requires teachers to deconstruct the image of science embedded in tradition of dogmatism and exclusivity. We argue in this paper and based on pre- and post- test analysis that CAT as espoused by Ogunniyi (2007a) offers an appropriate platform for dialogue between science and IKS corpuses. To contextualize CAT, we will first refer to Toulmin Argumentation Pattern (TAP) and explain its shortcomings in the case of an inclusive science and IKS and then we will refer to how Platonic and Aristotelian contiguity have informed the formulation of CAT.

Argumentation is a form of dialogue that can be used for instance in science classes, to engage students in building their knowledge through claims and justification about certain knowledge. It is a process of logical reasoning. A model for argumentation in science classes has been outlined. The model is constituted by claim, warrant, data, backing, and rebuttals. According to Erduran et al (2004, p. 918) Toulmin defines a claim as:

An assertion put forward publicly for general acceptance.” Grounds are “the specific facts relied on to support a given claim.” Backings are “generalizations making explicit the body of experience relied on to establish the trustworthiness of the ways of arguing applied in any particular case.” Rebuttals are “the extraordinary or exceptional circumstances that might undermine the force of the supporting arguments.” Toulmin further considers the role of qualifiers as “phrases that show what kind of degree of reliance is to be placed on the conclusions, given the arguments available to support them.”

Because arguments are by nature dialogical they may provide a critical environment for an inclusive curriculum. However as Ogunniyi (2008) states, one of the shortcomings of TAP is that it is appropriate to a deductive-inductive classroom discourse but poses some challenges when IKS is to be integrated with school science”. A deductive-inductive approach works well for exclusive science context where its epistemology is inspired by Cartesian dualism. However this approach would frustrate the aim to be inclusive of different kinds of
epistemologies and worldviews. If we took logic (deductive and inductive) as a form for reaching a certain assertion about the validity or fallacy of an argument, we have to admit that deductive and inductive logic are just one epistemological approach to knowledge, Taylor et al (in press) refers for example to different logics that can be used in research to reach a higher level of understanding of certain phenomena. They quote for example, dialectic logic “which promotes multiple faces of knowledge and knowing”, narrative logic which “promotes thinking grounded in everyday life worlds” and where knowledge is diachronically constructed, metaphorical logic (also referred by Lakoff and Johnson), etc. We are arguing that although TAP may be appropriate to enhance learners’ knowledge in a single worldview, in this case, science but it does not allow the accommodation of multiple worldviews. It holds by nature a dualistic approach for dialogue, “which can create unhelpful antagonisms between opposing attributes” (Taylor et al in press), while the aims of new South African curriculum is to integrate different worldviews.

CAT is rooted in the Platonic and Aristotelian Contiguity theory about different ways that ideas interact in the human mind and explore the positive aspects of argumentation, in a way that is dialogical. The Aristotelian Contiguity Theory “asserts that one or two states of mind (or as applied in the CAT two distinct co-existing thought systems e.g. science and IKS) tend to readily couple with, or recall each other to create an optimum cognitive state” (Ogunniyi 2009). In this way CAT adds to the traditional theory on argumentation the fact that this is a dynamic process. Learners and teachers move back and forward between the two different systems of thoughts. For the contiguity argumentative dialogue instead of dualistic logic there are categories which are contextual and dialectically existent. The five categories identified in CAT namely dominant, suppressed, assimilated, emergent and equipollent can move around in accordance with the context in which the student is operating. According to Ogunniyi (2009, p. 3):

A cognitive stage becomes dominant when it is the most adaptable to a given context. However, in another context the same dominant cognitive stage can become suppressed by, or assimilated into another more adaptable metal state. An emergent cognitive stage arises when an individual has no previous knowledge of a given phenomenon as would be the case with many scientific concepts and theories e.g. atoms, gene, entropy, theory of relativity etc. An equipollent mental state occurs when two competing ideas or worldviews exert comparably equal intellectual force on an individual. In that case, the ideas or worldviews tend to co-exist in his/her mind without necessarily resulting in a conflict e.g. creation and evolution.

A cognitive stage can metaphorically be understood as a discourse to a certain phenomenon, in which the meaning is given by the context (Afonso, 2007). The strength of CAT, in our view, is that learners from western and non western backgrounds are encouraged to explore the contiguous spaces between science and IKS. These contiguous spaces are occupied by phenomena and facts that both science and IKS have interpreted and employed for different purposes and in different contexts. Depending on the context a learner tend to mobilize a worldview deemed appropriate for the occasion. Contrary to the environment in traditional classroom (where only one view is normally welcomed) CAT provides an environment where each person has equal opportunity to express his/her viewpoint.

One aspect that may constitute an obstacle for the argumentative dialogue to take place is the traditional view of science as having the supreme and absolute discourse. As it can be seen CAT requires an eclectic way of seeing and thinking which cannot coexist with the so-called scientific objective ontology which at a meta-level can dictate rules in a science classroom. One can then understand that a step towards an implementation of CAT is to reflect on the NOS and NOIKS because there is a demand to critically deconstruct the image of science in
order to accommodate both systems of thought within the classroom.

Image of science

Abd-El-Khalick states that there is no definitive agreement on the definition of the Nature of Science (NOS) but a review of different definitions shows that scientific knowledge is tentative, empirical, theory-laden and socially and culturally embedded. However, NOS has not been mirrored adequately in most science classrooms where the image of science is that it is value free and objective. As Afonso (2007) has argued science developed with a modernist axiology based on grand and exclusive narratives and reflecting the empiricism and positivism paradigm from the times of Francis Bacon and Auguste Comte. This image of science and scientist is due in large to myths that historically have been carried out from generations to generations mostly from the era of the enlightenment when science was elevated to the position of bearing the truth and capable of providing solution for every human problem. These myths are normally perpetuated in classrooms. Taylor points out that the culture in a traditional classroom “is framed by powerful culturally-determined networks of beliefs and values, or cultural myths, that serve to reproduce a unitary and unproblematic social reality” (p. 2). He refers for example, to the myth of could reason which is associated to the idea of science/mathematics as having the Truth, that can act as an impediment in the classroom culture. Hodson (1999) refers to the image of science prevailing in many science classes and identifies ten myths among which are that: science comprises discrete generic processes; scientific inquiry is a simple algorithmic procedure; science is a value-free activity; science is an exclusive Western, post-Renaissance practice; and that ‘scientific attitudes’ are essential to the effective practice of science. Colucci et al (2006) also refers to myths in the science classroom among which is the notion that in science there is a solution for every problem. In fact as Lemke (1999) says although teachers try to build a positive attitude to science ‘we also tend to reinforce a special mystique of science, a set of harmful myths that favour the interests of the small elite (p. 129). According to Lemke (1999) this mystique of science is built through the style of language and through the authoritative ideology that science possesses all the truth. These myths build a paradigm where there is no space for ‘truths’ but for ‘the Truth’ constructing the scientism ideology about the power of science.

In a study done by Hanuscin and Lee (2007) they found that images of scientists drawn by pre-service teachers were similar to those drawn by students at elementary school and were stereotypical portraying for example scientist with wild hair, clashing, working inside laboratory and even surrounded by violent explosions. Teachers’ image about science and scientism shape their pedagogy in class and may act as a hegemonic impediment for the inclusion of IKS. As Milne (1997) observes myths can have a repressive or liberating effect, in this case these myths have a repressive effect. With the innovation of including IKS in class, there is a need for teachers to deconstruct the mystic image of science, so that knowledge from other ontologies can be equally discussed, applied and improved if necessary.

Methodology

In a period of two years teachers participated in a series of workshops as part of the requirement for their Master’s course. In these workshops teachers were exposed to CAT based instruction as a way to introduce IKS into their science classrooms. This was to help them respond to demands of the new curriculum. The questionnaire involved 19 items addressing issues of image of science, language and philosophical statements about science.
and IKS. The methodology was in most degree quasi-experimental with nonequivalent group design, it included however a small extension of experimental design by identified respondents who were present in both pre- and post test, for further analysis. With the exception of two teachers, all who participated in the workshop were working in secondary schools. To accomplish with the word limit requisite we present in this paper only responses to five items explicitly concerned with the image of science.

**Data analysis and interpretation**

The first four items were mostly statements to which teachers had to choose agree or disagree and in the last item we included here they were asked to describe their own views before and after the workshops. As the methodology included also an experimental design component, we tracked those who were present in both pre- and post-test and gave an overview of the responses given. The theoretical framework for our data interpretation relies largely on the interpretivism paradigm in which we “place major emphasis on our role in interpreting reality” (Afonso, 2007, p. ix) acknowledging thus subjectivity in this process. In reading our interpretation our focus was on credibility, dependability, confirmability and transferability rather than the positivist indices of validity and reliability.

We start our analysis with the first four items dealing with the image of science. Table 1 below shows an overview in terms frequency of teachers’ response choices relative to four of the items of NOS questionnaire developed for the purpose. Teachers were free to neither agree nor disagree (A/D) if they were unsure.

<table>
<thead>
<tr>
<th>Items</th>
<th>Pre test</th>
<th>Post test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>D</td>
</tr>
<tr>
<td>1. Science tells us the truth about the natural world</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Does the statement in Item 1 reflect the way you present science in class? Or do you present science differently? Please explain, provide examples.</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>3. Scientific knowledge is trustworthy because it was proved in experiments</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>4. Scientific facts can be tested, and every test should give the same result</td>
<td>8</td>
<td>10</td>
</tr>
</tbody>
</table>

A= Agreement; D= Disagreement; A/D= Agreement/Disagreement. Note that the disparity between the pre- and post-test frequencies are due to missing values.

The results show that in general, before attending a series of workshops, teachers had a more objective image about science as the way to get knowledge about the truth. Also we can see that the number of teachers who were unsure in some items decreased at the post test (7 at pre-test and 2 at post-test).

In the following paragraphs we will focus on each item.

**Item 1: Science tells us the truth about the natural world**

For this question 10 out of 21 teachers who responded to the question agreed with the statement that science tells the truth about the natural world, in contrast to the post-test results which shows that only one said so. Three of the teachers did not provide any response. We can see from the data that after the workshops most of the teachers were more skeptical on
their beliefs about NOS.
Examples of responses given at the pre-test and post-test are as follows:
Pre-test
EP: Agree. We as human are supposed to respect our environment that’s why science must tell us the truth to do so.
DT: Agree: It opens up the fact of this world through objective reasoning and explanation.
MP: Disagree. Some scientific theories/beliefs are contrary to what is happening in the natural world.
RC: Disagree. Up to some points science tries to explain the truth about the natural world.

Post-test:
ER: Agree. Science is viewed as the working of our natural systems in the natural environment.
KJ: Disagree. Science do not give you the whole truth, only the probabilistic truth.
RM: Disagree: There are other worldviews that influence our perspectives, such as IKS, the knowledge imbedded in traditional cultures. Truth is relative and temporary.

In general responses at post test convey less certainty about science than during pretest. Teachers at post test referred to science with probabilistic dimension and they started to mention about worldviews and revealed awareness of some ontological issues that frame different discourses to reality.

Item 2: Does the statement in Question 1 reflect the way you present science in class?
Or do you present science differently? Please explain, provide examples.

In relation to the way they present science in class 15 out 20 who indicated that their teaching practice reflected that view of science at the pre-test, while post-test results show that only two said so. However looking at their responses our interpretation is that they generally disagree that “science tells us the truth” but agreed that the way they taught had changed. Some of the responses given:

Pre-test:
RT: Agree. I do use this as the underlying principles as, in my mind, science aims to explain phenomena we observe in our daily lives, e.g. gravity, dissolution, the weather etc.
NM: Yes. Trying to make science more friendly and not ghost from books. Thus learners can understand better.
LS: Disagree: No. I can only teach science that can be proven physically or where proof are provided via research books and media.

Post test
DT: Now I teach with the perspective that science is visionary and my learners are to think more critically and debate issues more fervently backed by cogent arguments, also bring in more sociocultural issues.
MS: Yes. Since becoming aware of this I have changed the way I present science. For example when doing practicals or introducing concepts I try to do a historical background that illustrates how scientists have come up with laws and theories and how these have developed. Also when doing practical I use that to explain that if you don’t get the exact answer (for eg “g”) or straight line then we talk about how scientist operates and how they also did not necessarily get that the first time around. When discussing phenomena in nature I tell learners that many cultures have explanations other than the ones that are explained in the
science texts that although not considered as being as robust, is equally valid.

AD: My methods of presenting science has changed since the inception of NOS workshops. Certain topics I present in the old manner and other topics I encourage learners to debate and discuss so as to bring out other possible knowledge that they might have and so share it with their peers.
ZA: I try to point out the dynamic nature of science, although time constraints not always allow for in depth discussion with learners […].

These responses suggest that the workshops had an impact on the way they perceive science and this has been influencing them to change the way they teach science.

Item 3: Scientific knowledge is trustworthy because it was proved in experiments

At the pre-test 12 teachers out of 20 agreed that scientific knowledge is trustworthy because it was proved in experiments in contrast to the post-test where only four agreed with the statement. This may show that after the workshops teachers were more aware of other ways to know something, i.e. that other epistemologies are equally valid.

Examples of responses given

**Pre test**
MB: Agree. Before the fact was agreed, experiment/scientific inquiry was done, tested and approved through content based knowledge.
BJ: that is a common goal.
CM: Disagree: Not all scientific knowledge are facts. Some are theories that can change eg world was believed to be flat, but theory changed when evidence was found.

**Post test**
BP: Agree. In most cases substantive research has been conducted to provide concrete evidence.
PT: Disagree: Not all scientific knowledge can be backed with experiment. Sometimes we make use of unobservable assumptions for our theories.

Item 4: Scientific facts can be tested, and every test should give the same result

In this last question there is no significant variation with respect to pre and post-test figures. This can be an indication that teachers acknowledge the validity of different epistemologies, but that does not imply that one should disregard scientific methods. In other words, that in a scientific context there are conditions for a given piece of knowledge to be recognized as valid.

Example of responses

**Pre test**
AD: Agree. If test are conducted using the same evidence results will be the same.
XG: Disagree. Things change, people evolve so what might be a fact today might not be so in years to come due to certain factors.

**Post test**
LN: Agree: The results would be the same provided the conditions are kept the same.
MP: Disagree; The test will not give the same result but similar result.
The second stage of our analysis took into account those teachers who were present at pre and post test. We will look at how individuals have reacted after the workshops.

Question: What ideas of the Nature of Science (NOS) did you hold before and after being exposed to the SIKSP workshops?

(a) Ideas about the NOS before the SIKSP workshops:

ZA: *That science and its theories are ABSOLUTE TRUTH and that there is only one way in which they evolve.*

AD: *I had very basic knowledge about the nature of science before attending the workshop. I thought that the nature of science resolved around how to do science, as it was taught to us throughout high school and university. We were taught that science was a pure subject that did not encompass any other discipline and that there were only varying branches within science.*

MP: *did not even think about it. Therefore I was struggling with learning outcome 3*

DT: *[…] I also thought that all good scientists would not necessarily believe in God or be religious. That culture, religion and philosophy must be divorced from science.*

(b) Ideas about the NOS after the SIKSP workshops:

ZA: *that science is dynamic, ever changing and never static*

AD: *I now see that science is a melting point of various disciplines […]*

MP: *Science is probabilistic. When teaching science, you need to consider the background, culture, religion, etc. of your students[…]*

DT: *[…] People look at science from a cultural viewpoint. There are other worldviews other than western view.*

Reading these responses we assumed that the workshops did have positive impact on teachers’ views about the NOS. We see that in their vocabulary they started to include terms that were not references before such as 'worldviews' and 'absolute truth'. They also included some critical reflections on their own practice as teachers and on their experience as students at secondary school.

**Conclusion**

A number of conclusions can be drawn from the findings of this study. Firstly, the results show that the project helped to raise awareness on teachers about the NOS. It contributed to the teachers’ deconstruction of their own image of science. Most of the participants who had the view of science as being the Truth or as a pure objective and indubitable subject matter changed to a view of science as involving both objective and subjective elements. In this sense we are encouraged to say that the project does have merit. As we stated in our introduction, one of the obstacles for the inclusion of IKS in the school curriculum can be the image of science that teachers may uncritically hold. By deconstructing this image, they are able to see the water in which they swim (this in analogy with the Chinese proverb about the fish that is unaware about the water until he is pulled out from it) and thus to reflect critically about their own practices. Secondly, the results also suggest that CAT allows teachers to live with different epistemologies without conflicting or subjugating one worldview to another but rather being contextual. Results from item number four may well express this view, because after the workshops teachers did not express refutation of the scientific method rather their assertion was that it was contextual. We found this fact relevant from the point of view of
Inclusivity. It is important that teachers embrace a dialectic framework from which both science and IKS can be included and respected because, one of the frustration learners may feel when beginning school is that their own worldviews are excluded to the benefit of a sole Western scientific view. This may cause a psychological and emotional disruption in learners’ worldviews thus acting as a barrier to their performance in science classes. As Ngugi from Kenya have said:

“And then I went to school, a colonial school, and this harmony was broken. The language of my education was no longer the language of my culture” (in Macedo, p. xiii)

Similarly, the harmony is broken when a child enters to a system where no value is given to his indigenous worldview. CAT offers possibilities for including IKS in schools without subjugation of one system of knowledge to another. We believe that by recognizing that knowledge and discourse to knowledge are contextual the teachers will help their learners to harmonize different worldviews and will allow them to move along the five categories on CAT (dominant, suppressed, assimilated, emergent and equipollent).

Thirdly, we have also referred that in the context of postcolonial continent considerations for ontological and axiological issues become even more important because

“We have internalized the discourse of our masters on our cultures, their denigrating views on African ways of life and modes of thought. As a consequence we were and are still attempted to undervalue our own heritage, including the immense legacy of indigenous knowledge (Hountondji p. 25).

CAT may provide a tool to avoid such ideology prejudices (Hountondji, 2002) by opening an argumentative space where both worldviews are discussed through claims, rebuttals and warrants to contextually co-exist.

Fourthly, in the context of postcolonial theory with special reference to Bhabha’s notion of hybridity and third space, CAT recognizes the social and cultural hybrid nature of both learners and teachers and rather than advocate for a dualistic standpoint CAT acknowledges the five categories in which an individual can dwell and move and dwell according to the context. In that way CAT can be viewed as a process in which the learner instead of crossing the borders he is encouraged to negotiate these borders not as different territories but as being a contextually induced behaviour. Unlike in the case of collateral learning where learners construct meanings “side by side and with minimal interference and interaction” in CAT interactions is encouraged through the dialogical argumentative nature that the process embraces.

In this paper we argued that CAT offers many potentialities to integrate IKS in school science. However, we do not claim it to be the Holy Grail in science education. Furthermore, our feelings are that the journey to integrate IKS in school science cannot be resolved solely by this series of workshops. So, although we can speak about changes in teachers’ views, we suggest that the ideal would be that the process continues. Further dialogical conversations are needed in teaching settings by the teachers and the school community. We also suggest that further deconstructions of the structures and systems in which teachers work are necessary. We agree with Dei (2006), who states that, the process of including IKS in the school curriculum “requires the self relocation of the instructor in relation to the course material, the educational facility and the learners” (p. 310).

In sum, approaches to include IKS in the school science curriculum require a reorientation of teacher education programme and of school science teaching, it requires a paradigm which
supports teachers in deconstructing the dogmatic image of science. CAT has demonstrated to be an effective way to deconstruct teachers’ image of science, however a more extensive strategy that will involve schools systems and structures may be needed in order to support teachers in this endeavor to include both IKS and Science in their practice.

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First year students’ experiences of the Grade 12 Life Sciences curriculum- trend-setters or guinea-pigs?

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Abstract

This paper presents an exploration of what students (as learners) considered being interesting in the Grade 12 Life Sciences curriculum. A sample of 125 first year, pre-service Life Sciences and Natural Sciences teachers from a South African university responded to a questionnaire in regard to their experiences with the newly implemented Grade 12 Life Sciences curriculum. The study focused mainly on the Grade 12 Life Sciences curriculum but Further Education and Training (FET) cross-curricular comparisons were also made. The responses to the questions were analysed qualitatively and/or quantitatively. Friedman tests were used to compare the mean rankings of the four different content knowledge areas within the Grade 12 curriculum. The students experienced fewer problems with the Grade 12 curriculum, compared to the Grades 10 and 11 curricula. Their major concern was the inclusion of ‘evolution’ in the Grade 12 curriculum. From the results, it appears that the students found the theme ‘Genes, inheritance, genetic diseases’ the most interesting, and ‘Fundamental aspects of fossil studies’ the least interesting. The mean scores are indicating that there are no statistically significant differences between the Grade 12 themes within each content area. All four content areas of Grade 12 were considered as being more interesting than the other two grades. It is recommended that more emphasis needs to be placed on what learners are interested in, and on having this incorporated into Life Sciences curricula.

Key words: Life Sciences curriculum, interesting curriculum, problems, teachers, students

Background to curriculum reform in South Africa

Across the world, developed and developing countries have revised their curricula in recent years, to take into account the skills and knowledge required in a globalising 21st century.
Especially, the past decade has seen a renewed interest in the development of science curricula in many areas of the world (Rogan & Grays on, 2003; Rogan, 2004).

After South Africa’s first national democratic elections in 1994, the need for educational reform was widely recognised when this government came into power. For the first time in South Africa’s history, a government has the mandate to plan the development of the education and training system for the advantage of the whole country (Rogan & Grayson, 2003). Directly after this historic election the Government of National Unity issued several curriculum-related reforms intended to overcome the educational inequalities of the past and prepare citizens for full participation in a democracy.

According to Chisholm (2003, 2005) curriculum revision in South Africa was undertaken in three main stages: firstly, the ‘cleansing’ of the curriculum of its racist and sexist elements and purging of the most controversial and outdated content. Secondly, the most ambitious and comprehensive of these reforms was the implementation of outcomes-based education through a new curriculum, Curriculum 2005 (C2005) (1997). This drastic step was taken because the Department of Education considered the existing curriculum as narrow and outdated and with little focus on Africa (Gadebe, 2005). The Minister of Education launched C2005 in Cape Town on 24 March 1997, with implementation in Grade 1 scheduled for 1998, and Grade 7 in 1999. This curriculum was thus to be phased in progressively so that it would cover all sectors of schooling by 2005 (Harley & Wedekind, 2004). The intention was to introduce this curriculum for grade 10 learners in 2003, for grade 11 learners in 2004 and for grade 12 learners in 2005, but the curricula for these grades were not developed in time for implementation (Velupillai, Harding & Engelbrecht, 2008). Rogan & Grayson (2003), as well as Rogan (2004) identified the problem that too often the energies and attention of politicians and policy-makers are focused on the ‘what’ of desired educational change, neglecting the ‘how’. They argued that developing countries emphasize curriculum adoption and neglect implementation. The consequences are that a great deal of effort, money and time may be wasted, as good ideas are not translated into classroom reality. Harley and Wedekind (2004) point out that the new curriculum had three design features: it was outcomes-based, and this feature was positioned so centrally that outcomes-based education (OBE) became synonymous with C2005, it was an integrated knowledge system and it promoted learner-centred pedagogy. The adoption of an outcomes-based approach was due to the growing concern around the effectiveness of traditional methods of teaching and training which were content-based (De Waal, 2005; Rogan, 2004). Aldous (2004) described the curriculum as complex and warned that it would be open to misinterpretation. The emphasis in OBE shifts to what learners can do with their knowledge and, in particular, whether they can use what they know to meet the specified outcomes (Hattingh, Rogan, Aldous, Howie & Venter, 2005). OBE was designed to make learners more employable by teaching them skills, but did not prepare them thoroughly for tertiary training, where they would be given a lot of content to absorb.

The third stage involved the review and revision of C2005 (up to Grade 9) in the light of recommendations made by a Ministerial Review Committee appointed in 2000. This Review Committee recommended a major revision of the curriculum in order to make it more understandable in the classroom (Chisholm, 2003; 2005). C2005 was reworked into the Revised National Curriculum Statement (RNCS), which was introduced into Grades 1 to 3 in 2004, 4 to 6 in 2005, 7 and 10 in 2006, 8 and 11 in 2007, 9 and 12 in 2008 (Velupillai et al., 2008). The RNCS became official policy in 2002.
Admitting that this curriculum had major problems, the Department of Basic Education (DBE) was constantly reviewing the design and methodology of the OBE system. On 6 July 2010, the current Basic Education Minister announced a new education curriculum that will replace the widely criticized OBE system. The new education plan, titled ‘Curriculum 2025’, comes after years of criticism by teachers and education experts, who said it was destroying the education system. The OBE system will not be completely scrapped but will be modified to improve the performance of learners. ‘Curriculum 2025’ will put more emphasis on depth and content knowledge, rather than skills and attitude, as was the case before.

Implementing of the new Life Sciences curricula

The development of new Life Sciences curricula is a common event in countries across the globe. In South Africa, three different curricula have been used for Life Sciences in the Further Education and Training (FET) phase. Till 1995, the ‘apartheid’ curriculum directed teaching; during the period 1995–2006 the Interim Curriculum (IC) was used; and in 2006 the National Curriculum Statement (NCS) for Grades 10–12 was implemented. Since 2006, the subject Life Sciences has replaced the subject known as Biology in Grades 10–12 in the FET phase. The new Life Sciences curricula focus on three central Learning Outcomes (LOs): LO1 – ‘Scientific enquiry and problem solving skills’ deals with practical and critical thinking skills’; LO2 – ‘Constructing and applying scientific knowledge’ provides the foundational conceptual understanding’; and LO3 – ‘The nature of science and its relationships to technology, society and the environment’ incorporates values and attitude development. Four content knowledge areas were created for each curriculum. The content areas include: Tissues, cells and molecular studies; Structures and control of processes in basic life systems; Environmental studies; and Diversity, change and continuity. Several Botany, Zoology and/or human Biology related themes or topics were grouped under each content area (Department of Education, 2003). Pandor (2006, p. 2) described the newly implemented Life Sciences curricula as “modern and up to date” and “it starts our children on the road to understanding new scientific knowledge …”. But, how relevant are these curricula? How did the learners experience these ‘modern’ curricula?

Rationale and significance of the study

The Organisation for Economic Co-operation and Development (OECD) Global Science Forum (2006) reported that the declining enrolment of students in the sciences is often attributed to the uninteresting curriculum of science courses. It had already been recommended by Armstrong in 1973 that learners should be involved in choosing their curriculum topics. Today, more than 30 years later, curriculum design is still based on adult notions of what is of interest and of relevance to themselves, and not to the learners. Particularly noteworthy is that, interest, goals and motivation have been identified as important for learning and academic performance (Hidi & Harachiewicz, 2000). According to Baram-Tsabari and Yarden (2005), ‘interest’ and ‘relevance’ are often defined in reference to the teachers, rather than from the learners’ view. Wade (2001, p. 245) described the word ‘interest’ as “specific, develops over time, is relatively stable, and is associated with personal significance, positive emotions, high value, and increased knowledge”. In relation to the curriculum, an ‘interesting curriculum’ would therefore be one that arouses a feeling of interest in the learner or teacher (Kidman, 2010). The last-mentioned author suggests that students interests still need to have greater prominence in the design of science curricula. To
enhance student interest in science, Christidou (2006, p. 1184) advises the careful selection of topics: “A revised science curriculum should emphasize those topics that are of interest to the students, and encourage activities that are familiar and readily adopted by them”. Studies have indicated that a better fit between students’ interests and curricula could lead to better affective and cognitive outcomes in the sciences, as well as increased enrolments in the sciences (Trumper, 2006). The study of Osborne and Collins (2001), cited in Kidman (2010), highlighted that learners’ decreasing interest in science was due to the lack of discussion of topics of interest, the alienation of science from society, the absence of creative expression opportunities and the prevalence of isolated subjects. These learners were dissatisfied with science contexts that did not meet their interests. The study of Kidman (2010) found learners withdrawing from Biology courses in post compulsory settings due to lack of interest and perceived lack of relevance of the course. The following questions arise: Which Life Sciences curriculum or curricula can be classified as interesting? Which themes are interesting? How relevant are these curricula?

The matric ‘classes of 2008 and 2009’ were the first to write exams under the revised Life Sciences curriculum which focuses on OBE. Educators (teachers, principals, academics) see these learners as guinea-pigs of the system because it was essentially tested on them, was modified several times, and taught by teachers with little experience of the system. On the other hand, others see the 2008 matriculants as trend-setters who will be remembered as the first faces of a new chapter in education. The majority of participants in curriculum-based research studies involved teachers, politicians, teacher unions, non-governmental organizations (NGOs) and academics at teacher-training institutions and universities. Currently, little (if any) research has been done on learners’ first-hand experiences of the newly implemented Life Sciences curricula. The purpose of this study is to map, from the point of view of the learners, the problems which Grade 12s in 2008 and 2009 experienced with the FET Life Sciences curricula, and to rank the themes in each curriculum according to interest. Although all three FET Life Sciences curricula were involved in this study, the main focus of this paper is to present an exploration of what students (as learners) considered were the interesting Grade 12 Life Sciences themes (topics).

Objectives of the study

Based on the above rationale, the following research questions were asked in the study:

1. What problems did first year students (as learners) experience with the new Life Sciences school curricula?
2. Which themes in the Grade 12 Life Sciences curriculum did first year students (as learners) find the least and most interesting?

Research methodology

Sample and participants: In this study, the sample was purposively selected. A sample of 125 Bachelor of Education (BEd), pre-service Life Sciences and Natural Sciences teachers at a single, semi-urban university participated in this study. Only students enrolled for the courses Zoology and Botany or General Sciences were involved in this empirical study. The study ran over two years (2009 and 2010). All the students in the sample population were
exposed to C2005. Only students who matriculated in 2008 or 2009 and who wrote the Grades 12 Life Sciences examinations participated in the study. The 2008 and 2009 Grade 12 classes were the first cohort to enter the FET phase under the Revised National Curriculum Statement (RNCS) in Grade 10. They were also the first two Grade 12 classes to complete the new Life Sciences curriculum which focuses on outcomes-based education (OBE). These participants obtained the National Senior Certificate (NSC) in 2008 or 2009 respectively.

**Instrument:** Information was collected by means of a single questionnaire, which students completed voluntarily during routine classes. The questionnaire was approved by the Faculty Research Ethical Committee. The research met the ethical guidelines laid down by the university for educational research, including voluntary participation, informed consent, confidentiality, anonymity, trust and safety in participation.

**Data collection strategies:** The questionnaire contained both open-ended and closed questions, which elicited responses in regard to individual experiences and opinions. The responses yielded demographic data as well as information on students’ personal experiences of and opinions toward the Grades 10–12 Life Sciences curricula. The students were also asked to critically analyse the Grades 10–12 Life Sciences curricula mainly in terms of interesting themes. The demographic items had bearing on Grades 10–12 Life Sciences symbols, gender and area of specialisation. One section of the questionnaire dealt with the ranking of four content areas and its themes separately, for example, the Grade 10 curriculum (12 themes), Grade 11 curriculum (13 themes) and the Grade 12 curriculum (12 themes). These content areas and themes were obtained from the National Curriculum Statement Life Sciences FET (Department of Education, 2003). In each case the students were required to separately rank the themes of each curriculum according to interest. In another section, all the themes of each content area of all three curricula were grouped together. This section of the questionnaire dealt with the ranking of the combined themes under each content area, for example, *Tissues, cells and molecular study* (7 themes), *Structure and control of processes in basic life systems* (11 themes), *Environmental studies* (7 themes) and *Diversity, change and continuity* (12 themes).

**Data analysis procedure:** The responses to the open-ended questions were analysed both qualitatively and quantitatively. The responses to the closed questions were analysed only quantitatively. Statistical analysis (summary statistics, two-way tables) of the survey data was used to elaborate and enhance the discussion. Friedman tests were used to compare the mean rankings of the four different content areas in the curricula. The same test was also used to make cross-grade comparisons of the mean rankings of the same content area for all three curricula. Results are presented as percentages rounded to whole numbers.

**Validity:** The questionnaire’s content validity was face-validated by experts in the field of Life Sciences. The questionnaire was pilot-tested and based on the feedback of the pilot study and from the experts, the questionnaire was revised. Redundancies and ambiguities were removed to improve the clarity in the formulation of certain items in the questionnaire.

**Results**

**Biographical information**
One hundred and twenty-five student teachers completed the questionnaires. Ninety-four (75%) were Zoology and Botany students and the other 31 (25%) were General Sciences students. Of these, 49 matriculated in 2008 while 76 matriculated in 2009. All the students were first year students. The majority of students (72%) were female. The majority (41%) passed Life Sciences with a percentage between 60 and 69%, followed by 70 to 79% (30% of the students), 80% or more (14% of the students), 50 to 59% (13% of the students) and 40 to 49% (2% of the students).

**Popularity of the Life Sciences curricula**

From the results, it appears that students generally were positive about the new Life Sciences curricula (Table 1). In response to the question “What is your overall impression of the Grade 10, 11 and 12 curricula?” 81% of the students indicated that they were satisfied (responding either satisfied or very satisfied) with the Grade 12 curriculum. Slightly fewer students (76%) were satisfied (responding either satisfied or very satisfied) with the Grade 11 curriculum and just more than two-thirds of the students (68%) indicated a positive satisfaction (responded either satisfied or very satisfied) with regard to the Grade 10 curriculum.

Table 1. Degree of satisfaction regarding of the Grades 10–12 Life Sciences curricula

<table>
<thead>
<tr>
<th>Curricula</th>
<th>Degree of satisfaction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VD</td>
</tr>
<tr>
<td>Grade 10</td>
<td>2%</td>
</tr>
<tr>
<td>Grade 11</td>
<td>2%</td>
</tr>
<tr>
<td>Grade 12</td>
<td>3%</td>
</tr>
</tbody>
</table>

VD = very dissatisfied, D = dissatisfied, N = neutral, S = satisfied, VS = very satisfied

**Problems experienced in learning Life Sciences**

When participants were asked to describe the kind of problems which they experienced in learning Life Sciences, some students wrote more than one comment. Some students experienced several problems in learning the content of the new curriculum (Table 2). In response to the question “What kind of problems did you experience in learning Life Sciences in Grades 10–12 separately?” the majority of the students (n = 103; 82%) indicated that they experienced many problems with the Grade 10 curriculum, followed by the Grade 11 curriculum (n = 92; 74%). Two-thirds of the students (n = 83; 66%) experienced several problems with the Grade 12 curriculum. The students’ responses to the above open-ended question were classified into six to seven significant categories for each Grade (Table 4). In summary, the students experienced more problems with the Grade 10 Life Sciences curriculum than the other two curricula.

The main problem for the students in Grade 10 was their Life Sciences teachers (40 responses), followed by textbooks (32 responses) and terminology used in Life Sciences (20 responses). Teachers (23 responses), textbooks (22 responses) and practicals (21 responses)
were listed as significant problems in Grade 11. Many students (42) indicated that the theme ‘evolution’ in the Grade 12 curriculum should be replaced. The following comment reflects one respondent’s negative reaction: “It was the first time, 2008, when evolution was included in the curriculum. Don’t waste the learners’ time, we need doctors, not dreamers!” The students described their Life Sciences teachers as unmotivated, uninvolved, lazy, incompetent, often absent from class, unqualified, having no work ethics and using poor teaching methods. One student comment: “Everything was tested on us; at times we had to assist our teachers with the new curriculum”. Many schools had a shortage of textbooks; some did not use any textbooks. They also described their textbooks as outdated and having many errors.

Table 2. Problems students experienced in learning Grades 10 to 12 Life Sciences

<table>
<thead>
<tr>
<th>Categories elicited from students’ comments</th>
<th>Number of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grade 10 (n=103)</td>
</tr>
<tr>
<td>Teachers</td>
<td>40</td>
</tr>
<tr>
<td>Textbooks</td>
<td>32</td>
</tr>
<tr>
<td>Not enough practicals/excursions</td>
<td>18</td>
</tr>
<tr>
<td>Workload too heavy</td>
<td>12</td>
</tr>
<tr>
<td>Lack of equipment/apparatus</td>
<td>8</td>
</tr>
<tr>
<td>Too much new terminology</td>
<td>20</td>
</tr>
<tr>
<td>Evolution</td>
<td>n/a</td>
</tr>
</tbody>
</table>

n/a = not applicable

Ranking of Grade 12 Life Sciences themes

Table 3 shows the ranking of all the Grade 12 Life Sciences curriculum themes from the most to be least interesting. The mean value (\(\bar{x}\)) and standard deviation (\(s\)) were obtained for each content area to examine the internal consistency of the students’ responses to some questions. The results indicated that the theme ‘Genes, inheritance, genetic diseases’ is the most interesting theme (\(\bar{x} = 3.49; s = 2.68\)) and ‘Fundamental aspects of fossil studies’ the least (\(\bar{x} = 8.48; s = 2.68\)) interesting theme in the Grade 12 Life Sciences curriculum. The four content areas are ranked from most to least interesting as follows: *Tissues, cells and molecular study* (themes 1 to 3), *Structure and control of processes in basic life systems* (theme 4), *Environmental studies* (themes 5 and 7), and *Diversity, change and continuity* (themes 6 and 8 to 12). The mean scores indicate that there are no statistically significant differences between the themes within each content area. There are few differences between the standard deviation ranges (\(s = 2.54–2.93\)) of eleven themes (see Table 2).

The majority of students found the six themes under the content area *Diversity, change and continuity* more difficult to learn than the other three content areas. The number of responses for each theme is as follows: Origin of species (51 responses); Cradle of mankind (44
responses); Evolution theories, mutation, natural selection, macro evolution, speciation (42 responses); Fundamental aspects of fossil studies (34 responses); Biological evidence of evolution of populations (30 responses); Popular theories of mass extinction (24 responses).

Fewer found the following three themes under the content area *Tissues, cells and molecular study* to be difficult: Chromosomes, meiosis, production of cells, diseases (17 responses); Genes, inheritance, genetic diseases (16 responses); DNA, protein synthesis (16 responses).

The results indicate that the easiest theme for them to learn was: Reproduction and related diseases, classified under the content area *Structure and control of processes in basic life systems*. Of the responses, only 12 marked this theme as being difficult to learn.

**Table 3.** Most to least interesting themes of the Grade 12 Life Sciences curriculum

<table>
<thead>
<tr>
<th>Ranking of themes</th>
<th>Content area</th>
<th>$\bar{x}$</th>
<th>$s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Genes, inheritance, genetic diseases</td>
<td>TCM</td>
<td>3.49</td>
<td>2.68</td>
</tr>
<tr>
<td>2. DNA, protein synthesis</td>
<td>TCM</td>
<td>3.55</td>
<td>2.80</td>
</tr>
<tr>
<td>3. Chromosomes, meiosis, production of cells, diseases</td>
<td>TCM</td>
<td>3.64</td>
<td>2.68</td>
</tr>
<tr>
<td>4. Reproduction and related diseases</td>
<td>SPL</td>
<td>3.91</td>
<td>2.81</td>
</tr>
<tr>
<td>5. Effect of pollutants on human physiology and health</td>
<td>ES</td>
<td>6.96</td>
<td>2.86</td>
</tr>
<tr>
<td>6. Origin of species</td>
<td>DCC</td>
<td>7.26</td>
<td>2.93</td>
</tr>
<tr>
<td>7. Local environmental issues</td>
<td>ES</td>
<td>7.30</td>
<td>3.10</td>
</tr>
<tr>
<td>8. Evolution theories, mutation, natural selection, macro evolution, speciation</td>
<td>DCC</td>
<td>7.81</td>
<td>2.78</td>
</tr>
<tr>
<td>9. Cradle of mankind</td>
<td>DCC</td>
<td>8.35</td>
<td>2.79</td>
</tr>
<tr>
<td>10. Biological evidence of evolution of populations</td>
<td>DCC</td>
<td>8.35</td>
<td>2.54</td>
</tr>
<tr>
<td>11. Popular theories of mass extinction</td>
<td>DCC</td>
<td>8.39</td>
<td>2.85</td>
</tr>
<tr>
<td>12. Fundamental aspects of fossil studies</td>
<td>DCC</td>
<td>8.48</td>
<td>2.68</td>
</tr>
</tbody>
</table>

$\bar{x}$ = mean; $s$ = standard deviation; TCM = Tissues, cells and molecular study; SPL = Structure and control of processes in basic life systems; ES = Environmental studies; DCC = Diversity, change and continuity

**Comparisons of the mean rankings for Grade 12 content areas**

Table 4 shows the comparisons of the mean rankings of the four content areas for the Grades 12 Life Sciences curriculum. The mean value ($\bar{x}$) and standard deviation ($s$) were obtained for each content area to examine the internal consistency of the students’ responses of some questions. Statistical analysis of all four content areas shows that it was significant at the 0.05 level ($P = 0.0000$). Friedman’s test (ANOVA) indicates no statistically significant mean score difference between the content areas *Tissues, cells and molecular study* (3.55) and *Structure and control of processes in basic life systems* (3.92). There are also no statistically significant mean score differences between the content areas *Environmental studies* (7.21) and *Diversity, change and continuity* (8.15). Comparing the rank of interesting content areas, *Tissues, cells and molecular study* has the lowest mean score (3.55) which indicates the most interesting content area. In contrast, *Diversity, change and continuity* shows the highest mean score (8.15) which indicates the least interesting content area. The relatively low
standard deviation ($s = 1.65$) suggests that students were quite consistent in relation to what they perceived to be interesting.

**Table 4.** Results of Friedman’s ANOVA comparing the content areas for Grade12 in terms of interest

<table>
<thead>
<tr>
<th>Content areas</th>
<th>$\bar{x}$</th>
<th>$s$</th>
<th>Ranking</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tissues, cells and molecular study</td>
<td>3.55</td>
<td>2.20</td>
<td>1</td>
<td>0.0000*</td>
</tr>
<tr>
<td>Structure and control of processes in basic life systems</td>
<td>3.92</td>
<td>2.76</td>
<td>2</td>
<td>0.0000*</td>
</tr>
<tr>
<td>Environmental studies</td>
<td>7.21</td>
<td>2.74</td>
<td>3</td>
<td>0.0000*</td>
</tr>
<tr>
<td>Diversity, change and continuity</td>
<td>8.15</td>
<td>1.65</td>
<td>4</td>
<td>0.0000*</td>
</tr>
</tbody>
</table>

* Significant at the 0.05 level; $\bar{x}$ = mean; $s$ = standard deviation

**Life Sciences learners: Guinea-pigs or trend-setters?**

The participants do not see themselves as guinea-pigs. They were asked to comment on the following question: “Do you experienced yourself as a guinea-pig when implementing the new Life Sciences curricula?” Their responses were classified as yes (31%) and no (69%). In the follow-up question: “If yes, why?”, some responses were:

- “We did not know what was expected of us and what they expected us to know because even the teachers were confused”
- “The educators did not know how and what to teach us because they did not know how it will be asked”
- “The new Life Sciences curricula were tested on us; they were not sure if it would work”
- “No one knows if it will work, but they tried it anyway. Look at our standards now – it is bad. How many first years are failing because of this?”
- “We were the first group to do the new curricula, at times we had to assist our teachers with the curriculum”
- “Nobody knew what was going to be asked and to what extent your knowledge was going to be tested”

**Discussion and conclusion**

The findings of this study do not represent a wide range of South African learners but rather a more elite group of learners who are interested in the Life Sciences and have managed to get into university to study.

Although the NCS Grade 12 Life Sciences curriculum is clearly less conceptually demanding than those for both Higher Grade and Standard Grade National Educational Curricula
At Grade 12 level (Umalusi, 2009c), the overall national pass rate for Life Sciences in 2009 was 66%. This was down from 71% recorded in 2008 (Thutong, 2010). The participants of this study were part of these statistics and the results indicated that 44% of them passed Life Sciences with 70% or more. This percentage (44%) is much higher than the NCS 2008 (12%) and 2009 (12%) national results.

In terms of interest and content, the NCS Grade 12 includes very little plant Biology, and no animal Biology, other than human Biology. It includes evolution, biotechnology, environmental issues, a number of social issues, and indigenous knowledge, all of which were absent in the previous NATED 550 curriculum. The content specified in the Life Sciences curricula is very context-sensitive. Most students liked the Grade 12 curriculum more because they found it more interesting, useful and informative. Comparing the three FET curricula, almost two-thirds (60%) of the students indicated the Grade 12 curriculum as their first choices, followed by their second (23%) and third choices (17%) respectively. The results show that the themes of all four content areas of the Grade 12 curriculum are the most interesting; and the Grade 10 themes the least interesting. From the results, it appears that the students found the theme ‘Genes, inheritance, genetic diseases’ the most interesting, and ‘Fundamental aspects of fossil studies’ the least interesting. The mean scores are indicating that there are no statistically significant differences between the Grade 12 themes within each content area. Not only in Grade 12, but also with regard to the other two grades, the students experienced the following content areas from the most to the least interesting: Tissues, cells and molecular study the most interesting, followed by Structure and control of processes in basic life systems, Environmental studies, and lastly, Diversity, change and continuity.

The students identified many problems in learning the content of the new Life Sciences curricula. Six (Grades 10 and 11) to seven (Grade 12) categories were elicited from the students’ comments: unqualified teachers (mostly in Grade 10), lacking of textbooks and lack of thorough textbooks (mostly in Grade 10), not enough practicals, volume of content excessive, lack of resources, too much new terminology (mostly Grade 10) and the controversy of learning evolution (Grade 12). Learning support material is essential to effective teaching and good learning, and without sufficient comprehensive textbooks it is impossible. Learners are blaming the teachers for poor academic results, and on the other hand, the teachers are blaming the DBE of being overloaded with administrative work and therefore could not focus on teaching. The DBE has to double their efforts of providing greater quality and effective support to teachers. Most schools in South Africa don’t have the resources such as microscopes, models, charts, equipment for experiments and fresh material for dissection (Department of Education, 2008). As a result, with no resources, effective teaching and learning will be influenced. Although the students experienced fewer problems with the Grade 12 Life Sciences curriculum than with the other two curricula, the most negative responses included the evolution category. The majority of students did not consider evolution as a relevant theme. In spite of different religions and backgrounds, the students and teachers were respectively forced to learn and teach this controversial theme. Umalusi (2009c) reported that the volume of content decreases across Grades 10, 11 and 12 in the Life Sciences curricula. There is also a smaller volume of content in Grade 12 of the NCS curriculum than there was at the same level in the NATED 550 curricula. In this study, only a low percentage [Grade 12 (14%)] of the students pointed out that the volume of work was too much and the tempo of concluding the work too fast.
Participants in this study were able to articulate what was of interest and relevance to them in relation to FET Life Sciences curricula. Curriculum designers, politicians and academics should be encouraged to determine these interests and to relate the interests to subject matter to provide a base for new knowledge. The interest learners' show in terms of key ideas should contribute to the pedagogical thinking of those who plan curricula for the learners. Therefore, more emphasis needs to be placed on what learners are interested in, and having this incorporated into a Life Sciences curriculum which serves the learner. The Basic Education Minister urged teachers to provide input on the revised curriculum which will be implemented in 2012 – ‘Teachers have key role in reform’ (IOL News South Africa, 2010). Once again, the input of the learners is being excluded. Guinea-pigs or trend-setters – it doesn't matter how we refer to the 2008 and 2009 matric classes; they opened the way for new curricula which are more in line with the demands of the modern world.

Acknowledgements

Thanks are due to Jaqui Sommerville and Karien Adamski for their invaluable assistance with the statistical analysis on which this paper is based.

References


Effects of a Dialogical Argumentation Instructional Model (DAIM) on grade 10 learners’ conceptions of fermentation

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This study has been motivated by the Science and Indigenous Knowledge Systems Project (SIKSP) at the School of Science and Mathematics Education, University of the Western Cape. The project seeks to enhance educators’ understanding of and ability to implement a Science – IKS curriculum (Ogunniyi, 2007) through using the theoretical framework of argumentation such that their learners would grasp the nature of both thought systems. The study reported upon in this paper has been a direct response to the above initiatives. The study employed a quasi-experimental design as well as a qualitative research design. Two cohorts of learners from a secondary school have been used in this study. The data collected were both analyzed in terms of qualitative and quantitative descriptions. The main findings of the study revealed that, the pre-test scores of the two groups were comparable; holding to some extent valid conceptions about fermentation; and that they had a relatively positive attitude towards science and to some degree IKS as well. At the post-test the E group outperformed the C group in terms of the Conceptions of Fermentation Questionnaire (COFQ) and the Science Achievement Test (SAT). The E group subjects also showed a greater awareness about, and an understanding of the Nature of Science (NOS) and Nature of IKS (NOIKS) than the C group subjects.

Background

Since the introduction of the new South African Education Curriculum, C2005, a string of issues pertaining to its implementation have emerged. These issues include teacher opposition, untrained teachers, language of communication, language of instruction, resources, multi-level, multi-cultural and multi-lingual classes amongst others. In that regard, the November 2009 Ministerial Final report admitted that the problem was implementation and tried to identify the issues and the nature of the challenges involved. For example, issues such as advocacy, infrastructure, learning and teaching materials (DoE, 2009), teacher training in as far as the Nature of Science (NOS) and Nature of Indigenous Knowledge Systems (NOIKS) are concerned; and the need to find a plausible connection (Ogunniyi & Ogawa, 2008). The report did not focus on issues of the diverse knowledge belief systems that are crucial if it intended interfacing school science with IKS. Lastly, the task team did not give any details of the classroom instructional approach that justified the interfacing of the two worldviews.

The Department of Education (DoE) argue that:
IKS reflects the wisdom about the environment developed over centuries by the inhabitants of South Africa, and much of this valuable wisdom believed to have been lost in the past 300 years of colonization now needs to be rediscovered and utilized to improve the quality of life of all South Africans

(Ogunniyi, 2007: 963)

It is within the above context that this study is imbedded. Fleer (1999) suggested that, the two worldviews should talk to one another so as to establish commonalities and differences. Erduran (2006) argues that since science is a human construct and is nourished and grows on argumentation, different people and cultures explain natural phenomena in different ways. Fleer (1999) is of the opinion that scientific activity is as a result of the conglomeration of many cultures and societies. This study seeks to propose that one way in which the dream of a science and an IKS curriculum could be realized was to use a dialogical argumentation framework where the two distinct worldviews (Science and IKS) could exchange views and come to a consensus (Newton, 1999) as to what the status of each worldview could be (Onwu and Mosimege, 2004).

The concept of fermentation will be used in this paper as an exemplification of a topic showing elements of both school science and indigenous knowledge understandings. Most home-based and industrial-based foods and beverages use the process of fermentation. Fermentation is also a very important process involved in most medical and biotechnological products and hence its choice as a topical concept worthy of closer consideration. Fermentation is a concept whose biological processes involve microbes. The implication suggests that creating a teaching and learning environment for learners from indigenous communities, towards understanding the microscopic and counter-intuitive biological changes that occur, may require a measure of border crossing between what they currently know and what they need to learn about the science of fermentation in the science classroom. While the new curriculum places emphasis on group work activities that are expected to achieve certain outcomes, it does not spell out what methodology teachers should follow to facilitate effective implementation. This paper argues for a structured process of discussion in order to promote clarity and direction in the process of dialogical argumentation.

Theoretical underpinnings

The extant literature reveals that, several studies conducted in order to investigate the effectiveness or otherwise of an argumentation instructional model as an instructional strategy in the teaching and learning of science does enhance the educators and learners’ awareness and understanding of the NOS (Erduran, et al, 2004, Simon et al, 2006). For instance, Simon et al (2006) argue that, “science education requires a focus on how evidence is used to construct explanations…” (p. 236) and that, “the teaching of argumentation through the use of appropriate activities and pedagogical strategies is, we would argue, a means of promoting epistemic, cognitive and social goals as well as enhancing students’ conceptual understanding of science” (ibid).

This study is underpinned by two argumentation theoretical frameworks, that of Toulmin’s Argumentation Patten (TAP) as well as Ogunniyi’s Contiguity Argumentation Theory (CAT). As explicated by Ogunniyi (2008), Toulmin’s Argumentation Pattern (TAP) consists of a claim, evidence (data), warrant, backing, rebuttal and a qualifier. Accordingly, a claim, evidence and a warrant are the main ingredients of a practical argument while the other three
may or may not be necessary in the justification of a claim. On the other hand, CAT is a learning theory rooted in the Contiguity Theory and lends its origin to the Platonic and Aristotelian era. According to its origins, this theory asserts that “two distinct co-existing thought systems” such as science and IKS “tend to readily couple with, or recall each other to create an optimum cognitive state. In contrast to the TAP, “CAT deals with both logical or scientifically valid arguments as well as non-logical metaphysical discourses embraced by IKS” (Ogunniyi & Hewson, 2008: 146).

CAT is premised upon the notions that, claims or counter-claims on any subject matter within competing thought systems (like in science and IKS) can be valid, only and if only neither thought systems dominates the other (ibid). The point here is that, learners do not need to abandon their belief systems in order to understand school science, but need to be in a position to choose and utilize whichever explanatory model applicable for a given purpose at a given time (Ogunniyi and Hewson, 2008). Accordingly, CAT “explains a dialogical framework for resolving the incongruities that normally arises when two (sometimes multiple) competing thought systems (science and indigenous knowledge worldviews, cultural beliefs, commonsensical or intuitive notions) are placed side by side as in C2005” (Ogunniyi, 2007a: 970). CAT can be categorized into five main ideas. **Dominant, suppressed, assimilated, emergent and equipollent ideas.** These ideas are dependent on the context or socio-cultural background of the learner who is exposed to the new idea.

Gunstone and White (2000) concluded that:

> The issue now appears to be not of abandonment and the replacement, but one of addition, so that the earlier belief and scientific belief co-exist. The learner’s task is to learn the scientific belief, and to become clear about when it is appropriate to apply one belief or the other (p.298).

An illustrated example of CAT is the brewing of traditional beer (mainly in the isiXhosa culture) where many different methods and processes are used with associated rationale which are not normally based on logical or scientifically valid explanations, but based on cultural belief. The CAT suggests that, instead of attempting to replace those beliefs, the two distinct worldviews seem to interact and settles on a mutual verdict where the scientific view can be accommodated.

**Purpose of the study**

The purpose of this study was to determine the effects of a Dialogical Argumentation Instructional Model (DAIM) on grade 10 learners’ conceptions of fermentation as exemplified both in school science and Indigenous Knowledge Systems (IKS).

**Research Question**

What effect does a Dialogical Argumentation Instructional Model (DAIM) have on grade 10 learners’ conceptions of fermentation?

**Methodology**

Two groups of grade 10 intact classes were selected. The experimental group (E group) was taught using a DAIM. At the beginning of a lesson each learner was given an activity
worksheet and TAP writing frames. The lesson focus and argumentation rules were explained to the learners. Individual learners had to make their claims, give reasons (data) and to give reasons for justifying their data (warrants and backings). Sources of arguments had to be incorporated in the writing frames. A certain time was given to complete each individual activity and thereafter, learners within a group would discuss each other’s claims. The educator facilitated the group activities by giving leading or probing questions. When the group tasks were completed, a whole class argumentation was started where the members of each group argued among themselves before reaching consensus and understanding some sort. The teacher recorded the whole class claims, counter claims and rebuttals. Finally, the teacher would do a consolidation of ideas and clarify issues with respect to the targeted content learning outcomes. The comparison group (C group) was provided with learning materials on Science and IKS conceptions of fermentation, but taught by another educator using the traditional ‘chalk and talk’ method.

This study employed both quantitative and qualitative research methods were used where all data was derived from the learners’ performance scores and written responses in the pre and post-test Conceptions of Fermentation Questionnaire (COFQ) and Attitudes to Science Questionnaire (ATSQ) respectively. The quantitative aspect of the study used a quasi-experimental pre-test post-test control group design was used. All statistics were obtained by using SPSS statistics software, the average recommended Cronbach alpha reliability values obtained for all instruments in the pilot study as well as in the full study were greater than 0.7 (Ogunniyi, 1992, Pallant, 2001). Since two intact classes were used, normality tests dictated that non-parametric statistics be employed in the data analysis.

Data Analysis
2 out of 8 COFQ items were analyzed in terms of 5-point scale TAP argumentation levels giving a total mark of 40 and 1 out of 5 ATSQ item was analyzed in terms of CAT cognitive categories.

Results and Discussions

TABLE 1. Learners’ pre-test and post-test overall conceptions of fermentations.

<table>
<thead>
<tr>
<th>ITEMS</th>
<th>GP</th>
<th>PRE</th>
<th>POST</th>
<th>WSig.</th>
<th>t-ratio</th>
<th>t-critical @ df = 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>All 8 ITEMS</td>
<td>E</td>
<td>20.12</td>
<td>27.12</td>
<td>0.00*</td>
<td>-6.598</td>
<td>2.086</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>22.88</td>
<td>15.88</td>
<td>0.109</td>
<td>-1.866</td>
<td></td>
</tr>
<tr>
<td>BSig</td>
<td></td>
<td>0.453</td>
<td></td>
<td>0.003*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t-ratios</td>
<td></td>
<td>-7.58</td>
<td></td>
<td></td>
<td>7.222</td>
<td></td>
</tr>
<tr>
<td>T-critical @ df = 40</td>
<td></td>
<td>2.025</td>
<td></td>
<td>2.025</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Alpha value is 0.05; * significant difference.
Table 1 above gives the overall statistics of the COFQ as well as selected items which are discussed due to space limitation. An examination of the results shows that in the pre-test the E group and C group obtained overall mean rank scores of 20.12 and 22.88 respectively. The two scores are above 20 which is half the total of 40 points for the 8 items. A no-significance result of \( t = -7.58 \) at \( p = 0.453 \) was obtained, also confirming that the two groups were indeed comparable. Based on the pre-test quantitative data, the two groups were similar in terms of their conceptions of fermentation. In conclusion, the results suggest that both groups held to some degree valid scientific/IKS notions about fermentation.

**Pre Intervention discussion of COFQ**

An examination of Table 1 shows that the E group’s overall mean rank score (27.12) in the COFQ was significantly higher as compared to the C group’s mean rank score of 15.88. The independent group t-test value gave a significance at \( t = 7.222; \ p = 0.003 \). It was further noted that, the E group’s performance from a pre-test mean rank of 20.12 to a post-test mean rank score (27.12) was significant \( (t = -6.598; \ p = 0.00) \) as opposed to that of the C group \( (t = -1.866; \ p = 0.109) \).

The statistical tests tabulated in table 1 suggest that, the DAIM which the E group was exposed to might have been responsible for the E group outperforming the C group. In fact, the overall mean rank score of the C group had dropped from a pre-test mean rank score of 22.88 to 15.88 in the post-test COFQ.
The following excerpts show some of the learners’ TAP argumentation shifts from pre to post-test.

**Item 4: Yeast is used to raise dough (intlama) in baking bread, what other home made ingredient or material is sometimes used to do the same job and why?**

Learner E 15 (pre-test): “Put the dough in warm or hot place”

Learner E 15 (post-test): “Umqombothi has yeast inside” [Traditional beer has yeast inside].

This learner’s pre-test response shows that the learner had probably observed parents putting dough in the sun or a warm hut and probably did not know the purpose of the inoculant beer (called ivanya – borrowed from vino or vine) which is usually mixed with warm water. The learner’s pre-test claim was that the dough should be put in a warm place without giving any reason. The post-test response reveals a conceptual understanding of the similarities of yeast and traditional beer which has live yeast cultures. The learner claims that, “umqombothi” or traditional beer is used as an alternative to yeast in baking bread and the reason for her claim is that traditional beer has yeast in it. The intervention seems to have entrenched such conceptual understanding among the E group learners. When I examined the responses among learners in the C group, the following was found:

Learner C 24 (pre-test): “They use baking powder’

Learner C 24 (post-test): “It is the sun”

Learner C 24 pre-test response shows that she did have some ideas about baking of bread at home, but he was not explicit as to whether or not baking powder was home-made. In the post-test she used her everyday knowledge, but could not give reasons why the dough is put in the sun. Most of the learners on this item chose the “I don’t know” option. This can be seen by the fact that, the E group’s post-test mean rank scores were significantly higher than those of the C group while the C group’s mean rank scores actually decreased at the post-test.

**Pre and Post-test CAT analysis of learner E 15 and C24 responses for item 4**

A 5-item Attitudes to Science (ATS) questionnaire was administered to both groups at both the pre-test and post-test. The five items were in form of statements that the learners had to place a tick for their agreement or disagreement and then to give supporting reasons for their statement of belief. Their responses to the items were then categorized in terms of IKS Worldview (IKSW) and School Science Worldview (SSW). The Contiguity Argumentation Theory (CAT) was used to analyze the learners’ worldviews and hence assisted in finding out if the DAIM had actually enhanced the E group’s awareness about the Nature of Science (NOS) and Nature of IKS (NOIKS) better than their counterparts in the C group.

Table 2 below shows only 1 item to illustrate how the categories were used to analyze the qualitative data of this study. The learners’ responses to particular items of the Attitudes to Science (ATS) can be assumed to demonstrate what CAT’s cognitive category (science or IKS) was dominant, suppressed, assimilated, emergent or co-existing with another cognitive category. Hence, for the purpose of this study, learners’ worldviews on particular items have either been classified as dominant, suppressed, assimilated, emergent or equipollent.

**Table 2: Pre- and post-test of learners’ attitudes to science in terms of CAT’s cognitive categories**
A summary of observation based on the results of the pre- and post-test of the learners’ attitudes in terms of CAT’s cognitive categories displayed in Table 2 above is as follows:

**Item 2: I like science which deals with things in my home or culture - dealing with IKS-based science or knowledge**

**The dominant view category: IKSW**

- 14 E group learners in the pre-test displayed this dominant worldviews and the number increased to 16 at the post-test while the 16 C group learners displayed this dominant worldviews at the pre-test but this decreased to 11 at the post-test.

The above observation indicates that about three quarter (16 = 76%) of the E group learners displayed dominant worldviews at post-test as opposed to about half (11 out 21) C group learners in the post-test with respect to the relevance of science, and of course technology, since they did not make any distinction between the two. Since it was observed in item 1 (relating to school science worldview), that the majority of both groups’ (E = 11, C = 15) learners who displayed dominant worldviews in the pre-test was reduced to zero in the post-test, but now in item 2 (IKSW), the number of E group learners who maintained a dominant IKS worldview increased (14 to 16) while the number of learners in the C group who displayed dominant views in the post-test decreased (16 to 11).

The trend displayed above adds to the results observed for item 1. While there could be other factors, the major factor could only be attributed to the manner in which each group received intervention. As a conclusion, the E group learners’ attitudes to science improved because a considerable number of them expressed an emergent or equipollent views particularly the application of science to their daily lives and culture. Some of C group’s attitudes to science seemed to have been swayed. They probably saw science related to their culture as something just to introduce them to school science and thereafter to be abandoned.

To highlight the above findings further, excerpts for the pre- and post-test responses of some of the E and C group learners are cited below.

**LEARNER EXCERPTS FOR ITEM 2: IKSW**

**Learner E 14 Pre-test:** (Strongly Agree) – “I will learn something that I never here before.”

This learner strongly believes in home-based science. Cross-checking this with the post-test response of this learner suggests that this learner’s view is that of equipollency. I cite the post-
test response to support the equipollent view.

**Learner E 14 Post-test:** (Strongly Agree) – “It prove us that is a reality life.”
What this learner is probably saying is that he strongly prefers culturally based science because it makes more sense to him i.e. a culturally based science gives him a sense of reality. This to me suggests that the learner does accept school science, but feels and prefers that science be taught in contextualized manner which can make sense to him. The post-test response of this learner seemed to suggest that the manner in which the intervention was administered to her enabled her to maintain an equipollent view regarding Science and IKS-based or culturally based school science.

**Learner C 22 Pre-test:** (Strongly disagree) – “They are not true”
To start with, this learner strongly disagrees that she likes science which deals with her own culture. The learner regards what is practised in her culture as either ‘lies’ or not scientific. This learner might have understood the term ‘science that deals with things in her culture as myth. This could be the case since many learners believe that school science in the only ‘true’ knowledge.

**Learner C 22 Post-test:** (Disagree) – “Kwiculture ayidibani nayo” [meaning: in my culture the two do not mix or not the same]
As in the pre-test, it can be seen that this learner still does not see any science in her culture. The learner says that culture and science do not mix. From this learner’s response one could assume that this learner’s notion of what science is can be described as either as an assimilated or suppressed IKS worldview or a dominant scientific worldview despite her exposure to the DAIM which stressed a contextualized or what Ogunniyi and Ogawa (2008) call “indigenized science.”

Summary of the learners’ CAT cognitive categories revealed that:
1. The pre-test scores of both groups’ attitudes to science were fairly good. The number of learners within a particular CAT cognitive category was comparable in both groups.
2. The qualitative in-between groups’ comparisons of the pre- and post-test learners’ CAT cognitive frequencies revealed that the E group learners were developing more positive attitudes about science and IKS as opposed to the C group learners’ worldview which drifted more towards assimilative and dominant scientific worldviews at the expense of a worldview consonant with their sense of socio-cultural identity.

In conclusion, the above findings seemed to suggest that a Dialogical Argumentation Instructional Model (DAIM) did enhance E group learners’ awareness and understanding of, and attitudes towards a science-IKS curriculum more than was the case with the C group which was exposed to a teacher-centered instructional method.

**FINDINGS**
The major findings in this study were as follows:

- **Learners in both study groups held relatively good conceptions of fermentation processes.** Their attitudes to science as revealed in the questionnaire indicated that both groups possessed valid scientific conceptions about fermentation.

According to Le Grange (2004) learners do possess knowledge that could potentially be ‘lost’ if not properly harnessed. Some attempts have been made to change learners’ indigenous conceptions of various natural phenomena to the scientific worldview (e.g. Posner et al, 1982) but these have not resulted in much success. Based on their review of the extant literature in the area, Gunstone and White (2000) have come to the conclusion that:
The issue now appears to be not of abandonment and the replacement, but of addition, so that the earlier belief and scientific belief co-exist. The learner’s task is to learn the scientific belief, and to become clear about when it is appropriate to apply one belief or the other (p. 298).

In support of the view Ogunsola-Bandele (2009) has stated that science and IKS should be allowed to co-exist. In conclusion, the assertion of the finding that, learners held ‘valid’ or relatively good conceptions of fermentation were based on the questionnaire which was designed and structured in such a way that it was possible to extract ‘scientifically valid’ conceptions of fermentation from the learners’ pre-test responses.

- Learners exposed to a Dialogical Argumentation Instructional Model (DAIM) tended not only to develop better attitudes to science, but also to value the science embedded in IKS more (e.g. see Newton, 1999). This observation was suggested by the fact that the number of learners in this group with equipollent or dualistic views about science increased considerably after the intervention while those in the C group dwindled considerably.

The DAIM that the E group learners were exposed to, enabled harmonious dualism where the E group learners could hold two diametrically opposed worldviews without experiencing cognitive conflicts (Ogunniyi and Ogawa, 2008). Conceptual change theory requires a dramatic restructuring of the existing knowledge base (Feltham and Downs, 2002) since the existing knowledge base is regarded as misconceptions that are viewed as potential stumbling block for the ‘new’ scientific knowledge that the learners need to assimilate. The weakness of the conceptual change theory perhaps, as has been pointed in the extant literature (Ogunniyi and Hewson, 2008), is its assumption that learners would easily abandon their entrenched beliefs overnight as a result of a series of well formulated and implemented classroom instructions. Again as a review by Gunstone and White (2000) has shown:

*Making the scientists’ version intelligible and plausible caused no problem; teaching had long been directed at those matters. The difficulties seemed to be in bringing about dissatisfaction with existing beliefs, and in obtaining acceptance that change to the scientists' view would be fruitful in wider context than just learning to pass examinations (p. 298).*

The finding seem to confirm other related studies, that learners as well as adults hold multiple worldview presuppositions and that, teaching and learning should seek to harness these worldviews so that they can live side by side.

- Both groups’ pre-test responses to the attitudes questionnaire based on the framework of the Contiguity Argumentation Theory (CAT) revealed that although the equipollent worldview seemed to be frequent by the learners they demonstrated the different cognitive categories in a variety of ways, (i.e. Scientific and IKS-based) of fermentation. This means that, they held both the Scientific and the IKS-based views of fermentation in a co-existing manner. This corroborates earlier studies in the area (e.g. Aikenhead & Jegede, 1999; Fakudze, 2004; Ogunniyi, 1988, 2004, 2007a & b; Ogunniyi & Hewson, 2008; Ogunniyi & Ogawa, 2008).

The findings of this study, seem to be in agreement with the previous findings where Posner et al (1982) have pointed out that, learners do hold alternative conceptions that are hard to change in favour of more plausible scientific conceptions. The blessing of the conceptual
change theory by Posner and others (for example, Hewson, 1988; Hewson & Hewson, 1988, 2003) is that researchers became more aware of the importance of prior learning in the teaching-learning process. But as already indicated by Gunstone and White (2000) changing or replacing learners’ beliefs with the scientific belief is almost nigh impossible using the theory in the strictest sense. In addition, Jegede (1996) has also warned that, if care is not taken regarding learners’ pre-conceptions which he calls ‘mysteries’, they “are capable of causing blockage to any scientific knowledge the child might acquire as a result of schooling” (p. 18).

In the case of learners holding dualistic or equipollent worldviews, the Contiguity Argumentation Theory (Ogunniyi, 2007) seems to have elucidated the process of how conceptions flow within learners’ cognitive structures. Rollnick and Rutherford (1996) have also alluded to the fact that, “pupils utilize two separate knowledge systems in order to achieve this and operate happily in these two paradigms” (p. 91). However, most studies dealing with border crossing or dualistic worldviews seem not to have given an satisfactory explanation of how learners hold equipollent or dualistic worldviews.

According to Ogunniyi (2009), “the context of a particular discourse plays an important role in the amount or intensity of emotional arousal experienced by the participants in such a discourse” (p. 3), thus equipollency of the learners’ worldviews has been as a result of two competing worldviews exerting equal forces on the cognitive structure of an individual. The implication for instructional purposes is that, conducing learning environments such as the DAIM should be used in order to mediate between the two diverse worldviews so that, learners can be in a position to recognize and utilize whichever worldview is appropriate at a particular time.

**Conclusion**

Without a dialogical argumentation approach it would have probably been impossible to obtain or to describe the learners’ conceptions of fermentation ‘accurately’ since, “ideas that are unlinked to the content in an adult scientific logical sense may be linked for the student” (Marin et al., 2001: 685). Although, DAIM seem to require a lot of time to implement, it seemed to be effective in facilitating a learner-centered environment and the enhancement of teacher and learners’ awareness of and understanding of the Nature of Science (NOS) and the nature of IKS (NOIKS).

**References**


Practical Work in Primary Natural Sciences Classes: A Bridge to a Future of ‘Better Understanding’ or ‘Problematic’?

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The purpose of this study was to obtain information related to research questions on how practical work influences the conceptual knowledge of Grade 6 learners in the Natural Sciences class, the learning atmosphere in these classrooms, and to what extent practical work influences such learners’ attitudes towards Natural Sciences. Data was collected by having participating learners complete questionnaires on the practical work and their attitudes.
towards Natural Sciences, complemented by semi-structured interviews with Grade 6 Natural Sciences teachers. The main findings include that both learners and teachers confirm that practical work improves the conceptual knowledge of Grade 6 learners in Natural Sciences classes, and that it positively influences both the learning atmosphere in the classroom, and learners’ attitudes towards Natural Sciences.

**Purpose, Research Questions and Justification of Importance**

Akoobhai (2006:166, referring to Woolnough and Allsop) sees “(t)he role of practical work (as) crucial to the learning and teaching of science”, as it is “a powerful tool for making concrete a subject which is abstract and inherently difficult to understand” (ibid), and “the way learners (are) engaged in (such) scientific investigations” (Villaneuva & Webb, 2008:3) thus helps them to develop better conceptual knowledge in Natural Sciences.

Tlala (2006: 683) regards “laboratory work ... as an integral part of most science courses (because it) offers students a learning environment that differs in many ways from the traditional classroom setting”, while Kandjeo-Marenga and !Gaoseb (2009:113) point to research that indicates “that a conducive teaching and learning environment in science classes is essential as it might contribute to learners’ appreciation of science”. At the time when this study was undertaken, the second author taught Natural Sciences in Grade 4, and she believes that results from a study such as this one could positively influence the teaching and learning in primary classes.

We do not necessarily believe that “(t)he significance of practical work lies in the opportunity it provides to develop practical skills” (Kandjeo-Marenga & !Gaoseb, 2009:113), but rather place more value on the opportunities it creates for increasing and broadening learners’ “imagination, curiosity and ability to ask good questions” (Department of Education, 2002:9), and contributing to “the holistic development of values (and) attitudes” (Department of Education, 2002:82). Along with Schulze (2003:18, referring to Nukeri), we believe that it is important “to improve the attitudes of learners towards” Natural Sciences, by presenting and promoting the learning area in such a way that learners will want to learn more, and “in order to encourage more learners to” elect to continue with Physical and/or Life Sciences in the secondary school.

“Even though practical work (has thus been shown to) contribute in important ways to the learning” (Tlala, 2006: 683) of Natural Sciences, Stoffels (2005:148) warns that “it is important to bear in mind there is a growing body of scholarship that problematises the commonly accepted and variegated forms of science practical activities, and that casts doubts on its effectiveness as a teaching and learning strategy”.

Research questions to refine this enquiry therefore include:

- How does practical work influence the conceptual knowledge of Grade 6 learners in the Natural Sciences class?
- How does practical work influence the learning atmosphere in the classroom?
- To what extent does practical work influence learners’ attitudes towards Natural Sciences?

In summary, this study aims to “provide an indication of the progress being made towards bringing effective science education” to learners by using practical work (Hobden, 2006:359).

**Literature Review**

According to Hattingh, Rogan, Aldous, Howie and Venter (2005:13) the introduction of OBE led to a shift in focus, away from teacher input, towards “what learners can do with their
knowledge, and in particular whether they can use what they know to meet the specified outcomes” “of the learning process” (Rogan, 2004:165).

When the Revised National Curriculum Statement for Natural Sciences was introduced, teachers were required “to make changes to their teaching practices” (George & Sanders, 2006:335), and it therefore became necessary to bring “about change in pedagogical understanding and teaching behaviours that are prerequisites” for alignment to the spirit of curriculum innovation (Braund & Campbell, 2006:205), as “teachers’ beliefs can make or break the implementation of an innovation” (Kriek & Stols, 2010:439).

Along with Hattingh et al. (2007:84), we believe that “(p)ractical work has the potential to contribute to meaningful learning in science”, as “experiments (can) enhance (learners’) understanding and application of knowledge” (Mji & Makgato, 2006:254). However, studies by both George and Sanders (2006:335), and Tlala (2006: 683), point out that some teachers show a lack of sufficient background, or an incomplete understanding, of how to design practical work in order to enhance learners’ understanding, even after in-service workshops. We therefore “need (to develop) a better understanding of the (teachers’) beliefs that inform these decisions.” (Kriek & Stols, 2010:440).

While a paper by Stoffels (2005:147-8) “illuminates ... the impact of curriculum support texts on how science teachers structure and facilitate practical activities for their learners”, Rogan (2004:167-8) presents a profile for implementation for the Natural Sciences learning area, in terms of “the nature of the classroom interaction (what the teacher does and what the learners do),” as well as the “use and nature of science practical work”. Selected sections from this profile refer to:

**Level 1** “(A) traditional teacher-centred approach towards practical work” is followed (Stoffels, 2005:147), where the teacher performs “classroom demonstrations to help develop concepts”, using bought or improvised apparatus, or “specimens found in the local environment to illustrate lessons”;

**Level 2** Although some learners assist in planning and performing the demonstrations, and they use data from these demonstrations to construct their own “graphs and tables”, most of these “experiments and activities are performed using so-called ‘cook-book practicals’ ” (Cossa, 2006:240), where they are either told what to do by the teacher, or are “following a set of instruction as written in their textbook” (Tlala, 2006: 683) or worksheet. “(T)he use of (such) ‘cookbook laboratories’ has been criticized for its failure to provide students with opportunities to plan investigations and perform their own experiments enabling them to construct their own knowledge of the scientific phenomena” (Cossa, 2006:240).

**Level 3** Teacher designs practical work in such a way as to encourage learner discovery of information. Learners perform 'guided discovery' type practical work in small groups, to engage in hands-on activities that promote inquiry (thinking), rather than just illustrate concepts.

**Level 4** Teacher gives learners a problem or question and they then design their own experiment and ensure that their data is accurate.

In a review of these levels, Rogan (2004:174) reports that “as far as science practical work is concerned, the cases indicated lots of room for improvement. In a few instances, the teacher performed demonstrations, sometimes with the involvement of learners. In a few lessons, the learners were given apparatus and performed simple activities, using skills such as observation and measurement. In terms of practical work, most schools did not even engage in level one type practices, while a few were involved in level one and two actions.”
Similarly, Hattingh et al. (2005:21) indicate that “very few of the learners in the 12 case-study schools engaged in any kind of meaningful hands-on practical work. None had the opportunity to design an experiment as specified by LO1 of the ... curriculum.”

A paper by Kandjeo-Marenga and !Gaoseb (2009:113) “reports on the science laboratory conditions that prevailed in Namibian secondary schools and how such environments impact the teaching and learning of practical work in science education.” They seem to believe that “laboratories (need) to be well-equipped ... in order for teachers (to be able) to design well-thought through practical activities” (ibid). While Kandjeo-Marenga and !Gaoseb (2009:113) specifically “argue that (a) lack of laboratory resources (has) ... an impact on the teaching of practical work in most African countries”, Cossa (2006:240) points out that the effective implementation of practical work is a general problem in many developing countries. She believes that due to the realities of the environments within which many teachers teach, “they are not using different kinds of practical work activities”, and learners are therefore not being “provided with the opportunity to experience practical work in science.” (Tlala, 2006: 683).

An article by Hattingh, Aldous and Rogan (2007:75) “describes the quality of the practical work implemented by ... teachers” of Natural Sciences in Mpumalanga secondary schools. According to Hattingh et al. (2007:84) “(i)t would appear that in a school where innovation is generally supported, science teachers engage in higher levels of practical work” and that “(t)eachers who perceive their learners to be motivated and non-disruptive are more likely to engage learners in higher-level types of practical work.” (ibid).

Bosman (2009:3, reffering to Schultze & Nukeri) “found that a decreasing number of learners study science at schools and universities, which may be due to the negative public perception(s) of Chemistry and Science Technology.” Schultze and Nukeri (2002:154,172) are convinced that “(i)f more learners can be motivated to pursue the study of science so that they understand the importance and relevance of science in their lives, learners can be prepared to be effective citizens in the scientific and technological South Africa desired by all”.

**Theoretical and Conceptual Framework**

Keane, Mbhele, Malcolm and Rollnick (2006:397) deliberate around the issue of choosing “an appropriate theoretical framework for research – especially when working in the context of science education”, and then goes on to point out that “different frameworks provides for enriched approaches to data production and interpretation.”

In terms of ontological assumptions, we “assume that social reality can be understood ... through words and names created by the mind and within levels of individual consciousness (the nominalist ... position)” (Maree & van der Westhuizen, 2007:31), while in terms of epistemological assumptions, we view knowledge from a standpoint where “an interpretive, anti-positivist stance may be adopted ..., which might lead to a more subjective, participatory role” (Maree & van der Westhuizen, 2007:32), where the researcher is seen as “part of the phenomenon of study” (Schulze, 2003:9). The theoretical framework mentioned by Keane et al. (2006:397) is also “consistent with epistemologies of learner-centredness and constructivism.”

Schulze (2003:8-9) point out that most researchers identify interpretivism as “the paradigm underlying qualitative research”, which “studies individuals in depth, using mainly qualitative techniques such as interviews.” Based on the indicated epistemological assumptions, and the description of interpretivism as provided by Nieuwenhuis (2007:59), this study endeavours to
focus on learners’ and teachers’ “subjective experiences” of how learners ‘construct’ their ‘Natural Sciences’ worlds “by sharing meaning and how they relate to each other.” (ibid).

Gwimbi and Monk (2002:51) investigated “the classroom practice and the philosophy of science (PoS) of thirty three ... teachers in ... Zimbabwe.” Interestingly, they found that those teachers who “were significantly less process-oriented, less positivist and less inductivist” with regard to “PoS ... (i)n practical lessons ... demonstrated what had to be done and then left students to do it.”

Stoffels (2005:148, quoting from a 1997 Department of Education discussion document on specific outcomes, assessment criteria and range statements for Curriculum 2005) clarifies that the concept of ‘practical work’ “specifically refers to those teaching-learning transactions in which learners are given ample opportunities to practise the ‘processes of investigation’ ... These would involve any ‘hands-on’, ‘minds-on’ practical learning opportunities where learners practise and develop various process skills such as questioning, observation, hypothesising, predicting and the collection, recording, analysis and interpretation of data.”

Research Design, Methodology and Data Collection

As indicated by James and van Laren (2006:379) it is now necessary “to consider the methodological aspects of the research process and the context in which the research takes place.” The methodological preference of this research leans towards “an idiographic approach”, which “is characterised by a focus on the individual and on understanding individual behaviour” (Maree & van der Westhuizen, 2007:33). Some aspects of our research was also similar to those of Keane et al. (2006:397) - their “initial methodological framework was mindful inquiry ... (which) formed an ‘umbrella’ of overlapping frameworks that contributed to the research knowledge creation. (The) chosen methodology ... was (also) compatible (with the) orientations (of) Participatory Action Research” (PAR). A part of the description of PAR provided by Ebersöhn, Eloff & Ferreira (2007:126) refer to an emphasis being afforded to “‘equal’ collaboration”, with “research participants (being) involved as (an) integral part of (the research) design”, as well as outcomes being “linked to the participants’ feelings and understanding of the research project.” (James & van Laren, 2006:379).

Design and methodology

As researchers, we decided to adopt a multi-method “mode of inquiry” (Maree & van der Westhuizen, 2007:33), which meant that we combined “quantitative with qualitative data in order to add depth to findings ... in a strategy ...illustrated by the typology quan + qual”, in that quantitative and qualitative data were afforded equal priority.

Although Green and Naidoo (2006:78) point out that “(t)he strength of the qualitative approach is that it gives recognition to more important and less important statements that the quantitative method renders equal”, like Schulze (2003:8), we believe that “a combination of the two methods builds on the strengths of both.”

Data collection and instruments

All 99 of the Grade 6 learners for whom the language of instruction is English at a specific primary school in the Pretoria area was included in the population for this study. It was decided to use convenience sampling, in that this is the school where the second author was teaching Natural Sciences to Grade 4 learners at the time when this study took place. However, for reasons related to voluntary participation, Grade 6 learners were invited to take part in the study – this also (to some extent) addressed the issue of learners who might feel
obligated to answer ‘as nice as possible for my teacher’. The teachers invited to participate were Grade 6 Natural Sciences teachers at this same school.

Although participation in this study was voluntary for learners and teachers, all learners were required to participate in all classroom activities, including the experiments, as these form part of the Natural Sciences class activities. However, only those learners who were willing to participate, where both their parent/guardians and the learners themselves had signed letters of consent, completed a questionnaire to establish what the learners really think about the experiments in the Natural Sciences classroom. No specific inducements were offered to human subjects to participate in this study.

Similar to the study reported on by Tlala (2006: 683), the research instruments used in this study consisted of short questionnaires containing closed (structured) questions to learners, and semi-structured interview schedules used with the teachers, “to ascertain the attitude of these teachers towards practical work.” (Akoobhai, 2006:166).

Bosman (2009:188, referring to Nukeri) “acknowledges that the questionnaire as data collection instrument may ... be a cause of bias”, as “questionnaires consisting only of structured and closed items do not allow respondents to freely respond according to their experiences or preferences, but (instead) force respondents to choose between predetermined responses” (ibid).

Learners needed approximately 10 minutes to complete their questionnaires, after having participated in some experiments, while teachers’ once-off semi-structured interviews took no more than an hour each to complete, and were conducted with teachers outside of class time.

**Strengths of research design and data collection methods**

The fact that learners completed their questionnaires anonymously meant that they could answer as honestly (and frankly) as they wanted, because no one would know ‘who wrote what’. A questionnaire containing closed, structured questions was used, as we wanted fairly specific information, and also to support learners of these ages. The practical activities that teachers usually do in their classes, i.e. the experiments, were used as context, as this meant that learners did not feel overwhelmed by having to do something different from what they were used to.

We decided to use interviews for the teachers, as we didn’t want them to ‘just quickly’ fill out a questionnaire to get it over and done with. Furthermore, teachers could also not come up with ‘prepared’ answers.

**Shortcomings and possible sources of error in research design and data collection methods**

With regard to the population for this study and representative sampling used, Bosman (2009:188) points out that in order for inferences drawn based on this study “to be valid, the observed sample must be representative of the target population”. In this study, although the final sample of learners is fairly well representative of the learners in this school (see Table 1), their average ages do not necessarily match the national distribution for Grade 6 learners, and being from a school in a sub-urban setting, might not represent the views of inner-city or rural learners. Obviously, the two participating teachers cannot be seen in any way to be representative of all Natural Sciences Grade 6 teachers in South Africa, but being female, do represent the majority gender for such teachers. Results obtained can therefore only be used to reflect situations in schools approximating the circumstances as described here.

Another potential weakness in this research was the attitude of the learners towards the learning area specifically, and towards school and teachers in general. Because they
completed their questionnaires anonymously, learners could basically write on the questionnaires what they pleased. Despite learners completing their questionnaires anonymously, some of them still had concerns ‘just in case someone can see what they write’. Also, despite being urged to reflect their personal opinions on the questionnaires, many learners of this age might still provide those answers that they believe ‘the teachers want to hear’.

Having elected to work in the interpretive paradigm, we “prefer inductive data analysis” (Maree & van der Westhuizen, 2007:37) with no initially prescribed “themes and categories” (Maree & van der Westhuizen, 2007:34), but these, instead, being “identified during the research – from the participants’ ‘point of view.’” (Schulze, 2003:9; Barnes, 2005).

Discussion of Results

Results found for participating learners

Table 1. Biographical data.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Number of participants</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>42</td>
<td>57%</td>
</tr>
<tr>
<td>Male</td>
<td>32</td>
<td>43%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age</th>
<th>Number of participants</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>27</td>
<td>36%</td>
</tr>
<tr>
<td>12</td>
<td>43</td>
<td>58%</td>
</tr>
<tr>
<td>13</td>
<td>3</td>
<td>4%</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>1%</td>
</tr>
</tbody>
</table>

The gender and ages of the 74 participating learners are presented in Table 1, which shows that the learners are spread fairly evenly with regard to gender, and learners are on average aged 12 years.

With the exception of 6 learners (5 boys and 1 girl), the majority of participating learners indicated that Natural Sciences is their favourite subject. All learners, even those for which Natural Sciences is not their favourite subject, indicated that they enjoy the learning area.

31 of the boys like doing practical work in Natural Sciences and they believe that it helps them to understand the work better. Although the other boy said that he doesn’t like the practical work, it does help him to understand the work better. On the other hand, all the girls agreed that they like doing practical work, and with the exception of one girl, that it helps them to understand the work better.

Everyone agreed that doing practical experiments is not a waste of time. Generally, the Grade 6 learners feel that they use every day things to do the practical work, and all of them, with the exception of one girl, felt that their teachers make the practical work interesting. The general notion is that learners want to find out more about the work after they have participated in the practical experiments - only 4 learners disagreed with this last statement.

Learners were presented with a list of statements as reflected in Table 2 to choose form (they could select more than one option) to indicate what they think applies to their Natural Sciences classrooms.

Table 2 makes it clear that learners are actively taking part in the experiments and that their teachers are helping and supporting them. The general agreement was that learners can and
want to do more practical work – none of the learners felt that they were doing too much practical work.

Table 2. Learners’ perceptions of practical work.

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of responses</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>The teacher does everything</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>The learners aren’t allowed to touch anything</td>
<td>1</td>
<td>1%</td>
</tr>
<tr>
<td>We get a chance to use the apparatus</td>
<td>63</td>
<td>85%</td>
</tr>
<tr>
<td>Teacher and learners are involved with the practical work</td>
<td>66</td>
<td>89%</td>
</tr>
<tr>
<td>Sometimes we do everything ourselves (under supervision)</td>
<td>65</td>
<td>88%</td>
</tr>
</tbody>
</table>

In summary, learners want to do practical work, but they want to be involved in the experiments themselves – they don’t just want to observe. Learners made it very clear that they definitely understand the work better and that they want to learn more after they have participated in the experiments. They also indicated that because their Natural Sciences teachers make the work interesting and allows them to actively take part in the experiments, the learners have a positive attitude towards the learning area and practical experiments. Learners’ perspectives on the research questions are thus that practical work, if implemented correctly, definitely improves their understanding of the work, and even leads to learners wanting to learn or find out more about the work.

Results from interviews with teachers

Both the teachers felt that practical work in Natural Sciences is essential for the primary classes, and that it enhances learners’ understanding. They feel that the learners love to be involved with the experiments and that they can’t wait to see the outcome of the problem or process.

One of the teachers explained that in order to make the practical work interesting and fun, she creates a feeling of suspense, by telling learners what they have to bring to school for the practical work, but she doesn’t explain what they are going to do - the practical work stays a secret until the due day. By doing this, the learners get very excited and they can’t wait for the practical work.

Problems that occur with the practical work are that not all learners bring the necessities for the practical work to school. Therefore they cannot take part in the practical work – they can only observe. The teachers in this study clearly do know what the difficulties are that they experience with practical work, as opposed to teachers in a survey carried out by Muwanga-Zake (2001) in rural schools in the Eastern Cape, catering for Grades 7 - 12, which revealed that teachers from those schools “did not seem to know their problems in teaching science”, and they, for example, claimed “that they do not teach science practically because they do not have apparatus”, even though Hattingh et al. (2007:84) found “that the doing of practical work is not significantly dependent on whether teachers have physical resources”.

They feel that their learners enjoy the practical work, because it creates a visual format for the learners to see – and this in turn leads to a better understanding of the work. Furthermore, they both feel that even more practical work can be done, because the learners love to be involved and they learn much more from seeing the practical, than listening to a lecture-style class.

Both the teachers estimate that they allocate about 30% of their teaching time to doing practical work. When presented with a table containing different levels of practical work as outlined by Rogan (2004:168), and asked to indicate what percentage of their practical work
teaching time they allocated to each of the levels, they indicated that fairly equal amounts of time were being spent on each level.

**Reflection**

We believe that the research methods used were appropriate, as we gained insight into the opinions of the teachers, as well as the learners. The strengths of the chosen research designs and methods were used to best advantage, and were applicable for the purposes of this study. The research instruments used were also appropriate for obtaining the types of data we required. Although one or more open (unstructured) questions in the learners’ questionnaire might have led to interesting information or aspects that could have been overlooked, results obtained were adequate.

It is never easy to complete research in a short period of time, because it is very easy to overlook issues that could impact the research. Good planning and time management is key to completing research such as this study successfully. In some instances, time and effort could have been allocated more effectively.

**CONCLUSIONS**

As was the case for Tlala (2006: 683), our research findings “revealed that (practical work) does contribute to meaningful learning and positively change(s) learner’s attitude(s)” (Tlala, 2006: 683):

- Practical work influences the conceptual knowledge of Grade 6 learners in the Natural Sciences class in that when learners see what is meant by a specific concept while they are doing practical work in Natural Sciences, they develop a clearer understanding of such a concept.
- Practical work has a positive influence on the learning atmosphere in the classroom when learners can participate. They feel involved, which promotes a favourable learning atmosphere. When teachers make practical work interesting, and keep learners in suspense, it leads to excitement, which improves the learning atmosphere even further.
- Practical work influences learners’ attitudes towards Natural Sciences by changing the scepticism some learners feel in relation to the learning area, to interest and perceptions of ‘fun’. Learners’ improved understanding of the work and concepts result in positive changes in learners’ attitudes. They are no longer ‘scared’ of Natural Sciences, because they understand the work.

After learners’ questionnaires and teacher interviews had been analysed, we came to the conclusion that both learners and teachers are in favour of practical work, and that the practical work being done helps learners to form a better understanding of the learning area. It would seem that for teachers in this study, the biggest problem related to practical work is that the learners cannot always provide or bring the necessities from home. Tlala (2006: 683) advises that “(t)eaching using lo(w)-cost materials may alleviate (such) problems”.

If the question that Hobden (2006:359) asks, on whether “our current interventions (are) making a difference to the knowledge and skills of learners in science”, is in relation to practical work, the overwhelming answer from the participants in this study is YES!

**References**

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Unique Learning Styles in Natural Sciences: A Bridge to Future Human Beings

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This study investigated whether Grade 6 learners differ in their preferred learning styles, whether they chose to complete assignments aligned to these learning styles if offered choices between assignments in Natural Sciences focused on specific learning styles, and whether such choices affects learners’ achievement. Data was collected by having learners complete learning style questionnaires and three assignments. Learners’ marks for assignments were also used. Findings include that learners’ learning styles were spread almost evenly over the options tested, that the majority of learners elected to do assignments aligned to their preferred learning style, and achieved better marks in these assignments, compared to an assignment where they didn’t have a choice. We recommend that teachers offer their learners choices aligned to different learning styles in Natural Sciences.

Purpose, Research Questions and Justification of Importance

The Revised National Curriculum Statement (RNCS) states that “(t)he Natural Sciences Learning Area” both “envisages a teaching and learning milieu which recognises that the people of South Africa operate with a variety of learning styles, as well as” starting “from the premise that all learners should have access to a meaningful science education” (Department of Education, 2002:5). In line with this statement, and along with Tanner and Allen (2004:197), we believe that “(u)nderstanding the variety of learning styles that students bring to a science classroom will not only help some students learn more science, but also help more students learn any science.” However, in order to provide this kind of access “to science learning and encourage a broader spectrum of students to pursue studies in the sciences, ... teachers ... must begin to address the diversity of learning styles among the students in (their) classrooms” (ibid) and use instructional methods to reach learners “who span the spectrum of learning styles” (Felder, 1993:286).

Where there is a greater alignment between learners’ learning styles and the teaching styles used by their teacher, they tend to retain more information for longer, acquire more competencies, apply these more effectively, and have better attitudes toward the subject (Felder, 1993; De Boer & van den Berg, 2001; Wirz, 2004). Stols (2006, referring to work by Eick & Reed) point to evidence that suggests that teachers incorporate their own preferred learning style(s) into their approach to teaching science.

This research was thus carried out to establish:

• Do Grade 6 learners differ significantly with regard to dominant learning styles?
If offered choices with regard to assignments in Natural Sciences focused on specific learning styles, do learners choose to complete assignments aligned to their dominant learning styles?

Does offering learners choices with regard to assignments focused on specific learning styles affect learners’ achievement in such assignments?

Similar to some of the research described by Willems (2007:1068), the purpose of this study can thus broadly be summarised as “to identify the impact of learning style preferences on” Grade 6 learners’ choices and marks in Natural Sciences.

**Literature review**

In terms of ontological assumptions, McLachlan (2006) believes that different learners are driven by different things: Learners “have different levels of motivation, different attitudes about teaching and learning, and different responses to specific classroom environments and instructional practices.” (Felder & Brent, 2005:57). “Each individual (therefore) has his/her unique way of learning” (Kinshuk, 2004:3): learners “preferentially focus on different types of information, tend to operate on perceived information in different ways, and achieve understanding at different rates” (Felder, 1993:286) “– which is to say, they have different learning styles.” (Felder & Spurlin, 2005:103).

Moore and research have begun emerging during the last three decades within the field of education that shows that learners are characterized by significant differences in their preferred learning styles (Sanders & Vally, 2009). Such differences in “(l)earning style greatly affects the learning process, and therefore the outcome(s)” of learning (Kinshuk, 2004:3).

Felder and Brent (2005:57-58) point out that “(d)iversity in education usually refers to the effects of gender and ethnicity on student performance.” However, they believe that “three other important aspects of student diversity” consist of learning styles, “approaches to learning” and “intellectual development levels” (ibid).

**Baumgartner.** Lipowski and Rush (2003:ii) used a “selection of differentiated instructional strategies to improve” targeted Grade 2, 3 and 7 learners’ achievement, which included providing these learners with choices between a variety of learning tasks. The learners not only demonstrated greater mastery of the skills they were tested on, after the implementation process was complete, but their attitudes also improved, along with their “perceptions about their own ... abilities.”

In their excellent review, **Coffield, Moseley, Hall and Ecclestone (2004:138)** “examined in considerable detail 13 models of learning” styles to select “the most important models from the literature. This was done by means of assessing the theoretical robustness of each model and evaluating the implications of these models for learning” (Du Toit, de Boer & Bothma, 2010:13). The report by Coffield et al. (2004) also “documents an investigation into the wide range of existing learning style instruments designed to identify a student’s preferred style of learning” (Du Toit, de Boer & Bothma, 2010:13), which show “that some of the best known and widely used instruments have such serious weaknesses (e.g. low reliability, poor validity and negligible impact on pedagogy) that (they) recommend that their use in research and in practice should be discontinued.” (Coffield et al., 2004:138). “(O)ne of the most obvious conclusions is the marked variability in quality among them; they are not all alike nor of equal worth and it matters fundamentally which instrument is chosen.” (ibid).

Nixon, Gregson and Spedding (2007:39) found “little objective evidence in support of” the effectiveness of learning styles. This “lack of unambiguous evidence” for “these models and practices leaves the continued popularity of these models and instruments as a puzzle.” They
argue that “the simple and direct appeal of these models ... in part explains their continued popularity”, and when these models are situated “in the arena of contemporary pedagogic practice ... it becomes possible to discern a number of ways in which they can also be recognized to serve specific instrumental ends.” Van Zwanenberg, Wilkinson and Anderson (2000:365) also discuss “(t)he general lack of significant correlations between learning style scores and performance” and draw conclusions about “the activity-centred nature of learning styles”.

Two of the four types of “research-based models of learning styles” that Sanders and Vally (2009:524-525) describe respectively focuses on learners’ “preferred cognitive approach to understanding and assimilating information (e.g. Kolb’s model of information processing)”, or is “(b)ased on preferred learning environments and instructional methods (e.g. the model of ... Felder and Silverman).”

De Boer and van den Berg (2001:120) point out that Kolb’s Learning Style Model “classifies students as having a preference for” one of four learning styles, that correspond to each of four different types of knowledge, which Kolb (1984:76–77) defines as follows:

• The converger “relies primarily on abstract conceptualisation and active experimentation” (Coffield et al., 2004:61) to finalise “practical application of ideas”;
• The diverger “emphasises concrete experience and reflective observation” (ibid) to view situations from a wide range of perspectives;
• The assimilator “prefers abstract conceptualisation and reflective observation” (ibid) to put ideas into concise, logical form, and understand a wide range of information by creating theoretical models; and
• The accommodator “emphasises concrete experience and active experimentation”, and is at ease with obtaining information from people.

Felder (1993) originally noted five matched pairs of learning styles that showed different methods of processing and organising information, differing cognition paths, and favouring of information. The five pairs of learning styles relate to domains for “sensing (facts) and intuitive (theories) learners; visual and verbal learners; active and reflective learners; ... sequential and global learners” (Willems, 2007:1068), while Kinshuk (2004:3) points out that “the inductive-deductive dimension has been deleted from the previous theory, because of pedagogical reasons.”

The Index of Learning Styles, an instrument based on a model developed by Felder and Silverman, collects quantitative data on learners’ “learning styles across four learning domains” (Willems, 2007:1068) by broadly answering four questions (Felder & Brent, 2005:60):

1. What type of information does the learner preferentially perceive: sensory (sights, sounds, physical sensations) or intuitive (memories, thoughts, insights)?
2. What type of sensory information is most effectively perceived: visual (pictures, diagrams, flow charts, demonstrations) or verbal (written and spoken explanations)?
3. How does the learner prefer to process information: actively (through engagement in physical activity or discussion) or reflectively (through introspection)?
4. How does the learner characteristically progress toward understanding: sequentially (in a logical progression of incremental steps) or globally (in large “big picture” jumps)?

The report by Coffield et al. (2004:138) concludes that Herrmann’s whole brain model “is suitable for use with learners .... (and) may prove especially valuable in education ..., since it ... foster(s) creative thinking and problem solving.” Although Coffield et al. (2004:138) point out that “it encourages flexibility, adaptation and change”, they also caution that “the
Herrmann ‘whole brain’ approach to teaching and learning needs further research, development and independent evaluation within education”, as “(r)elatively little assessment has been performed on the applicability of” this model “to instructional design” (Felder & Brent, 2005:58).

Now that we have reviewed literature in terms of the latest and most relevant research findings on learning styles, it is time to provide a “scholarly reflection” of the theoretical and conceptual frameworks that contribute to this study (Du Toit et al., 2010:5).

Theoretical and Conceptual Framework

Huebner (2010:79) point out that some of the “practices that provide the foundation” for differentiated instruction validated through solid research “include ... promoting student engagement and motivation ... (by) responding to learning styles” – a lot of this is also included as part of the model for differentiated instruction presented by Rock et al. (2008:33), which “is composed of a theoretical framework ... rooted in cognitive psychology and based largely on research on student achievement”, while some of their “guiding principles that relate to differentiating classroom practices” include responding “to individual student differences (such as learning style)” and integrating “ongoing and meaningful assessments with instruction” (Huebner, 2010:80, referring to Anderson, 2007).

As Felder and Spurlin (2005:104) warn that “(l)earning style dimensions ... are continua, not either/or categories”, the theoretical framework provided by Coffield et al. (2004:10) places learning styles preferences and models on a continuum as “a simple way of organising the different models according to some overarching ideas behind them.” Learning styles are captured with regard to whether these are claimed to be “relatively fixed” and stable, as opposed to being “more flexible and open to change”. Tanner and Allen (2004:198) agree that “learning styles should be considered to be flexible, not immutable - an individual’s learning style could be actively adapted, to a certain extent, to different learning environments”, and “can (also) be affected by a student’s educational experiences.” (Felder & Spurlin, 2005:105). Likewise, according to Kolb (2000:8), a learning style is not a fixed trait, but “a differential preference for learning, which changes slightly from situation to situation. At the same time, there is some long-term stability in learning style”.

Coffield et al. (2004:10) “assigned particular models of learning styles to” so-called theoretical ‘families’, in order “to impose some order on a field of 71 apparently separate approaches.” However, “some models are difficult to place”, “because the distinction between ... styles ... is not always clear-cut” (ibid) in terms of these being “increasingly amenable to adaptation” (Sanders & Vally, 2009:524-525).

Tanner and Allen (2004:197) explain that there are multiple answers to the conceptual question “what is a learning style?” as “(a)n individual’s learning style can be defined in many ways”:

- a learning style, as experienced by learners, is how information is recognised and processed (Kolb, 1984);
- “characteristic cognitive, affective, and psychological behaviors that serve as relatively stable indicators of how learners perceive, interact with, and respond to the learning environment” (Felder & Brent, 2005:58, referring to Keefe);
- a “predisposition on the part of some students to adopt a particular learning strategy regardless of the demands of the learning task ... a strategy that is used with some cross-situational consistency” (Sanders & Vally, 2009:524, quoting Smeck); and
- “general behavioural dispositions that characterize performance in mental tasks: they are intellectual personality traits” (Stott & Hobden, 2006:682, quoting Baron).
Kinshuk (2004:3) defines a learning style “as the unique collection of individual skills and preferences that affect how a student perceives, gathers, and process learning materials”.

**Research Methodology**

All the Grade 6 learners for whom the language of instruction is English at a specific primary school in the Pretoria area was included in the population for this study - these learners consist of 46 boys and 53 girls, aged between 11 and 14 years. It was decided to use convenience sampling, in that this is the school where the second author was teaching Natural Sciences to Grade 7 learners at the time when this study took place. However, for reasons related to voluntary participation, Grade 6 learners were invited to take part in the study.

Although participation in this study was voluntary, all learners were required to complete assignments. However, only learning style preferences and marks for those learners participating in the study were included as data.

At the start of the study, all Grade 6 learners completed a learning style questionnaire in their Life Orientation class, which it had been hoped should not have taken more than one class period (about 30 minutes) to complete. The questionnaire queried learners on the ways that they normally learn and how they act in learning situations. The Life Orientation class was used, because this kind of questionnaire fits into the curriculum for that learning area.

Felder and Spurlin (2005) specifies results from several studies that provide evidence of both convergent and divergent construct **validity** of Felder-Soloman’s Index of Learning Styles (ILS): Zywno (2003:1) not only discusses construct validity, but also includes results for “test-retest reliability, ..., internal **reliability**, total item correlation and inter-scale correlation”, and Litzinger, Lee, Wise and Felder (2005) specifically collected data on the reliability and validity of the ILS in an education context. These studies “conclude that the ILS meets or exceeds accepted reliability standards for an instrument of its type.” (Felder & Brent, 2005:62).

Over the course of the normal sequence of one of the topics that Grade 6 learners are supposed to cover in Natural Sciences, learners completed two mini-tasks and one extended task. One of the advantages envisaged by the RNCS for the latter is that “(t)he three Learning Outcomes ... do come together when extended tasks are designed for learners” (Department of Education, 2002:6).

Some of the ways in which differentiating instruction was considered in this study was by varying “expectations for task completion” (Rock et al., 2008:33) and “including different types of activities in order to cater for different learning styles” (Grandell, 2005:211). For each of the mini-assignments, learners had a choice between two tasks to do, while for the larger assignment, they had a choice between four tasks. Each of the tasks was geared towards learners with a specific learning style: For assignment 1, learners had a choice between tasks related to learning styles C and D, for assignment 2 between tasks related to learning styles A and B, while for the semester assignment four tasks, one geared to each of the learning styles, were available. The mini-assignments would each take about two hours to complete, done over two weeks, while the larger assignment would take about three hours to complete, done over three weeks.
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Average: 70%  75%  78%  86%
Results

The columns in Table 1 represent (from left to right):

- The different learning styles indicated by learners’ completion of the learning style questionnaire;
- Learners’ choices in terms of the specific learning styles for each of the three assignments;
- Learners’ marks for a previous assignment where they had no choice between different assignments; and
- Learners’ marks for each of the three assignments specified in terms of learning styles.

A summary of the first column reveals that just more than a quarter of participating learners’ preferred learning styles fall within each of three of the options provided: Fifteen (29%) of the learners preferred learning style A, 14 (27%) learners each preferred learning styles B and C respectively, and 8 (16%) learners preferred learning style D.

When completing assignments 1 and 2, all of the learners chose tasks aligned to their preferred learning styles, when these were available. For the semester assignment, only seven (14%, shaded in Table 1) learners chose tasks that were not aligned with their preferred learning styles.

The averages shown in the bottom row of Table 1 seem to indicate that learners’ marks improved when they had a choice between tasks, with the best results obtained when all learners’ learning styles were available in the semester assignment.

Discussion of Results, Implications and Recommendations

The statement by De Boer and van den Berg (2001:124) “that every classroom represents a complete spectrum of” learning styles was again “proven to be correct”, as our study similarly “reveals that there is a distribution of learning preferences” for all learning styles tested for in these Natural Science classrooms, and that these learning styles are fairly “equally represented” (ibid). It is therefore recommended that teachers seriously consider offering their learners choices aligned to different learning styles in the Natural Sciences class.

Although the learning style questionnaire that was used to gather data in this study, as was the case for the research conducted by Kinshuk (2004:3), provided “a convenient and practical approach to establish the dominant learning style of each student” and “proved to be a valid and useful diagnostic assessment tool” (De Boer & van den Berg, 2001:124), it is recommended that such an instrument be customised very carefully to learners’ level (that will be easier for the learners to understand), because many learners struggled with some of the words.

Felder and Brent (2005:57) believe that the one of the most important of the “(t)hree categories of diversity that have been shown to have important implications for teaching and learning are differences in students’ learning styles”. One of the implications “of these observations is that to ... improve the thinking and problem-solving skills of (learners), ... schools should attempt to improve the quality of their teaching, which in turn requires understanding the learning needs of today’s ... students and designing instruction to meet those needs.” (ibid). Along with Mtetwa and Kwari (2006:515-516),
we therefore **recommend** that teacher training should address “elements that ... empower and broaden learner horizons in harmony with their preferred learning styles”.

Moallem (2002:71) point out that research such as that conducted by Baumgartner et al. (2003) “provides information on the” **implications** of research literature on learning styles with regard to “the quality of students’ learning and their attitude and satisfaction” and although it provided “valuable insight into the potential impact of differentiated instruction on achievement of diverse learners, by no means does it fill the apparent gap in research on this important and timely topic.” (Anderson, 2007:52). “(M)ore illustrations and examples of research methodologies used for examining its effectiveness when implemented with diverse students is critical in determining whether or not this instructional approach to teaching students with diverse ... learning styles is indeed, a viable approach to teaching all types of learners” (*ibid*).

One of the questions that could be investigated in a further study include looking closer at whether the improvement in learners’ marks shown in this study was really about learners having access to tasks related to the different learning styles, or were learners maybe just inspired by having a choice? What would the effect be if learners could choose between different tasks, but were all tasks were based on one specific learning style?

This study also only focused on providing learners with a choice with regard to assessment options – could Grade 6 learners’ achievement in Natural Sciences be equally influenced by tailoring instruction to their different learning styles and/or providing them with choices in class activities?

Natural Sciences teachers and classrooms could further be investigated, to establish whether there are specific learning styles that are predominately used in the learning area and/or that lead to better learner achievement.

One of the strengths of this study was that both parents and learners reacted positively to this study right from the start – a contributing factor definitely being that the research was conducted at the school where the second author was teaching. This situation also made it easier for her to gather the data, control the process and stay within the time frame required.

The amount of time that learners was allocated to complete their assignments was also enough, as learners handed their assignments in on time, and didn’t ask for extensions. The informal feedback from learners about the assignments was positive: they enjoyed the fact that they had a choice, and feelings of being important and belonging were expressed.

One of the lessons learnt from conducting this research was that letters of consent for learners to take part in a study should be handed out as early as possible, or, even better yet, to hand these out to the parents after the meeting where the research was explained to them, instead of giving the letters to the learners. Most of the learners forgot to bring their signed letters back, and therefore couldn’t take part in the research – we would have liked for more learners to have taken part, as larger sets of data contributes to the reliability of results.
Conclusion

This study illustrated that Grade 6 learners have different learning styles, even for only 51 learners. It also demonstrated that if these learners have a choice between tasks geared to different learning styles, the large majority of them elected to do assignments aligned to their preferred learning style, and achieved better marks in these assignments, compared to an assignment where they didn’t have a choice.

As was the case for the research presented by Willems (2007:1069) the findings in our study not only challenges “the notion of one-size-fits-all approaches to the construction of ...learning environments”, but also challenges “teachers (to) recognize that there are differences in the ways that students learn.” (Wirz, 2004). The RNCS for Natural Sciences suggests that “(a) learner profile (that)... gives an all-round impression of a learner ... (can also assist) the teacher ... to understand the learner better, and therefore to respond appropriately to the learner.” (Department of Education, 2002: 82).

Felder and Brent (2005:58) also advise that it would be good if learners could be equipped with skills associated with different learning style categories, regardless of their personal preferences, since learners could then try to do assignments in other learning styles, so that not only, in future, no assignment will be a problem to complete, but they will also be better equipped with multiple learning style “skills to function effectively as professionals.”

De Boer and van den Berg (2001:125) believe that exposure of learners “to a variety of teaching methods” aimed at different learning styles, which focus “on the same key points”, can facilitate effective learning. Another way in which Natural Sciences teachers can accommodate different learning styles in their classes is by incorporating “active, experiential (and) collaborative student-centered learning” (Zywno, 2003:2).

“(T)eachers need to investigate their applications of ‘differentiated thinking’ toward instructional planning and implementation” (Anderson, 2007:52), because “(t)he more thoroughly instructors understand the differences, the better chance they have of meeting the diverse learning needs of all of their students.” (Felder & Brent, 2005:57). “For the educator, (learning styles) can be useful in considering ... how they approach their own teaching and learning, but also how they construct ...learning (opportunities) for their students so that all may learn.” (Willems, 2007:1069).

Stott and Hobden (2006:682, referring to work by Baron) believe that “learning styles ... should ... be the focus of instruction”, because of “the high generality, and thus transferability, of learning styles” (ibid). In this way, reflective opportunities can be created “for curriculum development and teacher professional development at school and district levels” (Department of Education, 2002:7) that “encourage teachers to apply differentiation with flexibility, creativity, and choice; and provide teachers with high-quality professional development” (Huebner, 2010:80).

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“Man’s mind, once stretched by a new idea, never regains its original dimensions”

( Oliver Wendell Holmes, US author & physician, 1809 - 1894)

Let us hope and strive for teacher professional development that stretches teachers’ minds, and all the growth that such stretching promises!
References


Using food science concepts to enact science-indigenous knowledge systems classroom based discourses

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ABSTRACT

According to the World Bank and United Nations Educational, Scientific and Cultural Organization (UNESCO), Indigenous knowledge systems (IKS) could serve as leverage for augmenting policy formulation regarding health, environment and education. By exploring the appropriate pedagogic approaches, the potential exist for integrating IKS into the conventional western based science classroom environment. This study is part of the Science and Indigenous Knowledge Systems Project (SIKSP) at the University of the Western Cape. In response to the new South African curriculum to integrate school science with IKS, the reported study involving science teachers used food science based concepts as part of an instructional model to enhance the teachers’ ability to engage in science-IKS classroom based discourses. The study involved 13 primary and secondary science teachers who attended bi-weekly science-IKS workshops for two consecutive six months. The teachers demonstrated the potential to: (1) enact science-IKS teaching and learning discourses, (2) articulate coherently the link between science and IKS concepts (3) discern science concepts embedded in traditional food processing techniques (4) unravel the wisdom in IKS and (5) value IKS as a useful body of “owned” knowledge.

Introduction

The National Curriculum Statement formulated by the South African government encourages the
indigenization of school science. Educators (teachers) are called upon to incorporate Indigenous Knowledge Systems (IKS) into school science discourses. The curriculum entreats educators to decontextualize school science by adopting IKS-science based lesson activities. Since school science is essentially based on a mechanistic worldview and the western model of education, educators must be well equipped to effectively implement IKS based largely on anthropomorphic and metaphysical worldview in their classrooms. By the same token, it was our view that any attempt to relate the two distinct worldviews together implies the provision of an intellectual space for dialogue or what Bhabha (1994) calls third hybrid space to reflect on classroom context. Our view was that a classroom based on a dialogical argumentation instructional model could provide such a space. Hence we have adopted Toulmin’s (1958) Argumentation Pattern (TAP) as a pedagogical framework for implementing a science/IKS-based curriculum. Also, because IKS are embedded within a metaphysical framework, the Contiguity Argumentation Theory (Ogunniyi, 1997) approach was adopted in this research, where IKS and science are considered as equipollent or complimentary cosmologies in need of a form of dialogue that would result in meaningful learning.

Educators are currently being trained as facilitators for effective implementation of the new IKS educational policy. Video and audio archives from focus group discussions, workshops and classroom-based activities serve as guide in implementing science/IKS-based lessons. Already exemplary materials have been developed and piloted on indigenous food systems such as gari, fufu powder, lafun and umqombothi. Gari, fufu powder and lafun are food products processed from cassava tubers and these are popular in western, eastern, certain parts of southern Africa as well as Asia and the West Indies. Umqombothi is a traditional beer prepared by various ethnic groups in South Africa and is consumed during ceremonies such as marriages and home coming after circumcision initiations. The dialogical argumentation discursive worksheets based on earlier studies (e.g. Ogunniyi, 2004, 2007a &b) being used in the workshops have been developed around the nutritional values of indigenous foods, health implications and their traditional methods of preparation. Indigenous knowledge embedded in the various stages of the traditional food processing techniques is linked to the ethnographic narratives from local people.

In this research food science concept such as Hazard Analysis Critical Control Point (HACCP) system was employed to identify critical control points in indigenous food processing flow charts, and sensory analysis was used to evaluate the gari. HACCP system is used as a guide to identify critical control points in the food processing chain, especially where potential food safety hazards could be introduced as contamination (Fletcher et al, 2009). Proximate analysis concept and testing for the nutritional components give insight into the nutritional efficacy of food (Kolapo et al, 2007). Sensory analysis techniques (Seo et al, 2007) are also used to evaluate food products by using human senses such as taste, smell, touch and sight. The scientific knowledge derived from these food quality assurance processes is mapped unto indigenous knowledge to generate discourses for dialogical argumentation. This research does not intend to compare separately the pedagogic outcomes of IKS and science. The aim of this study is therefore to explore how to equip teachers with the essential pedagogic skills necessary to enact science-IKS classroom discourses.

**Purpose of study**

The need to promote IKS as leverage to augment school science curricula appears to have taken a snail pace. Therefore robust pedagogic approaches need to be exploited in the development of science-IKS curricula materials. The purpose of the study therefore, was to determine the effects of food science based instructional model on teachers’ ability to: enact appropriate science-IKS based classroom discourses; articulate coherently the link between science and IKS; realize the
worth of IKS concepts; and discern science concepts embedded in traditional food processing techniques.

**Methodology**

As stated earlier, a Dialogical and Argumentation Instructional Model (DAIM) was employed as the pedagogic framework together with the Contiguity Argumentation Theory (CAT), a philosophical model for integrating science with IKS concepts. For the purpose of this discourse, science and IKS were considered as complementary and equipollent even though IKS could be situated within a metaphysical context. The worksheets and workshop discourses are based on a pedagogical framework consisting of individual and small group tasks, and whole class discussions. The role of the facilitator is to mediate the whole class discussions and co-constructs the knowledge of the teachers to enhance their conceptual understanding of both IKS and scientific phenomena. During the course of dialogical argumentation, individuals may realize their disagreement on scientific claims and grounds and this may lead to cognitive conflict. Although certain claims and grounds may be rebutted at each stage of the argumentation processes (individual task, small group task and whole class discussions), individuals and groups are encouraged to reach a consensus on claims and grounds pertaining to IKS-science phenomena. The IKS-science dialogical argumentation may involve inductive, deductive and analogical logical reasoning strategies. Once cognitive harmonization has been attained, the individual could achieve cognitive optima. The levels of argumentations are determined at each stage of argumentation (individual, group and whole class) to ascertain whether the educators are developing high-level argumentations skills. Higher incidences of rebuttal of claims and grounds by colleagues involved in the argumentation discourses could lead to the attainment of high level of argumentation (e.g. Simon et al, 2006; Ogunniyi, 2007a &b). This research reported here involved 13 primary and secondary school teachers with different pedagogic skills who attended the IKS-Science workshops for a three-hour bi-weekly for two consecutive six months. The teachers were divided into 4 groups and were denoted as T1 to T13. The teachers were expected to gain pedagogic skills necessary for the implementation of science-IKS classroom discourse. The teachers were assigned the following task: (1) perform sensory analysis on gari, (2) identify the critical control points in the provided process flow charts (A, B and C) for indigenous processing of food, and (3) identify the process flow chart for production of gari from cassava out of the 3 charts (A, B and C) provided. The process flow charts employed in this study were designed by modifying the charts originally produced by the International Institute of Tropical Agriculture (2005).

**Results and Discussions**

The results reported here were obtained from the transcribed video archive and discursive worksheets designed for the purpose of this study. For lack of space, the details on the effectiveness of DAIM and the various levels of argumentation traversed by the teachers during this discourse will be reported elsewhere. Here we are focusing on the effectiveness of using food science concepts such as sensory analysis, HACCP system and indigenous preparation of African foods to enact science-IKS based discourses. In addition, we also explored the ease or otherwise with which the teachers critically interrogated coupling of both western-based scientific and non-western based IKS concepts in the context of CAT.

**Evaluating the effectiveness of sensory analysis**

The teachers carried out sensory evaluation on gari as directed in the worksheet. This task was done individually. Sensory analysis can be combined with other detection methods to identify or
authenticate food products (Arvanitoyannis & Vlachos A, 2007) as well as used in the experimentally determination of food product shelf-life (Koutsoumanis, 2001). Sensory analysis is therefore the ultimate in evaluating the quality or otherwise the success of food products (Drake, 2007). Sometimes trained expert are used to gather data for both qualitative and quantitative analysis. For the purpose of this research, the teachers involved are not trained experts and we adapted the consumer testing as well as the affective testing approaches. The teachers were allowed to use their individual subjective judgments so as to determine if they will appreciate the gari and the IKS embedded in its preparation. The obtained results were not quantitatively analysed but rather qualitatively. The knowledge obtained at this stage was used to enhance the discussions at later stages. We present a summary of the results here focusing on four teachers, one from each group (Tables 1a-d). In addition, we analysed the overall discourses with the aim of identifying potential emerging insights during the activities.

**Table 1a. Sensory analysis report of T1 also in group 1**

<table>
<thead>
<tr>
<th>Flavour and taste:</th>
<th>Slightly flavour after it has been in the mouth for a few seconds, slightly bitter taste, [and] slight sting on the tongue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texture:</td>
<td>Rough</td>
</tr>
<tr>
<td>Smell/Aroma:</td>
<td>No smell</td>
</tr>
<tr>
<td>Appearance (colour):</td>
<td>“Creamish” [cream like], yellow</td>
</tr>
<tr>
<td>Appearance (shape):</td>
<td>Small fibres, granular, irregular in shape</td>
</tr>
<tr>
<td>Appearance (size):</td>
<td>Granules range in size- small to medium</td>
</tr>
<tr>
<td>What is your overall evaluation of gari (use your own discretion) and is there a competitive product in South Africa?</td>
<td>No competitive product available. An adaptable product that can be used in variety of dishes</td>
</tr>
</tbody>
</table>

Dry gari is granular flour with creamy-white appearance, and has a slightly fermented flavour as well as slightly sour taste. The teachers though not trained experts could evaluate gari to certain extent. The sensory analysis results of the remaining eight teachers did not differ substantially from the reported results. At the end of this exercise they appreciated the product and the IKS associated with. From the reported snapshots, T1 suggested that since there was no competitive product to gari produced in South Africa, it could be adapted in a variety of ways. Furthermore, T8 suggested that the roughages in gari could have nutritional value. T11 and T8 also proposed maize meal and wheat meal (T8 only) as competitive products in South Africa. “Competitive product” mentioned here does not mean nutritional alternative but rather a staple food alternative that consumers can turn to.

**Table 1b. Sensory analysis report of T4 also in group 2**

<table>
<thead>
<tr>
<th>Flavour and taste:</th>
<th>Bland, slightly acidic with fermented taste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texture:</td>
<td>Rough, granular, dehydrated</td>
</tr>
<tr>
<td>Smell/Aroma:</td>
<td>Odourless, slightly acidic, garlic and sour</td>
</tr>
<tr>
<td>Appearance (colour):</td>
<td>Cream, very light yellow</td>
</tr>
<tr>
<td>Appearance (shape):</td>
<td>Dry granules, flakes, crystal like, fibrous</td>
</tr>
<tr>
<td>Appearance (size):</td>
<td>Small, big granules fibrous, grated, milled</td>
</tr>
<tr>
<td>What is your overall evaluation of gari (use your own discretion) and is there a competitive product in South Africa?</td>
<td>Processed tuber which has been possibly grated, grinded, fermented, slightly baked</td>
</tr>
</tbody>
</table>
Table 1c. Sensory analysis report of T8 also in group 3

<table>
<thead>
<tr>
<th>Flavour and taste:</th>
<th>Starch, tasteless initially and with time tastes like breadcrumbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texture:</td>
<td>Dry, hard, can’t break individual crystals with hands, only the wheaty [wheat like] flakes are breakable</td>
</tr>
<tr>
<td>Smell/Aroma:</td>
<td>It’s got a sour-like smell</td>
</tr>
<tr>
<td>Appearance (colour):</td>
<td>Cream</td>
</tr>
<tr>
<td>Appearance (shape):</td>
<td>Granular (different shapes to irregular)</td>
</tr>
<tr>
<td>Appearance (size):</td>
<td>Small crystals, flakes</td>
</tr>
<tr>
<td>What is your overall evaluation of gari (use your own discretion) and is there a competitive product in South Africa?</td>
<td>It looks as though it consists of starch. There are tiny small flakes and roughage that could be cassava. This roughage could be vital for digestive system (utilized as fibre). The competitive product could be wheat bix or maize meal</td>
</tr>
</tbody>
</table>

Table 1d. Sensory analysis report of T11 also in group 4

<table>
<thead>
<tr>
<th>Flavour and taste:</th>
<th>Taste like milk powder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texture:</td>
<td>Course</td>
</tr>
<tr>
<td>Smell/Aroma:</td>
<td>No smell</td>
</tr>
<tr>
<td>Appearance (colour):</td>
<td>Cream</td>
</tr>
<tr>
<td>Appearance (shape):</td>
<td>Amorphous</td>
</tr>
<tr>
<td>Appearance (size):</td>
<td>Small granules</td>
</tr>
<tr>
<td>What is your overall evaluation of gari (use your own discretion) and is there a competitive product in South Africa?</td>
<td>Yes, we have mealie meal [maize meal] as a staple food</td>
</tr>
</tbody>
</table>

Although gari is an indigenous food, the evaluation method they employed was scientific. They also realized sensory analysis was not that different from the local way of evaluating food. It is a well-known fact that food is evaluated in the traditional homes by tasting and smelling. Unlike the traditional homes where familiarity with the product serve as evaluating criteria, sensory analysis combines both statistical methods and biochemical characterizations. From these discourses the teachers were able to link the scientific concepts in sensory analysis to the IKS associated with gari. They also saw the suitability for adoption as potential introductory activity in food science and nutrition classrooms discourses. Teachers therefore can exploit the possibility of blending their pedagogic content with the approach reported here to decontextualize the science curricula.

Evaluating the effectiveness of HACCP concepts

Each group was required to carefully study the process flow chart and identify the critical control points essential for product quality, safety and storability according to the HACCP system. According to the Food and Agricultural Organization’s Food Quality and Safety Systems Manual (1998), Hazard Analysis and Critical Control Point (HACCP) System: “is a tool to assess hazards and establish control systems that focus on prevention rather than relying mainly on end-product testing and inspection.” HCCP system therefore identifies, evaluates, and controls hazards that are significant for food safety. Critical Control Point (CCP) is also defined as: “A step at which control can be applied and is essential to prevent or eliminate a food safety hazard or reduce it to an acceptable level.” A typical HACCP system has been established by the Food and Nutrition
Service (FNS), USDA (2009), FNS require that school food safety program must comply with HACCP system established by the Secretary of Agriculture. We present here a summary of the results and explanations given for the critical control points chosen.

Group 1
In identifying the critical control points essential for product quality, group 1 identified sorting, peeling and washing. They went further to explain that sorting produces “fresh product with no rot”, “peeling removes woody tips”, whilst “washing cleans the product”. Concerning product safety, they identified steeping, fermentation and pressing as the critical control points. They explained that, “steeping removes cyanide content”, “fermentation removes cyanide and regulate microorganism activity”, whilst “pressing removes liquids with cyanide content”. They further identified drying, packaging and storing as essential for product storability. They posited their claims that, “drying removes micro-organisms and moisture”, “packing reduces exposure to air”, whilst “storing increases shelf-life”

Group 2
In identifying critical control points essential for product quality, group 2 identified pressing, grating and fermentation. Even though they did not assign any specific reasons to their chosen control points, they went further to speculate that these processes contributed to the properties of the product. Concerning product safety, they identified fermentation and pressing. They posited their claim that, “within product B [referring to process flow chart B] fermentation is followed by pressing which results in the removal of cyanide. They identified roasting stage as the critical control point essential for product quality even though they did not assign any reason. They went further to contend that, “…B more of indigenous process, C industrial…”

Group 3
In identifying critical control points essential for product quality, group 3 identified washing, crushing, steeping and dewatering. They contended that, “washing removes insecticide and microorganisms [for hygienic purposes]”, “crushing increase flavour”, “steeping removes toxic or virulent cyanide”, whilst “drying decrease moisture in product, may prevent processes of moulding, and increase in shelf-life.” They did not assign any specific benefits attributed to dewatering. For the product safety, they identified washing, steeping and drying and attributed the same reasons as assigned earlier. They also identified drying as essential for product storability contending that it extended the product expiry.

The critical control points identified by the last group (4) and assigned reasons followed the same trend as the reported groups. It emerged that group 2 critically compared all the 3 provided indigenous methodologies for food processing to identify instances where both traditional and improvised “mechanized” technologies were incorporated together. Method C involves grating using motorized grater and drying using rotary dryer. These two methods (i.e. motorized grating and rotary drying) may have influenced their decision to consider method C as industrial. This appeared to have been confirmed in later stages where each teacher was supposed to identify the process flow chart for the production of Gari. T4 also the group 2 leader began by making the following assertion that process flow chart C could be industrial, and further made a counterclaim by suggesting process flow chart C could be used to produce gari and her grounds were “…because of the rotary dryer, … to produce a dry product.” They seemed to have identified how “mechanized” technologies arising out of the need for mass production of food are integrated with traditional way of food processing. Nowadays it is a common practice to see local people in Africa incorporating “semi-mechanized” technologies in the way they do things. For example instead of pressing fermented food paste in sacks with heavy stones, simple hydraulic presses are sometimes used to speed the process. Nevertheless, local people sometimes consider these semi-mechanized technologies as their ‘own’ since they have been around for decades. In process flow chart B, roasting is done in large, shallow cast-iron pan over a fire, with constant stirring, usually
with a broken piece of calabash (gourd) or wooden paddle for 20-30 minutes or alternatively use rotary dryer. Group 2 was able to identify scientific alternative to indigenous way of food processing. From the aforementioned, the group appears to have appreciated how science can be integrated with IKS to attain meaningful discourses. They also discovered there was so much scientific knowledge embedded in the indigenous way of food processing. The essence of the discourses was not for the teachers to accurately predict the critical control points and substantiate their choice with valid reasons; they were rather expected to demonstrate their understanding of scientific knowledge embedded in IKS by unraveling the link between the two philosophical concepts. The reasons all the groups assigned to the critical control points selected were scientifically reasonable. They were able to identify roasting as one of the critical control point and essential for the storability of the gari. They contended that roasting and drying decreased the moisture content thereby inhibiting microbial growth. The teachers were also able to identify the fermentation stage as a critical control point in the processing of cassava to produce gari. They went on further to explain that fermentation removed cyanide and also impact on the taste and flavour of gari. Fermentation has been reported to reduce the cyanide content in or the bitterness of cassava (Akullo et al, 2007).

Biochemically, the cyanogenic glucosides contained in cassava are hydrolyzed by linamarase to cyanohydrins, which in turn breakdown to cyanide. Cyanide intoxication seems to be a major health problem in some cassava growing areas in Ethiopia; acute cyanide intoxication in children from high cassava consumption area was reported (Abuye, Berhane & Ersumo, 2008). Cyanide ingested from cassava has also been implicated in konzo, an irreversible paralysis of the legs predominant in children and young women from Mozambique and Tanzania (Cliff et al, 2010; Bradbury, Cliff & Denton, 2010). Affected communities need to be educated on processing techniques to remove the toxic cyanide in the cassava. The pedagogic approach used in our research could complement other training programs for rural health personnel to combat cyanide intoxication. We are not proposing our approach as an alternative solution but we believe that it could serves as a useful resource for education pertaining to cassava intoxication. This demonstrates the need to place emphasis on IKS not only in the school science curricula but also on health policy formulation.

Evaluating the effectiveness of DAIM and CAT
Here we demonstrate how the teachers used DAIM and CAT to facilitate the epistemology of science and of IKS. We present snapshots of activities in some of the group. Each teacher in group 3 was supposed to identify the process flow chart for gari from the 3 different process flow charts provided in the discursive worksheet. The identified process chart was considered as the claim, whilst the reasons, evidence or data used to substantiate the claim were considered as the grounds. The verbatim dialogical argumentation discourses in group 3 is presented below:

T8 chose process flow chart A as the chart for gari production, to substantiate the claim, T8 contended that, “because I felt sorting of the cassava, peeling as well as dewatering and drying and storing are the most important things to get the final product.” T8 supported her claim by identifying unique processes in the chart A which could results in the final product. Nevertheless, T7 also the group leader of group 3, demanded further evidence from T8 by contending that, “T8 how different is your B from A according to your claim?” T8 then provided backings to augment the evidence provided that, “B does not have a steeping process of which is important to remove the cyanide which is poisonous from the cassava and C does not have the dewatering but steeping is there”. T8 used the absence of steeping in process chart B and dewatering in C respectively to reject both as potential process charts for production of gari, even though C involved dewatering. T8 provided extra grounds for rejecting B that, “Drying is not in method B, so is very important”. T8 considered drying as very critical in achieving the final gari food characteristics. T10 like T8 chose process chart A as the claim but did not provide any concrete evidence to support the claim.
T10 posited the claim to the colleagues by saying, “can I tell you why I selected A? A safe product fits for use can be produced by local people still using all the production processes”. It seems T10 seemed to believe the use of entirely indigenous approach with no blending of “mechanized” technology was reasonable enough to predict A. As indicated earlier, there is no semi-mechanized technology employed in chart A.

T9 selected process flow chart B as the claim. T7 demanded evidence for the claim that, “T9, why did you choose B then?” T9 supported the claim with the following grounds, “Chose B, I followed the three methods and saw that the methodology A and C will not give the final product that we have, the dry gari. Only B will give. So I follow each one sequentially, the steps.” T9 seemed to have considered the effect of each process in the three different process flow charts could impact on the characteristics of the dry gari. T9 used a step-by-step approach and demonstrated this in method A by contending that, “If you look at A, you when you peel, which is common in all, the third step in A you reduce the size, either chop it or break it down…. Then you steep when sizes are reduced, then crushing is after you have steeped”. T9 further supported the claim made that, “in each sequence I noticed that there were some sequence that will not result in the dry process that we will have. Some will results in different products other than gari”.

T7 argued that, “chose C because of fermentation. In A there is no fermentation… Size reduction is important but is not in B though in A.” T7 used the absence of size reduction in B and fermentation in A respectively to reject these process charts. T7 further provided backings for the claims that, “chose method C, if you look at it in a chronology way, the point of settling is very important but not in others. Decanting is very important… It is like a separation method”. T9 later during the argument expressed the desire to rebut some of the claims made but did not rebut following further explanations and conversation within the group.

The dialogical argumentation pedagogic approach seem to have enhanced the quality of dialogue and appeared to have provided space for the teachers to critically analyze the science-IKS discourses. DAIM also provided platform for effective scaffolding of knowledge, since the teachers exhibited the potential to articulate coherent discourses. According to T7 continuous argumentation appeared to have augmented their understanding about the scientific concepts embedded in indigenous way of food processing. This assertion could be corroborated by the statement made by T7 that “as we arguing we getting more sense”. The essence of these activities was not accurate prediction of claims but rather to engage in critical argumentation using the problem solving approach. Although the arguments proposed by the other teachers in this group were reasonable to certain extent, T9 was able to propose correctly chart B as the potential methodology for the production of gari by identifying roasting as the vital process that could result in the low moisture content of gari. From the epistemic interactions the teachers appeared to have engaged in quality argumentation. Although not reported here, during the whole class discussions, the group leaders presented their respective arguments and the workshop facilitator mediated the discourses to reach a consensus using knowledge co-construction.

In order to gain insight into the trajectory of science and IKS concepts experienced by the teachers we reviewed their discourses using CAT categories. It should be noted that the teachers have been exposed to the Nature of Science (NOS) and Characteristics of IKS (CIKS) through their weekly attendance of the workshops for about six months period, so they are not naive in terms of NOS and CIKS. Since some of the teachers were not familiar with cassava processed food products such as gari, they were keen and enthusiastic to participate in the activities but others were initially concerned about tasting the gari during the sensory analysis. After the facilitator had made an analogical comparison between cassava and sweet potato, the teachers gladly tasted the gari since they were familiar with sweet potato. In designing science-IKS curricula, researchers are advised to explore the use of resources with IKS concepts that are “owned” by the teachers or students. This assertion appears to have been corroborated during the
subsequent activities using Umqombothi, a traditional beer that the teachers were familiar with. Before the activities the teachers were enthusiastic and keen to participate. The details of the Umqombothi science-IKS research will be reported elsewhere. In *Pedagogy of the Oppressed* Paulo Freire (1993) suggested the use of knowledge “owned” by people as the foundation for development of curricula by integrating the sociocultural attribute of their daily lives. Before the gari activities the conceptions held by most teachers were dominated by science with IKS being emergent. According to CAT two distinct cosmologies or school of thoughts (i.e. science and IKS) can co-exist harmoniously by recalling each other. In an earlier study reported (Ogunniyi & Hewson, 2008), science was the dominant conception held by the teachers whilst IKS was suppressed before the supposed activities. After the discourses most teachers considered science and IKS concepts as equipollent since they were able to unravel the inherent wisdom embedded in IKS.

For example, similar to the conceptions held by other teachers, T3 in group 1 contended that, “…naturally prepared foods have got a higher quality. This is the assumption we have. Is it really true? Then you use scientific knowledge to verify that”. T3 further consolidated IKS views held by contending that, “You can put the IKS and scientific knowledge on par”. T3 also explained that both science and IKS employed intuitive approaches during investigation by saying, “Some people take faith as knowledge systems, gut feelings as valid as scientific knowledge and sometimes have used it too. If I do it this way, this is going to work. And every scientist has used this method to make short cut. This intuitive knowledge then becomes the bedrock of IKS. Then it becomes established....”

**Conclusion**

This study based on a dialogical argumentation model has used a topic in food science as an exemplar for science teachers to enact a science-IKS curriculum in their classroom. Although the focus of this paper was to provide a snapshot of the workshops, our experience in the larger study (not reported here) showed that the instructional model research was effective in enhancing the teachers’ ability to implement the curriculum in their classrooms. Further, the teachers consolidated their conceptual understanding of both science and IKS. They were motivated and also exhibited keen interest and positive attitudes towards IKS-science based lessons. The teachers engaged in critical and analytical thinking and also relied on prior knowledge to construct concepts. When developing science-IKS curricula materials, teachers need to consider incorporating IKS concepts “owned” by the students. We have also illustrated how this approach could be used to supplement public health education efforts especially in eliminating cyanide related cassava intoxication as well as adapted for other pedagogic purposes.

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**Using an argumentation framework to analyze teachers’ views of the scientific and indigenous ways of interpreting experience with selected natural phenomena**

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**ABSTRACT**

In pursuance of one of the goals of the new South African curriculum to integrate science with Indigenous Knowledge Systems (IKS), this study, which forms part of Science and Indigenous Knowledge Systems Project (SIKSP) at the University of the Western Cape was concerned with finding out how a dialogical argumentation enhanced in-service science teachers’ conceptions of a number of familiar natural phenomena. Specifically, this paper reports finding derived from a study which attempted to facilitate the understandings of 41 in-service teachers about two familiar natural phenomena namely, rainbow and lightning. An argumentation instructional model was used both to facilitate as well as evaluate their understanding of the two phenomena. The results show that though course enhanced the teachers’ conceptions of the rainbow and lightning their overall worldview regarding the phenomena was an amalgam consisting of scientifically and IKS based notions of both phenomenon and concomitant misconceptions of both systems of thought each warranting some level of amelioration. Despite this, the argumentation-based course seemed to have made the teachers to be positively disposed to the teaching of IKS along school science. They all expressed the need for follow-up activities and the inclusion of the course in teacher training programmes.

**Background to the study**

The National Curriculum Statements (NCS) for Grades R-9 (Schools) Natural Sciences, Life Sciences and Physical Sciences express in principle an emphasis on valuing indigenous knowledge systems. It provides the following guideline in Learning Outcome Three: Science, Society and the Environment.
The learner will be able to demonstrate an understanding of the interrelationships between Life Sciences and Physical Sciences, Technology, indigenous knowledge, the environment and society. One of the underlying differences between modern science and technology on the one hand, and traditional and indigenous knowledge systems on the other hand, is the existence of different world-views...Learners hold these world views ...one can assume that learners think in terms of more than one world-view and cross several times a week from the culture of the home, over the border to the culture of science, and then back again. Indigenous knowledge of the last three hundred years needs to be rediscovered and to be examined for its value to present day (Department of Education, 2002, 10-12).

According to the above quotation teachers are required to recognize the need to use indigenous knowledge to support scientific knowledge in the science classroom. This creates interesting challenges for lesson planning and instructional practice. It requires teachers to develop an understanding of IKS. Teachers also need to acquire and use innovative instructional strategies. Teachers may be required to develop teaching and learning environments that will enable learners to acquire the ability to develop scientific understanding without losing their sense of social identity. Social identity refers to their religious, cultural and societal beliefs (Leitao, 2000, Odora-Hoppers, 2010). Feyerabend (1975) stresses the importance of equipping learners with knowledge that would enable them to appraise their understanding and experience of reality and consequently, develop order in the seemingly chaotic world around them. Odora-Hopper (2010) argues for purposeful introduction of IKS into the science curriculum and cites aspects in the curriculum statements of where this entry can be made. These aspects includes history of science, ethics of science, scientific heritage of South Africa and Africa, science as a human activity and social justice amongst others. She expresses concern that the curriculum is not more explicit about IKS and that teachers may cling to the familiar and ignore the elements in the curriculum that speak to diversity and inclusiveness of knowledge heritages.

The Contiguity Argumentation Theory (CAT) adopted for this study regards science and IKS as complimentary cosmologies rather as polar opposites. The theory provides a useful guide that can assist teachers to see the connectedness between the two corpuses of thought systems (Ogunniyi 1997). Teachers who have the task of facilitating the teaching and learning process in the science classroom would need to contend with a new social organization of science education. Policy makers, curriculum designers, educators and learners have to contend with new and relevant ways of imparting meaning to the science curriculum. Feyerbrend, in Cordero (2001:20) exhorts society to protect the naturally fertile imagination of children and to develop to the full the contradiction that exists in them, all of which, he thinks, would be greatly helped by granting equal classroom opportunity for science, voodoo, creationism, astrology and the like. Why we do not go so far, we believe that each system of thought does have value people living in an age with so much uncertainties ranging from terrorism to global warming and similar threats. In fact, it is our view that while encouraging the integrating of science and IKS effort must be made to avoid any form of indoctrination be it scientism or religious fanaticism. Nor do we subscribe to Feyerbrend’s pluralistic notion that anything and everything is alright.

Culture is seen as a changing and dynamic phenomenon that allows space in which human beings seek to construct and represent themselves and others. The African ability to integrate diverse cultural elements without the contradictions raised by the dualistic thinking of the West is evident in the design of the science curriculum (Balcomb, 1995). It makes a lot of sense to teach science in a way that does not alienate learners from their socio-cultural environment. School science must equip learners to develop process skills that enable them to solve practical problems whether
at school or the world outside. Besides, and contrary to the impression conveyed in textbooks and science classrooms, most problems in practice have more than one plausible solution. The educator as a science facilitator must be empowered to understand the nature of science and the nature of indigenous knowledge systems through grounded theory and relevant pedagogy in order to generate critical thinking in the teaching and learning environment.

This creates interesting challenges for lesson planning and instructional practice. It requires educators to develop new instructional strategies that will enable learners to acquire the ability to develop scientific understanding without losing their sense of social identity. Social identity refers to their religious, cultural and societal beliefs. Through reflective practices, educators may be able to contribute to developing instructional materials compatible with the mandate and postulates of the new curriculum. George (2001), an advocate of “Science for All” and “Science for Daily Living”, considers the relevance of teaching science to children. To her, understanding diverse phenomena in traditional, non-industrial settings is passed on through modeling (imitation) as well as orally from generation to generation. Thus many times common sense knowledge and not science knowledge is used in making much of the some decisions about daily scientific activity. Conventional science and indigenous knowledge co-exist and educators require teaching strategies to treat both worldviews in a way that will not be biased. Langenhoven and Ogunniyi (2009) are of the opinion that educators should be engaged in co-constructing learning programmes and curriculum development that can be used in the science/IKS classroom.

**Theoretical framework**

Aikenhead (1996), Le Grange (2004) and Onwu (2005) argue for a complimentary framework for dealing with science and indigenous knowledge in the science classroom. The interesting development of what may be termed the “Third Space” results from this amalgamation of the two knowledge systems in the cognitive processes of both educators and learners (Turnbull, 1997). Ogunniyi (1995) formulates the Contiguity Argumentation Theory in the process of traversing the dialogical space within and between people. This theory underpins the study and asserts that co-existing systems of thought exist within the consciousness of an individual. This cognitive state of the mind houses conceptions that can move between different mind states and even amongst persons involved in dialogues.

The Contiguity Argumentation Theory (CAT) which consist of five cognitive categories, describe the movement of conceptions amongst teachers involved in dialogues about scientific and/or IKS-based conceptions. The CAT is used in this study to analyze teachers’ views about selected natural phenomena. The five conceptions that exist in a state of flux in the mind of the teacher are: dominant conceptions, suppressed conceptions, assimilated conceptions, emergent conceptions and equipollent conceptions. A conception is dominant when it is the most adaptable to a given context yet on the other hand it may be suppressed or even assimilated. An emergent conception arises when no prior knowledge was present whilst an equipollent conception can co-exist with another without causing conflict (Ogunniyi 2002, Ogunniyi and Hewson 2008). Each mental state is dependent on the given context e.g. a scientific or a religious discourse. He uses this theory to develop the Argumentative-Discursive-based Course intervention programme and also draws on the Practical Argumentation Framework which identifies four features, namely, the main features of the Nature of Science (NOS) and Indigenous Knowledge Systems (IKS); secondly the contiguous relationships between the NOS and IKS; thirdly analyzing the commonalities and/or differences in the claims or counter claims in terms of socio-cultural
norms; finally determining the knowledge (epistemology), context (ontological) and values (axiology) of the claims and supporting elements. Educators are implicitly engaged in argumentative-discourse as they navigate the crossing between what is scientific understanding and personal understanding. George (1999, 2001) suggests that educators should be equipped through pre and in-service programmes to design teaching and learning strategies and teaching aids that create environments conducive for learners to navigate between science and indigenous knowledge and to see the relevance of science/IKS in everyday living.

Purpose of the study

The purpose of this study was to analyze teachers’ views of the scientific and indigenous ways of interpreting experience with selected natural phenomena using an argumentation framework. Specifically, the study addressed the following questions:

1. What ideas about the occurrence of the rainbow do teachers hold?
2. What ideas about the occurrence of lightning do teachers hold before and after being exposed to a dialogical argumentation course?

Research methods

Sample

The sample consists of forty-one (41) in-service science teachers from the Western Cape Province of South Africa who are enrolled for an Advanced Certificate of Education in Science & Technology. There are twenty (20) male and twenty-one (21) female teachers. The area urban/rural are evenly grouped with twenty from urban areas and twenty-one from rural areas. Teaching experience of these teachers range from two to thirty-eight years compiled as follows: 1-9yrs = 6 teachers; 10-19yrs = 11 teachers; 20-29 yrs = 19 teachers; 30-39 yrs = 5 teachers. These are teachers who completed a three year teaching diploma at an Education College and are required to upgrade to a fourth year post matriculation study in order to meet the requirements of the new education policy of the South African Qualification Authority (SAQA). These teachers are required to complete ten modules for the qualification: four science modules, four technology modules and two elective modules. One of the science modules is in science education which includes a teaching unit on teaching strategies for integrating science and indigenous knowledge. One of the teaching strategies is argumentation. The research is directed at this new group that started in March 2010 for the following reasons:

1. The group was not exposed to discussions around the nature of science and the nature of indigenous knowledge
2. The group was at the same qualification level, that is, Diploma of Education III completed at a college.
3. The full group was supported by Western Cape Education bursaries. They meet at scheduled week long contact sessions during school holidays in March, June and September of each year for a period spanning two years (2010-2011).
4. It was easy to track group for interviews, classroom observation and video recordings when needed.

The teachers were introduced (via lecturing activities) to the Nature of Science (NOS) and the Nature of Science and Indigenous Knowledge Systems (NOSIKS) discussions in order to supplement their content, context and methodological teaching and learning background.
A case study involving a dialogical-argumentation course was used to facilitate the teachers’
knowledge about NOS and IKS. Details of the course have already been published (Ogunniyi 2007 a & b) and do need to be repeated in the paper. Characteristics of Indigenous Knowledge (CIKS) questionnaire was used to explore the teachers’ conceptions of the rainbow and lightning. The course, underpinned by the Contiguity Argumentation Theory (CAT) as espoused by Ogunniyi (1997) was used to explore the teachers’ scientific and indigenous knowledge about the two phenomena. Also, it was our view that to teach IKS along school science meaningfully would necessitate the selection of topics amenable to both worldviews as well as relevant to the teachers’ and learners’ daily experiences rather than esoteric philosophical or socio-cultural issues. As the teachers got engaged in authentic arguments and expressed diverse conceptions about one phenomenon or the other during the course, it was clear that despite their apparent scientific outlook, they nevertheless held consciously or unconsciously alternative conceptions about such phenomena. The rainbow which is the focus of this study is a common phenomenon that forms part of the experiences and belief systems of many groups of people and cultures in Africa and hence serves as a useful entry point to interrogate the teachers’ alternative worldviews more closely. The CIKS questionnaire originally consisting of ten items was subjected to a sequence of refinements based on critique from a panel of four science educators. Later, it was pilot tested among 42 experienced science teachers attached to eight higher institutions in South Africa. Based on further critique by a panel consisting of eight science educators and 12 experienced science teachers the CIKS questionnaire was reduced to six items. Finally, the CIKS questionnaire was subjected to pair-wise rating of items from 1-5 (where 1 was a poor item and 5 a very good item) by four science educators. The Spearman Rank Difference formula, yielded correlations ranging between 0.95 and 0.98, indicating a strong face, construct and content validity of the instrument.

Characteristics of Indigenous Knowledge Systems

For this reason three questionnaires were used to collect data on their views about the nature of science and the nature of indigenous knowledge. These questionnaires were (1) Nature of Science (NOS) questionnaire, (2) Characteristics of Indigenous Knowledge System (CIKS) questionnaire and (3) Integrated Nature of Science/Nature of Indigenous Knowledge Systems (NOSNIKS) questionnaire. These questionnaires underwent rigorous validity and reliability examination. According to Ogunniyi (2002) and Webb et al (2006) the final version of CIKS questionnaire which was used in this study consisted of seven main items with two sub-items each; the average ratings by four experts in terms of clarity of CIKS questionnaire ranged between 3.5 and 4.5 on a scale of 1-5 and pairwise comparisons ranging between 0.95 and 0.98 using Spearman Rank Difference formula. These indices showed strong face, content and construct validity. Each item presented a brief scenario focusing on the origin of the universe and the world, the effect of modern medicine and traditional healing, the origin of the rainbow and the source of lightning. Pre-test data was collected in March 2010 followed by intervention lessons and activities during June/September 2010 with final post-test data to be collected in March 2011. This paper analysis teachers views on selected natural phenomena using CAT.

Results

The following summary provides which provides a glimpse into the teachers’ responses have been categorized under four headings, namely, scientific understanding (science view only), scientific and personal understanding (mixed view), personal understanding (cultural, religious view only) and misconceptions. The numbers provided in the Table refer to the number allocated to the teachers’ responses. This paper will attempt to analyze these responses of the teachers to
the two natural phenomena namely, rainbow and lightning.

The frequencies in Table 1 depict four categories used to organize the responses of teachers. Category 1 lists the respondents who agree with the science part of the statement on natural phenomenon, category 2 are those teachers who expressed a science view and a traditional/religious view, category 3 are teachers with a traditional/cultural/religious view and category 4 lists conceptually unsound responses i.e. teachers in favour of traditional/religious belief for the occurrence of the rainbow scores 33% (25/77) as compared to traditional/religious belief on the occurrence of lightning which scores 11% (8/69). Some teachers hold ambivalent views as shown in category 2 where occurrence of the rainbow scores 19% (14/77) and occurrence of lightning scores 8% (8/69). The results also show that teachers have a better conception for occurrence of lightning (58%-40/69) on scientific understanding than for teachers’ conception on scientific understanding for the occurrence of rainbows (29%-23/77).

Table 1. Frequency of teachers’ views on the occurrence of the rainbow and lightning

<table>
<thead>
<tr>
<th>scientific view</th>
<th>scientific/personal view</th>
<th>personal view (tradition)</th>
<th>misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occurrence of rainbow</td>
<td>4, 7, 9, 10, 12, 15, 16, 19, 20, 21, 22, 26,</td>
<td>1, 1, 2, 3, 6, 9, 13, 22, 24, 26,</td>
<td>27, 29, 31, 34, 36, 37, 39</td>
</tr>
<tr>
<td>2, 5, 8, 11, 5, 7</td>
<td>14, 8, 10, 11, 13, 14, 15, 17, 19, 34, 35, 37, 39</td>
<td>22, 23, 25, 27, 28, 31, 36, 37, 39</td>
<td></td>
</tr>
<tr>
<td>18, 18, 16, 20</td>
<td>14, 15, 17, 19, 34, 35, 37, 39</td>
<td>32, 34, 38, 40, 41</td>
<td></td>
</tr>
<tr>
<td>25, 28, 29, 30, 30, 33, 35, 35, 38, 37, 38, 40</td>
<td>32, 34, 38, 40, 41</td>
<td>29% (23/77)</td>
<td>19% (14/77)</td>
</tr>
<tr>
<td>Occurrence of lightning</td>
<td>1, 1, 5, 5, 7, 8, 8, 9, 10, 10, 11, 11, 12, 14, 16, 17, 18, 18, 19, 19, 20, 20, 22, 24, 25, 29, 29, 30, 32, 33, 34, 35, 36, 39, 39, 40, 40, 41</td>
<td>3, 9, 15, 14, 21</td>
<td>4, 6, 13, 13, 17, 21, 23, 26, 27, 27, 28, 30, 31, 37, 38</td>
</tr>
<tr>
<td>8% (6/69)</td>
<td>2, 3, 6, 7, 15, 22, 24, 16, 26, 27, 27, 28, 30, 31,</td>
<td>11% (8/69)</td>
<td>22% (15/69)</td>
</tr>
</tbody>
</table>

The amount of conceptual misconceptions that exists is recorded as 19% (14/77) for occurrence of the rainbow and 22% (15/69) for occurrence of lightning. The advantage of tracking these misconceptions by teacher number allows for possible remedial work. In other words there are twenty-one (21) teachers having misconceptions about either the rainbow or lightning occurrence whilst five (5) teachers have misconceptions about both occurrences. Further interrogation of the
qualitative results will produce more insight. In view of space limitation, we can only select a few excerpts to analysis using CAT analysis framework.

Q 4 Scientists describe the occurrence of the rainbow as a result of a refractive dispersion of sunlight. However, in many traditional beliefs, the rainbow is seen as a good or bad omen. What is your view in terms of your (a) scientific understanding and (b) personal understanding?

(a) Scientific understanding:
It was given to man to be a sign that the water with which God destroyed the earth will end. It is not a sign of good/bad luck. What God did was to show mercy to His people. (T1)

(b) Personal understanding:
If the rainbow was the sign of good/bad luck, then why the reoccurrence when it rains? Why doesn’t it appear throughout the year? God gave this sign to show that He is merciful and to spare those who listened to him. God give and He taketh. (T1)

It is clear that the dominant view held is of religious origin with a strong belief in the narratives as espoused in the Christian bible. In both responses myth is suppressed (no belief that the rainbow brings good or bad luck). There is no mention of scientific agreement hence placing both understandings under personal views.

(a) Scientific understanding:
The rainbow is formed from the water breaking the light that reflect a spectrum of colours. (T26).

(b) Personal understanding:
The rainbow is water breaking the light by putting God in its place. (T26)

Here the science view is dominant but with some equipollence present in the personal view. Science is acknowledges and is equated with God. This response shows a measure of some doubt.

Similarly

(a) Scientific understanding:
When sunlight hits water it breaks up the white light so that the different colors of white light is displayed on the other side. (T18)

(b) Personal understanding:
I think it’s the break-up of light when it hits water, which acts as a prism, to break the white light. (T18)

Here a dominant science view is expressed in both categories and one can assume that this teacher has a strong concept of the event and how a rainbow is formed.

(a) Scientific understanding:
I agree with the scientific fact. (T20)

(b) Personal understanding:
I agree with the scientific fact as well as the fact that the rainbow is a promise from God that there won’t be a flood as in Genesis. (T20)

This response is clear on the science fact in the statement but the personal response shows a measure of holding both views which is an equipollent position of thought. One can assume that this teacher is comfortable in considering scientific viewpoints as well as religious belief. The last comment about the flood shows dogma of belief, when media shows floods happening all over
the world. The response may be used as a platform for engaging in discussion around worldviews.

The final exemplar is used to illustrate misconceptions and I list a few similar responses:

- It depends on the weather and the season changes. (T31)
- The rainbow is a reflection of sunlight. (T36)
- Reflection of sun rays through thick clouds. (T37)
- Rainbow is the result of the sun rays that reflects on rain. (T39)

The dominant misconception seems to be the context within which the term reflection is understood, in spite of the term refractive being used in the context statement. T31 has an idea that weather is involved but seems to be out of context.

**Q5. Lightning is an electric discharge in the atmosphere. The very large and sudden flow of the charge that occurs in lightning has enough energy to kill people or do serious damage to buildings or infrastructures. In many traditional beliefs lightning can come from other sources. What is your view in terms of your (a) scientific understanding and (b) personal understanding?**

With this question, I am going to list a few exemplars under scientific understanding and personal understanding and then use the categories according to Table 1. In addition, I will use the cognitive frames of reference as suggested by CAT (Ogunniyi and Hewson 2008).

(a) Scientific understanding:

- It is created in the atmosphere. The sources in the atmosphere create friction and lightning is the result.” (T1)- dominant science view

- There is no other evidence to support the belief that lightning can come from other sources or are there? (T9)- dominant science view, IKS view suppressed

- Scientists believe that there are many other sources that also can discharge lightning. (T15)- equipollent view

- Traditional beliefs that clouds bring rain and rain- has animal characteristics, like bulls and it is made angry, you get lighting. (T16)- IKS view dominant, suppressed science view

- I believe that they are just theories that cannot be proven. (T21) - assimilation

- It is a clash of cold and warm clouds and friction occurs in lightning. (T26)-science misconception

- Lightning is electrons that rub against each other and so doing generating energy in a form of a lightning bolt. (T27)-science misconception

As indicated in Table 1 the science explanation was represented by 58% of the respondents. In most cases, teachers merely repeated the explanation in the statement without providing any additional backings. One can assume that much more clarity is required when facilitators give instructions on completing the instrument. Those teachers who attempted to provide an explanation in their own words had difficulty writing down their ideas coherently.

Here are some exemplars of
(b) Personal understanding:
If it comes from other sources, prove it to me. No proof, no understanding. (T1)-emergent view.

God is angry he will bring floods & chaos. (2)-dominant IKS view

In my traditional belief lightning is made by people who hate you, they send lightning to you so that you can be killed or die. (3)-dominant IKS

The traditional healers can also play with lightning by doing their witchcrafts. (T6)-dominant IKS

I believe in the science argument although certain indigenous people believe it is the ancestors talking. (T14)-dominant IKS

I believe in the creation as confirmed in the Bible. I still believe that the world in all its’ magnificence is God’s work. (T21)-dominant IKS

People say that the God’s are angry. (22)-dominant IKS

It is all systems that God puts in place. (T26)-equipollent view

I have heard of people who were killed during a storm when struck by lightning. (T36)-ambivalent view

The lightning is a sign of harsh weather patterns which may follow at that particular region. (T37)-dominant science view.

The views above are largely influenced by cultural and religious belief. These beliefs can be traced to the socio-cultural context from which teachers come. Some of them are emphatic about their belief whilst other talk in the third person “I have heard” and “people say”. This mix of socio-cultural contexts amongst teachers is also the mix found in the science classroom

**Recommendations**

These preliminary results are important for science education lecturers:

1. To understand the socio-cultural environment of the teachers undergoing upgrading training in science and indigenous knowledge concepts.
2. To implement the curriculum statement of interrogating the science/IKS interface with science teachers thus leading them to a greater understanding of socio-ecological, indigenous knowledge and health promotion concepts (Henton 1996).
3. To develop programmes for teachers that would help them reach optimum levels of critical thinking through application of argumentation methodology amongst others.
4. Teachers experiencing difficulty in understanding natural science concepts can be identified and remediation strategies can be applied.

**The way forward**
Educators should be fully engaged in the development of teaching and learning materials that recognize the interface and interconnectedness between science and indigenous knowledge
systems (Michie and Linkson 1999). Now that the views of these teachers are known on science/IKS understandings an intervention programme on NOS and IKS will be followed using dialogical argumentation as an instructional tool. Toulmin’s (1958) model of argument provides a framework for developing worksheets, facilitating discussion, analyzing levels of argument and evaluating written argument. Recent research shows the value of promoting and supporting argumentation in science classroom (Newton et al. 1999, Driver et al. 2000, Leitao 2000, Duschl and Osborne 2002, Simon and Johnson 2008, Samson & Grooms 2009). This group of teachers is ideally situated in a research environment where this methodology can be tested. They have 18 months to completion. The research schedule will consist of the intervention module (NOS/IKS) through dialogical argumentation, post-questionnaire, classroom observation, audio & video recordings and focus group interviews. At the end of this research schedule a concise assessment can be made on the success or otherwise of the teachers’ ability and capability of meeting the challenges proposed for teaching a science/IKS curriculum.

Conclusion

The study recorded the views held by teachers on various concepts of science that is open to interpretations from a belief system present in the community where teachers teach and schools are situated. Whilst recognition is given to the importance of teaching and learning science concepts in order to advance science and technology in a curriculum we cannot ignore the socio-cultural context. For teacher educators research in this direction provides a platform for programme development and instructional strategies. The CAT framework can be used in many ways, both as an analytical tool as well as an instructional tool for teachers and learners. Theory becomes clearer, helping participants to reflect critically on their own experiences and developing their schema to make meaning of their understanding of the complexities of teaching science. The study is important since it recognizes educators as being stakeholders and curriculum implementers of the National Curriculum Statements for the Sciences in a transformation process that is constructive. Understanding teachers’ views about natural and other phenomena and events can assist the facilitator in identifying and tracking teacher conceptions on integrating science and indigenous knowledge in the science classroom more meaningfully. The IKS policy document acknowledges the need to synergize national education strategy with that of indigenous knowledge:

In the development of New Curriculum Statements, there has been a strong drive towards recognizing and affirming the critical role of IK, especially with respect to science and technology education (Department: Science and Technology, 2004).

In an attempt to enact the mandate of the new South African Curriculum, the Science and Indigenous Knowledge Systems Project (SKISP) at the University of the Western Cape has been training prospective and practising science teachers since 2004. In its third phase, the project has provided useful insight about the challenges that teachers face in implementing the new curriculum. The findings so far have shown that teachers lack the needed knowledge and instructional skills to implement the new curriculum. However, by exposing the teachers to an argumentation-based course in form of seminars, lectures and activity-based workshops, the teachers who have been involved in the project have grown in their knowledge and awareness about the Nature of Science (NOS) and Nature of science of Indigenous Knowledge Systems (IKS) and in which context the two worldviews are compatible or incompatible. Although the potential of the project await future exploitation are positive indicators as we see the teachers move away from the stage of incoherence to a stage where they express themselves confidently.
about how diverse natural phenomena depicted in the new curriculum or impinge directly their sensibilities.

References


Modelling the integration of IKS into the teaching and learning of Science

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Abstract
This study follows the professional development of six Masters students as they grappled with issues pertaining to the integration of Indigenous knowledge systems in their teaching of science concepts for grades 2 – 12 learners. Argumentation was used as the main strategy for this integration. The teachers were interviewed and observed as they carried out several science-IKS tasks. Some of the teachers were also observed teaching in their natural classroom environment. Such observations were videoed and follow-up interviews were held with the teachers. The study revealed different levels of difficulties experienced in integrating science content with indigenous knowledge systems (IKS). In addition, the study suggests that both teachers and learners benefitted from integrating IKS with Science.

1.0 Introduction
In 2004, the South African parliament adopted an Indigenous Knowledge Systems (IKS) policy as part of its transformation and empowerment strategy. The policy
marked the first milestone in the government’s efforts to “recognize, affirm, develop, promote and protect indigenous knowledge systems in South Africa” (DST, 2009, p3).

Policy implications for education involve the integration of IKS into the school curriculum and underscored the need for science, mathematics and technology teachers in South Africa to review and adopt teaching approaches that will help learners to: (1) relate school science to their socio-cultural environment; (2) appreciate the interface between science and IKS; and (3) affirm their dignity as citizens in a democratic multi-cultural society.

This paper explores how the models used in integrating IKS and science, have impacted on the teachers’ perceptions of their professional development during twelve months of engagement.

2.0 Background

UNEP (2010) defines indigenous people as a group or community that have lived in the same geographical locality over a long period of time, such that they have developed a stable and intimate relationship with their environment that has enabled them to survive over generations of time. Similarly indigenous knowledge (IK) is seen as a type of diachronic knowledge about the environment that a community accumulates over time and which enables the community to survive over generations. Thus IK is context bound and also linked to community survival by definition. By the same token, indigenous knowledge tends to be based on qualitative observations. Another striking characteristic of indigenous knowledge is that the observers are the resource users and their very survival is inextricably linked to reliable and accurate observations, for example, farmers need to be able to make reliable observations about weather patterns if they are to make accurate predictions about rain, drought etc. For this reason, Berkes (1993) and Pierotti and Wildcat (2000) argue that the observations have to be localized over generations. In addition, indigenous knowledge is interwoven and virtually inseparable from the social and spiritual context of the culture. It is value laden. Berkes (1999) and Hunn (1999) both claim that indigenous knowledge systems include an ethic of reciprocity between humans and nature. IK provides a holistic view of the environment which is a contrast to the dominantly consumptive view of western science.

Western science, by contrast, is conducted in an academic setting in which nature is viewed strictly objectively. This dispassionate view of science places humans apart and above the environment in which they live. Nature and the environment become the object to be manipulated and are exploited at will. Scientific knowledge tends to have high reliability and also high synchronicity as it is verified quantitatively using data gathered in focused locales.

There is an increasing awareness in the wake of global climate change and other environmental challenges for these two types of knowledge to be harnessed and used in an integrated manner. In 2007, the SADC secretariat produced an
Education for Sustainable Development (ESD) report identifying issues that could be addressed through the integration of IKS into the curriculum. The SADC ESD report for 2007 highlighted the issues in table 1:

<table>
<thead>
<tr>
<th>ESD Issue</th>
<th>Science-IKS Integration benefits</th>
</tr>
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<tbody>
<tr>
<td>Addressing cultural imperialism</td>
<td>The basic premise of the Science-IKS integration is the acknowledgement of the sound scientific basis behind most traditional and cultural industry (be it dye making, construction, metallurgy or health practice. This acknowledgement seeks to restore dignity and pride to the indigenous peoples.</td>
</tr>
<tr>
<td>Increasing science awareness and the participation of learners in subjects such as science and technology is important in ESD processes. Knowledge of technologies to improve livelihoods (including indigenous technologies) is needed (South African ESD Consultation Report)</td>
<td>Integrating IKS with science / mathematics makes these subjects culturally relevant to the learners, and restores pride in their cultural heritage.</td>
</tr>
<tr>
<td>There is a need to balance cultural induction (a process that occurs through education) and criticality (the ability to critique cultural perspectives), and to support learners to deal with complexity and paradox (South African ESD Consultation Report).</td>
<td>The use of dialogical argumentation in the integration of Science and IKS helps learners to be more critical and to seek for grounds for claims made.</td>
</tr>
<tr>
<td>It is important to mobilise people’s prior knowledge and understanding. Often we assume that poor supposedly ‘underdeveloped’ people (e.g. the illiterate fishermen)know very little, but they actually know a lot. Often this indigenous knowledge is sidelined. It is important to take time to listen to people, and to create learning spaces so that people are not simply spectators in the learning process (Mauritius ESD Consultation Report)</td>
<td>The integration of Science-IKS creates learning spaces by involving the community in collecting, recording and archiving indigenous knowledge through community service learning. By tapping into the the vast indigenous knowledge reservoir, teachers can contextualise science / mathematics / technology and health curricular in such a way that learners identify with the content taught and thus enjoy the learning process.</td>
</tr>
<tr>
<td>Indigenous knowledge systems play a critical role in informing and shaping environmental education / ESD content and approaches. Working with IK in ESD is of paramount importance and should be vehemently pursued … IK facilitates ESD programmes by enabling ESD practitioners to become more alert to the social, cultural</td>
<td>This is also the underpinning conceptualisation of Science-IKS pedagogy model of instruction. Through working within the context of the local communities, teachers make science and maths more relevant and empowering to their learners.</td>
</tr>
</tbody>
</table>
and political context in which they are working. (Zimbabwe ESD Consultation Report).

Meaningful people’s participation is key to the success of ESD (Swaziland ESD Consultation Report)

Contextualising and localising learning with local sustainable development knowledge and skills makes learning meaningful to the learners (Zambia ESD Consultation Report)

Promotion of participatory approaches and capacity building of local communities has enabled communities to get into partnership agreements with the government in protecting the environment (Tanzania ESD Consultation Report)

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<th>Table 1: IKS issues prioritized in SADC ESD report (Abridged and adapted from– UNECA, 2007)</th>
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<tbody>
<tr>
<td>In general, integration of IKS into the curriculum can be justified on several grounds:</td>
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<tr>
<td>a) Historically, South African indigenous cultures had accumulated a vast amount of indigenous knowledge over many centuries. The knowledge acquired extended from mathematical, architectural, engineering, to health knowledge. However, 300 years of colonisation and apartheid resulted in the atrophy of indigenous cultures and knowledge systems (Ogunniyi and Hewson, 2008). In-fact apartheid systematically sought to extinguish and subsume indigenous knowledge and culture as part of the total subjugation strategy for the indigenous peoples. Strategies used included stratified education specializing in disinformation, including the selective omission of non-European achievements, inventions and technologies; the distortion of data; surreptitious naming; and euro-centric education. Thus recognition and appreciation of IKS is a source of healing, in the context of unhealthy imbalances, distortion, trivialization and neglect. Integration of IKS into the curriculum will therefore assist in dismembering the remnants of apartheid domination. These include psychological, intellectual, and economic structures of dominance and dependence, associated with the apartheid and some post-apartheid policies.</td>
</tr>
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</table>
| b) The impact of globalization, on the South African society has resulted yet again in the sub-sumption of indigenous cultures to the dominant cultures of the west. Emeagwali, (2003) argues that one of the challenges of globalization for Africa, is the protection of intellectual property rights. In a continent where all world views are subjugated to that of the western-based scientific enterprise, Warren et al

Integration of science and IKS can be designed to enable local community participation in collecting, recording and archiving IKS. As custodians of their cultural heritage, the local community, through their participation, take full ownership of IKS and are acknowledged as the rightful holders of intellectual property rights regarding their cultural heritage. The learners, as the direct heirs of the products of science-IKS integration, will grow up with technological, scientific and indigenous awareness to the challenges of the environment. This awareness will enable to select the most appropriate solutions to the challenges they face. |
(2008) contend that African indigenous knowledge systems have been exploited and abused, without giving credence to the owners of this knowledge. For example, they argue that modern technology exploits indigenous knowledge and interfaces the products with science to produce life-saving drugs, which are then patented without giving due recognition to the original owners. Integrating IKS into the curriculum will help raise awareness and pride in our heritage, and thus prepare the younger generations to defend and protect indigenous intellectual property rights.

c) Indigenous knowledge systems provides a wholesome overview of the world and how to survive within it. It carries with it a philosophy (Sikkerveer and Brokensha, 2004); values, (Semali, 2004) and attitudes that circumscribe the person’s behavior. Indigenous knowledge helps the person to fit within the society and community in which they live. Barnhart (2005) argues that Indigenous Knowledge is a system for survival. However, several researchers (e.g. Le Grange, 2007) argue that indigenous knowledge has been romanticized as a panacea for post-colonial ills, yet it has failed to live up to expectations. Briggs (2005) further argues that the failure of integration of IKS into the mainstream curriculum can be attributed to several factors, namely, the current focus of IKS on artefacts, as historical vessels of knowledge and the disjunction between scientific and IKS worldviews. In the former case, IKS is perceived as being mired in past glories that may be irrelevant or meaningless to modern day hustle and bustle. In the latter case, Snivelli and Corsiglia, (2001) argues that;

IK seems to be relatively less transferable than conventional science, given its holistic socio-cultural and even spiritual dimensions. IK appears to be largely communitarian in terms of motive, nor is it prone to large-scale mass production and economies of scale. IKS provides excellent examples of community based, and community biased research. (p8)

Interestingly, the authors believe that the nature of IKS as described above is closer to the nature of science, as practiced by scientists. The view of science as a dispassionate activity has long been discredited (see Ogunniyi, 2005; Yakubu, 1994). Scientific knowledge, as a product of human endeavour is generated through collaboration and peer review, whilst indigenous knowledge, being diachronic, was built over many generations, mainly through trial and error, observations and consensus. Thus the authors contend with the right instructional approaches, indigenous knowledge can be integrated with science curricula to enrich and empower African learners.

Science curricula are organized around different models of instruction. In one model which was widely used in South Africa, and in colonial Africa (see Van Wyk, 2004), knowledge was organized around an independent body of facts that had to be assimilated and transmitted through good teaching, and, by means of thorough coverage of specific textbooks. Students were effectively assessed by occasional exams that included objective tests, structured questions or essays. This model was generally teacher-centered and examination - driven, and the teacher was considered an expert and a major actor in the learning process. The content was logically arranged in a sequence of
structured units. Educational content was discipline-specific. Even after the introduction of Outcomes Based Education in South Africa, in 1996, this model still held sway in schools as there was a perception that it was more effective (see IOL; 25 July, 2006). Supporters of this model argue that it adequately prepares the students for their examinations, though not necessarily increasing their critical awareness of their environment or the societal inequalities. The main weakness of this model is that it lends itself more easily to a teacher-centred transmission mode of teaching. The model’s reliance on specific textbooks also makes it a high risk choice especially in the face of curricula reforms that aim to integrate science with indigenous knowledge. If the textbooks are euro-centric, as is most often the case, they will most likely not be free from subliminal insinuations, ridicule and negative representations of African indigenous knowledge, that perpetuate Euro-centric superiority and may hold both teachers and learners hostage to the text. In addition, the high rate of change quickly renders today’s curriculum content irrelevant for tomorrow, thus textbooks quickly become outdated and curricula require frequent revision to remain relevant to the community’s needs.

(Krugly-Smolska, 1994) describes a model that she feels is better suited for integrating IKS within the curriculum. She further argues that this model would be more critically engaged and socially oriented. Students are encouraged and trained to challenge existing relations of power and domination in terms of a transformative epistemology. Awareness of societal ills at local and global levels preoccupies discourse, and, the curriculum is viewed as an instrument of empowerment.

With this model, the use of the library media center and other resources, is extensive. Learning and teaching strategies are decisively student centered. There is a greater range of methodological experimentation and more willingness to utilize student centered resources. This model also aims at developing the mind and the intellect, in the context of rigorous intellectual activity, and community-oriented research. Its implications for indigenous knowledge are manifested in affective, cognitive and methodological approaches, including a more experimental use of instructional resources. There is a keen awareness that knowledge production is socially derived, and that relations of domination and oppression could affect content (Nzimande et. Al., 2008). Evaluation in the context of this approach is not associated with objective tests, and the like, but rather, with measuring attitudes and social consciousness, and, this is negotiated through critical dialogue and argumentation. Such a model is more in sync with outcomes based education

By way of illustration, the Western Cape Education Department produced a strategic plan for the period 2010 – 2014. Table 2 illustrates how integration with IKS can assist the teacher to meet the priorities.

<table>
<thead>
<tr>
<th>Priority Area (Reading and Writing)</th>
<th>Alignment</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improving Literacy Integrating IKS and argumentation into the curriculum helps teachers to develop classroom materials</td>
<td>By training teachers (and by default) learners how to use argumentation principles to support their claims in class</td>
<td></td>
</tr>
<tr>
<td>Improving Numeracy</td>
<td>The integration of indigenous methods of numeracy with formal methods. This makes numeracy more relevant and less isolated from the learners experience.</td>
<td>Recognizing that learners employ several numeracy strategies at home, provides a useful context for learning numeracy in school. In turn, this helps learners to adapt more easily to what they learn in school.</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Increasing numbers passing Maths and Science</td>
<td>Teachers Integrate IKS into the science / maths &amp; technology curriculum by: a) Developing science &amp; maths / IKS instructional materials b) Developing lesson activities that have an argumentation component embedded</td>
<td>The integration of IKS into the science and mathematics curriculum helps to make the two subjects authentic and relevant to the learners’ context. Developing an argumentation-based model of instruction increases engagement levels and the level of interest in the subject.</td>
</tr>
</tbody>
</table>

Table 2: Benefits of using IKS on the Education Department’s priority areas

The models described above, form opposite ends of a continuum, with different types of hybrids falling in between. In South Africa, as in most of post-colonial Africa, resource constraints and poverty constrain the type of model to be used. Hence the failure to fully implement OBE in recent years has resulted in more voices calling for the ditching of the student-centred model in favour of a more “back to basics” approach (Lloyd, 2010; Business Day: 2 June, 2010). Yet IKS provides more resources for the enlightened teacher than available anywhere else (Semali, 2004). The challenge has been to develop a model that is well suited for the South African context and yet at the same time, promising reasonable yields in terms of the integration of IKS and Science curricula. SAARMSTE conference proceedings from the past five years seem to indicate that this problem has been the focus of several research groups in South Africa and beyond (see also Aikenhead, 2000; Jegede and Aikenhead, 1999).
It is against this background, that the SIKS group, based within the School of Science and Mathematics Education, at the University of the Western Cape (UWC) developed an IKS and Argumentation model in 2004 and have been trialing it with teachers ever since. Over the years, the participating teachers have been exposed to a series of workshops which have assisted them to become aware of the relevance of science and IKS to modern life. Figure 1 is a depiction of the general model format.

![Pedagogical Process using the POE Structure](image)

Fig. 1: Model of the structure of a lesson integrating IKS and Science

Generally, either a scientific-technological application, depicting the science process under study, for example: *Why does a thermos flask keep hot things hot?* Leading to the study of heat transfer; or an IKS application: *How do thatched huts keep us warm in winter?* leading to the same transfer of heat; is used to introduce the topic. The question is asked in such a way as to elicit predictive responses from learners either using their pre-existing scientific conceptions, or their indigenous (community derived) knowledge. Individually, and then in groups, the participants discuss their predictions seeking consensus in the way described by Nakashima et. Al., (2000) and Erduran et. al. (2004). They then put forward their unanimously agreed positions. Using either, guided group /
individual experimentation, or worksheets, the teacher then guides the participants through investigations. The participants make observations adhering to the rigours of scientific investigations: for example, in an experiment to compare the cooling curves of water in a thermos flask and in exposed air, they are expected to make accurate repeated readings and plot graphs. The participants then discuss as they resolve their explanations to be compatible with their observations until they agree on an explanation that fits the observation. This argumentation process fits with Ogunniyi’s Contiguity Argumentation Theory (see Ogunniyi and Onwu, 2007).

The model recognizes and affirms the following aspects of the IKS-Science integration:

a) That IKS offers an alternative worldview to the scientific paradigm, but is nevertheless as valid as science. Any attempts to improve teachers’ understanding of the nature of science without helping them to translate the science and IKS interface in their daily experiences were found to be inadequate. As a knowledge system, IKS is not only valuable (representing the accumulated values and wisdom of people living in Southern Africa over many centuries), but is also based on sound scientific principles. (Ogunniyi, 2007, 2009).

b) That argumentation at every stage of the teaching / learning process stimulates active learning and promotes learner engagement in the classroom (see Erduran et. al., 2005).

c) That the Prediction, Observation, Explanation process provides a simple and predictable structure to lesson planning that makes it easier for both teachers and learners to implement (see White and Gunstone, 1991).

Early studies from using the UWC model have produced the following results with respect to the teaching of science:

- Participating teachers were more favourably disposed to accepting IKS as a potentially legitimate aspect of a science curriculum. (Onwu et al., 2006)
- Participating teachers were more able to distinguish between science and IKS. (Ogunniyi, 2005)
- Participating teachers were more aware of the appropriate context to use the scientific or IKS worldviews than was the case before the onset of the project. (Ogunniyi, 2006)
- Participating Teachers found it easier to integrate Science Learning Outcomes 1, 2 and 3 and thus made science and mathematics more relevant to the daily living contexts of their learners. (Ogunniyi, 2005)
- The interface of IKS and argumentation by teachers reportedly produced learners who were more critical and able to support their observations and views. The results were even more striking with learners in the Foundation Phase. (Ogunniyi and Hewson, 2008)

The success of the UWC project, though encouraging, raised some questions about the sustainability of the positive changes observed. Of central concern to the authors, was the extent to which the individual teachers’ practice had been changed by their experiences. This paper focuses on the reflections of the teachers who passed through this programme and attempts to answer the following research questions:

a) How did the teachers integrate IKS into their science teaching?

b) How did the teachers’ integration of IKS and Science affect their professional
development?

3.0 Methodology

This study is part of a bigger study on the relationship between IKS and the nature of science (NOS) currently underway at the University of the Western Cape. Seven masters students were asked to share their experiences and participate in the development of a model for integrating IKS with the teaching of Science. These seven students were chosen because they were part time students who were currently employed as full time teachers in their schools. They agreed to be observed while teaching, and were prepared to share their ideas on how the theoretical modeled translated into classroom practice. Program activities included attending workshops on dialogical argumentation, nature of science and indigenous knowledge systems, materials development and lesson planning. In between workshops, the teachers were expected to implement an integrated IKS-science curriculum in their classrooms. The teachers received support from the research team through support visits. During these visits the research team observed and videoed the teachers teaching. They followed up the lessons with interviews, which were also recorded. Lastly, the teachers were asked to complete a questionnaire-cum-interview in which they reflected on their own professional development during this process. Complexity theory (see Mushayikwa and Lubben, 2008) and principles of self-directed professional development, as developed by Mushayikwa and Lubben (2009) were used to analyze the impact of modeling IKS on the teachers’ perceptions of their development.

4.0 Results and Discussion

The two research questions posed earlier in this paper will be used as organizers for this section. The first question refers to the classroom efficacy of the teachers (see Mushayikwa and Lubben, 2009) and the second question looks at the professional efficacy (again as described in Mushayikwa and Lubben, 2009).

Teacher Profiles

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Teaching Subjects</th>
<th>Teaching Level</th>
<th>Teaching Experience</th>
<th>Experience with integrating DA in teaching</th>
<th>Experience with integrating IKS in teaching</th>
</tr>
</thead>
<tbody>
<tr>
<td>UM</td>
<td>Life Sciences</td>
<td>FET</td>
<td>2 Years</td>
<td>6 months</td>
<td>5 months</td>
</tr>
<tr>
<td>SS</td>
<td>Maths</td>
<td>FET</td>
<td>16 Years</td>
<td>3 years</td>
<td>2 years</td>
</tr>
<tr>
<td>PH</td>
<td>M; Sci; Tech</td>
<td>GET</td>
<td>6 Years</td>
<td>2 Years</td>
<td>6 Years</td>
</tr>
<tr>
<td>LR</td>
<td>LS; NS</td>
<td>GET-FET (7-12)</td>
<td>2 years</td>
<td>2 Years</td>
<td>2 Years</td>
</tr>
<tr>
<td>CO</td>
<td>Literacy, Num</td>
<td>Foundation</td>
<td>14 Years</td>
<td>3 Years</td>
<td>3 Years</td>
</tr>
<tr>
<td>AB</td>
<td>P. Sci.</td>
<td>FET</td>
<td>9 Years</td>
<td>2 Years</td>
<td>2 Years</td>
</tr>
<tr>
<td>KT</td>
<td>Maths; P.Sci</td>
<td>GET-FET</td>
<td>4 Years</td>
<td>1.5 Years</td>
<td>1.5 Years</td>
</tr>
</tbody>
</table>

Table 3: Participant teacher profiles

Table 3 summarizes the profile of the teachers who are part of this study. All the teachers had a recognized teaching qualification and were studying towards their Masters in Education degree. Teacher LR participated in the IKS programme even when she was B.Ed (Hons) student and therefore had been using IKS in her classroom throughout her teaching career.

Table three shows that the seven teachers were teaching across the whole spectrum of the...
curriculum. When asked about their experience with using both dialogical argumentation (DA) and IKS, all the teachers admitted to having used the two innovations in the classroom, but they had varying experiences. Two teachers had recently been introduced to DA and IKS – having started the M.Ed. degree less than two years before. The other remaining teachers had been in the programme for at least two years, with one teacher claiming to have used IKS for six years in her teaching. According to Sawyer (2001), teachers pass through phases of survival, exploration and adaptation. Novice and inexperienced teachers with less than two years experience tended to be concerned with coping (survival) issues. Teachers who had mastered their survival concerns and were now confident and established in their jobs, (typically teachers with two to ten years experience) tended to be interested in exploring ways of enhancing their teaching. The third group of teachers, with extensive experience (those who had seen it all) usually with more than ten years of experience, were more concerned with adaptation issues, such as adapting to new curricula. Teachers in this sample fell within Sawyer’s phases i.e. novice teachers (UM and LR); exploratory teachers (PH, AB and KT); and adaptive teachers (SS and CO). These categories will be used in analyzing the teachers’ responses to the questions below.

4.1 How did the teachers integrate IKS into their science teaching?

This question is answered in two parts: how teachers felt about using the model, and how they actually used it in the classroom.

4.1.1 How do you feel about using the IKS model in your teaching?

Novice teachers were quite upbeat about using the IKS model in the classroom. Their responses were very positive, but also tinged with disappointment. Both teachers indicated that they tried to use the model regularly in their teaching, however UM complained that the time periods allocations for the various subjects in his school, were inadequate to accommodate the use of dialogical argumentation and IKS interrogation in his classes. He also believed that his subject, life sciences was very fertile in terms of interrogating IKS and integrating it into the curriculum. LR on the other hand, felt that as a new teacher in a new school, she could not introduce the model as she was still under supervision from the HOD. She had the sense that the HOD would be against any such move as the school was a perennial under-performer.

UM mentioned that one of his best experiences with the model, was when he prevailed over a discussion on preparation and preservation of foodstuffs. His Grade 11 class brought indigenous food from home and they discussed how it was made. The class was so engrossed that when the bell for the next lesson rang, the students were quite reluctant to leave, and they agreed to continue their discussions in the afternoon. He added that “the students were so happy they could link their IKS experiences to Science”. In this way, it appears that the students learned science through IKS.

However, like LR, UM also had misgivings about the efficacy of the model. He indicated that one of his worst experiences with using the model, was when one of the students refused to participate in an umqombothi / fermentation discussion because it conflicted with his religious beliefs. As a result of this experience, UM said he felt that learners are more comfortable if they are placed in situations where they do not question their values and belief systems. LR added that one of the limitations of the model was the fact that
argumentation is culture bound, and some cultures prohibit minors from questioning assertions made by the initiated or adult members, so it is difficult for the students to question authority. This comment is in sync with what other researchers (such as Bloome and Carter, 2005; Foucault, 1984) have also observed.

Sawyer (2001) argues that exploratory teachers are curious about their profession. They are always on the lookout for ways to improve their teaching repertoire. They are more confident in their teaching and want to discover new ways of maintaining the interests of their students. In this sample, PH, AB and KT fell into this group.

Although PH and KT had a positive attitude towards using IKS and argumentation in their classes and used the model “always”, AB did not share his enthusiasm and admitted that she only used it rarely. She argued that the use of the model competed with demands from the education department to finish the syllabus and the model consumed time both in terms of preparation and implementation in the classroom. All teachers indicated that they had some memorable experiences while using the model. PH started a science club and prepared his students to present their inventions at expos. He used the model to help them discuss their findings because:

I have been able to teach children content material that is above that which is gauged by curriculum documents since learners know this thing already. The problem for most learners is self expression in a foreign language and they are unable to synergize and correlate what they know with what they think in a different language since there are no parallel concepts bridges readily available to them” (PH)

KT on the other hand indicated that his most precious moments with the model was when his grades 10 and 11 classes discussed energy sources, lightning and gold mining. He claims that the discussions were so lively, even those students who normally do not contribute in the lessons, were interested enough to participate, one shy student, even presented and argued for his groups position. In this case, IKS was made a vehicle through which the students learnt science. AB’s most enjoyable experience with the model was when she took her chemistry class to a local university for practical sessions in organic chemistry. She prepared the worksheets and used the model. The University professor who ran the practical was impressed by the quality of reasoning the students used to arrive at their answers. She also used aloes and medicinal plants to discuss the contribution of local knowledge to modern medicine. In this case, students learnt about IKS through the medium of science.

The only negative emotions associated with the IKS model were voiced by KT who reported that once the principal came into his classroom and found the children happily engaged in discourse and he chastised him saying that he must pay closer attention teaching as “that is your job sir!” this was after his grade 12 learners challenged his use of the model by asking; “Must we know this for the exam?” and then promptly reported him to the principal. Davis (2003) and other change theorists contend that teachers often frustrated and discouraged by unsupportive school heads. Kyriacou (2001) and Thomas (2001) equally argue that frustration with authorities in the school is the main cause of teacher burnout.

KT indicated that in his experience, the IKS model could not be applied as is for most topics, as they were either too abstract, or they depended too heavily on the teacher’s
knowledge of local culture. The other two teachers did not identify any limitations of the model.

Adaptive teachers, according to Sawyer (2001), are firmly entrenched in their profession and are more threatened by change. When change does come, they are more preoccupied with adapting to the change. SS and CO had teaching experiences of over ten years and therefore fall into this category. SS teaches Mathematics and Physical Science, whilst CO teaches literacy and numeracy in the foundation stage.

Both teachers reported frequent use of the IKS model, but both teachers were also not confident with their use of the model. SS reported that he had always toyed with the idea, but that he was implementing it cautiously. CO admitted that her confidence level was shaky. She however indicated that she was amazed that even foundation learners in grades two and three had so much to offer if given a chance.

Both teachers contended that they found the IKS model really useful. CO indicated that one of her best experiences in using the model was when “learners who were seen as naughty or slow became the most involved in her class”. They participated and shared ideas, with some even leading in group discussions so that she discovered new sides to them. She thought that this was because “they could use the opportunity to express themselves in a positive way, what they had to say was valued”.

However, SS reported that the same unraveling of character, that was a positive experience for CO, turned out to be negative for him. The learners became noisy and rowdy, and he found himself treading on unfamiliar ground and could not anticipate learner behavior. This reaction from SS is very revealing as it confirms the fact that his main concern is that of adaptation.

4.1.2 How did the teachers integrate the IKS model into their teaching?

For the novice teachers UM and LR, integrating IKS into their teaching was not easy. The teachers indicated that the main constraint was enacting a lesson within the time stipulated was difficult when learners were expected to take an active part. UM argued:

> The science time table at my school does not provide room for argumentation or even experimentation. Imagine that I have to teach science everyday but for only 35 minutes per lesson. You cannot cover much in that time…."

LR also pointed out that the problem was also much bigger if the school has a multicultural context; i.e. many learners from different backgrounds come from the school. Her argument was that there would be little room for consensus as far as IKS was concerned. The concerns raised betray a concern for survival, in line with Sawyer (2001)’s arguments.

The teachers were however unanimous on the benefits that they saw as emanating from integrating IKS into their teaching repertoire. UM added that the IKS model provided opportunities for tapping into the unexploited and rich body of knowledge and this enabled the learners to connect to the sciences in a unique manner. Thus although the teachers felt intimidated by the integration of IKS into their teaching repertoire, they acknowledged and accepted the potential of IKS in enriching science education. This view is in agreement with the sentiments of Van Wyk (2002), who argues that IKS can transform the balance of power wielded by western society over science.

The views of the “survivalist” teachers were carried over by the “experimentalist”
teachers. PH in particular felt that although OBE had been designed to accommodate such innovations as IKS, its practical implementation did not permit them because the syllabus was too unwieldy and “the forms of assessment do not synchronize with IKS and DA”. KT continues:

…I have found that you need to establish a platform in providing learners with information, allow the learners to internalize it and then construct knowledge out of it. In the chemical reactions leading to gold extraction I had to provide information, perform similar types of experiments and then apply it.

AB concurred, adding that the current NCS curriculum is romantic and idealistic, and does not reflect the realities on the ground. Thus, for these teachers, IKS integration into the science curriculum is difficult currently because there is no support on the ground for its implementation.

The logistical failure of the curriculum did not detract from the benefits of IKS integration, in the eyes of these teachers. AB argued that the shortage of resources, especially in the disadvantaged schools could be counterbalanced by drawing on the learners’ rich and abundant indigenous knowledge. “Learners understand better when I use their local knowledge with science. It makes them more confident to voice their ideas”

The same pattern was carried over to the adaptive teachers. They agreed that IKS had benefits similar to those already discussed above, but added that there needs to be alignment between the NCS and the way the Department translates it for the provincial Departments, Districts and Schools. They pointed out that principals are blissfully ignorant of what IKS entails. The Districts, even though they should know, are not doing enough to effect implementation on the ground and the examination system does not help matters by completely ignoring indigenous aspects in its assessment.

The discussion above highlights the following:

a) The uptake of the IKS model was as expected for the different teacher phases, as described by Sawyer (2001). Novice teachers tended to focus on issues of survival and where they used IKS it was integrated as a survival strategy. In doing so, their main concern and cause for frustration was that there was a disjunction between what they understood as important in using the IKS model, and the way the school curriculum was structured. IKS was used more widely by the group of teachers belonging to Sawyer’s experimental phase. They also provided rich examples to illustrate their use of the model. This is in-line with what is expected for this phase. Experienced teachers tended to be much more cautious in their approach to IKS, and tended to pay more attention to details, e.g. noting that the use of IKS introduced an hitherto unknown element in the teaching equation. They felt threatened by change.

b) The integration of IKS into the science curriculum was likewise positively hailed. However all the teachers felt that the model’s successful implementation was hampered mostly by the way the curriculum was structured at school level. The overall feeling was that at most schools there was not enough time provision to allow for argumentation activities to take place. In addition, Principals and district officials were ill equipped to support IKS innovations. Furthermore, the
Assessment and Examinations units did not take IKS or argumentation into consideration when setting national examinations, even though the NCS specifically mentioned IKS as one of its outcomes. Teacher PH elaborated:

My personal view is that …the syllabus and the common papers that are circulated to schools do not reflect the necessity for IKS since there is very little IKS. This then makes teachers ask the question ‘why teach something that is not going to be assessed?’ Here assessment connotes importance and hence drives the curriculum, instead of the curriculum dictating the forms of assessment

4.2 How did the teachers’ integration of IKS and Science affect their professional development?

Teachers were more upbeat concerning their professional development. Below are some of the statements teachers made on this aspect:

KT: I have benefited greatly from integrating IKS in my classroom. My classes that are using argumentation are doing much better than my Grade 12 class that reported me to the principal … One of the challenges that I and other teachers face, is to get the learners away from thinking “the teacher is the source of knowledge” IKS has enhanced my level of thinking and maturity in researching alternate methods of teaching. Dialogical argumentation for example, has helped me. I am looking forward to see what happens to my current grade 11 next year (2010). They did much better this year (2009). If I can help to make them researchers and critical thinkers, and enhance their knowledge with IKS, then I will have achieved something.

AB: It affected me positively. I was already using Dialogical Argumentation, but did not know it, but now I know. I also know now how to logically organize argumentation using TAP. Using these tools, I can now integrate IKS into the classroom.

PH: …..I believe the deliberate integration and practicing of DA and IKS will enhance my teaching practises as well as my content knowledge as it will encourage me to learn all aspects of what I need to teach. It also enables me to appreciate different reasoning styles and different worldviews, hence respect for how other people and see the world around them.

CO I am now more proficient at eliciting learners thinking and reasoning. I am becoming more localized and proudly South African!

The testimonies from the teachers above show that they have all benefited equally from the IKS integration course regardless of the phase they were in. Some teachers, like KT, also claimed that their students have benefited from the integration of IKS into science.

5.0 Conclusion

This paper set out to evaluate the IKS-Science integration model developed by the University of the Western Cape’s School of Science and Mathematics Education, from the point of view of the participating teachers’ professional development. The paper looked at how the teachers used the model, how they felt when they integrated the model into their repertoire and also what impact they think the model had on their professional development. From the first question, an analysis of the responses showed that teachers
used the IKS model in three ways:

a) Learning Science content through IKS – Content extraction from IKS / Cultural Practices e.g. clay pot making, drum making, iron smelting, fermentation, food preservation etc. (e.g KT)

b) Learning about IKS through Science - IKS knowledge acquired through science content e.g. the physics of traditional home making, thermal properties of grass huts, lightning, etc (see UM)

c) Learning about Science through IKS - Emphasis on the nature of science, Applications of Science and technology, values, beliefs (see CO) e.g. How IKS informs Science and Technology, e.g in architecture, (The Calabash stadium!) etc.; also Interface between Sciences and IKS (ethics, intellectual property …)

The responses to the second and third questions showed that the teachers did integrate the model into their teaching of science and that they found the experience to be beneficial to them and to their learners. However, teachers also reported serious impediments to the implementation of the model. The main concern was the apparent disjunction between the NC requirements and the statutory requirements needed to implement it. Other constraints pertained to the unpreparedness of the school, district and provincial authorities to implement IKS into the school system, despite its proven benefits.

References


**Ethical dilemmas in carrying out AIDS research: Does the end justify the means?**

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The paper discusses several issues associated with carrying out Randomized Placebo-Controlled Trials. The paper arises from a research methods training course that was introduced to fifteen Masters and PhD students in the School of Science and Mathematics Education at the University of the Western Cape. A case study was selected, using the FHI and CAPRISA 004 HIV/AIDS trials that were recently carried out in KwaZulu-Natal. The participants were asked to comment on the ethical acceptability of the study from the point of view of both the researchers carrying the study, the women who would have participated in the study, the bigger community and as IKS stewards. In the discussions, some methodological issues were also unravelled. The participants were unanimous in their conclusion that, while the researchers in the CAPRISA study took every precaution to meet their legal ethical responsibilities, there were serious breaches of moral ethical principles and that this inconclusive study might have caused more harm than good, to the participants and their partners. The study concludes by suggesting the inclusion of a broad based ethics board that is inclusive of community representatives and social scientists in addition to the medical personnel and others already represented.

Keywords: Randomized Controlled Trials (RCTs), Legal ethics, Moral ethics, Placebo, Indigenous knowledge systems

1.0 Introduction

David Resnick (2000) identifies ethics as a code of conduct that defines what is acceptable, from what is not. Ethical practices enhance the academic integrity of the researcher, the institution and the profession that the researcher represents. Resnick also identifies the following values as pillars of academic integrity:

a) Fairness: Fairness implies that knowledge will not be sacrificed for the sake of politics or expedience. Fairness adds a critical dimension to academic inquiry as it forces the researcher to focus on ideas, not people. Institutions that are perceived by the public to be fair in their research outputs can be trusted to provide impartial and balanced research evidence. In terms of ethical practice, fairness implies that the researcher treats all subjects as equal and recognizes the right of service of all participants, including those in control groups.

b) Honesty: Intellectual and personal honesty in research advances the ideals of academic freedom. Honesty is a fundamental value even to the other virtues of academic integrity. Trust, fairness, respect, and responsibility presuppose a foundation of honesty. Without honesty, we can only realize diminished versions of these other values.

Dishonesty undermines the process of research. By cheating, lying, misrepresentation, deception, fraud, forgery, theft, and dishonesty in all its forms, researchers lose all credibility, and in addition, irreparably damage the reputation of their university, in the eyes of the community.

In ethical practice, honesty translates to providing accurate information that enables participants to give informed consent about participating in the research.

c) Respect: Respecting people means acknowledging their worth and treating them as ends in themselves, not just as a means to our own purposes. It is a
fundamental virtue of community; without respect, people are often treated as mere objects. Collegiality and collaboration requires mutual respect from the researchers. Academic respect for communities in which the researcher is working fosters reciprocal respect and trust among community members. Such respect translates to observing the client’s right to anonymity and confidentiality.

d) Responsibility: Responsibility for academic integrity lies with every member of the research community. Researchers are mutually accountable to the institution, the community and the participants who assist in their research. Responsible research involves holding oneself, and others accountable. There is a responsibility not only to act with integrity in our own research, but also to take action in the face of wrongdoing. For the researcher, the Helsinki declaration (see WMA, 2002) requires the researcher to take responsibility for the protection of the client from harm.

e) Trust: Honesty breeds trust, just as surely as dishonesty breeds mistrust and suspicion. Trust is the natural response to consistent honesty. We seek not only to encourage trust in the academic community, but even more importantly to promote those actions and policies that encourage and justify an attitude of trust from others. Mutual Trust encourages the free exchange of ideas. The absence of trust means individuals decline to share ideas and information for fear that work or credit will be stolen, careers stunted, reputations diminished. Trust within the community enhances institutional credibility. However trust is mutual. Researchers also need to trust their clients and research participants if their research results are to have any meanings at all. Thus for the researcher, cultivating trust among participants will ensure that they will participate voluntarily. Voluntary participation is one of the rights enshrined in the United Nations Bill of rights.

The five pillars of academic integrity also scaffold ethical practice for research practitioners. Although many people can agree on what constitutes these values, in research, the situation is complicated by the fact that different individuals and indeed organisations interpret, apply, and balance them in different ways in the light of their own priority values and life experiences. The variable application of ethical standards has led to many disputes among academics and between academics and the communities in which they work.

Makgoba (2001) suggests that research ethics, like any other codes of human conduct, are driven by power relationships. In most cases, those in power determine the specific interpretations with regards to the five pillars of academic integrity. He goes on to add:

“....professionals, just like all human beings, are by and large products of their environments and the political systems under which they operate. ....This white, androgenic ethical model, whilst couched in reasonable language and principles, was in reality a mere facade for and an extension of the powers and political systems that be.” (p. 3)

Francis et. al. (2006) goes further to argue that in terms of human relations, power, in all its facets, is the sole authority from which all other authority is derived. Those who have power can influence decisions and have their way around issues affecting the powerless.
Though this is not a very romantic way of looking at relationships, unfortunately, it is true, and ethical researchers who are genuinely concerned about their subjects will do well to be attentive to the power relationships that exist between them and their subjects, so as to give them true autonomy. To illustrate the power effect, Makgoba cites examples from several incidences that took place during the apartheid era and continues...

“As a result, research projects were approved that would, with hindsight never have been approved. ....There were also cases where ethics were simply ignored...” (p. 3)

The examples given by Makgoba show that even highly learned and respected academics, are not above manipulating and falsifying results if the power differential is steep enough. The people who suffer from ethical abuse are always the weak, the voiceless and those rendered powerless through marginalisation, isolation and deliberate disenfranchisement. The main incentives to abuse of ethics, according to Resnick, (1998) are money, political power and academic prestige. Thus for true justice to prevail, power differentials must be addressed in a way that takes cognisance of the plight of the powerless, or as Makgoba (2001) concludes: “It is in the protection of the abuse of this power that ethics has played a central role and emerged as a critical discipline in the development of medical practice and health research”(p.4).

In trying to highlight the ethical dynamics that students will have to overcome as researchers, the Indigenous Knowledge Systems (IKS) in education group at the University of Cape Town reviewed a case study of a research conducted by the Centre for the Aids Programme of Research in South Africa (CAPRISA) in conjunction with the Family Health International (FHI), which became known as the CAPRISA 004 Study.

This paper is a critique of the CAPRISA 004 Study, highlighting the ethical dilemmas that researchers have to resolve and reflecting on the dilemmas of conducting research in such an emotive area, as HIV/AIDS.

The study attempts to answer the following questions:

a) In what ways did the study design assist or hinder ethical practice?
b) How fairly did the study treat its participants?
c) How sensitive was the research to the needs of the participants?
d) How much information was communicated to the participants to enable their recruitment?
e) What human safety issues needed to be addressed by this study?

Ethical dilemma is an area of study that is growing increasingly relevant to all researchers working with people. Researchers in IKS are particularly affected as they have to deal with similar issues of culture, taboo, social coherence and intellectual property. Thus IKS practitioners will have to face similar dilemmas.

1.1 The CAPRISA 004 study

The CAPRISA 004 (Karim et. al., 2010) study was a three year randomized controlled trial in which a vaginal gel containing the microbicide tenofovir was tested on 889 mostly rural women at two clinics in KwaZulu-Natal. 449 of these women were given placebo
gels, while the remainder received gel with the active microbicide. The research was double blinded so that none of the researchers and participants knew which gel they were allocated. Both the gels and the applicators were identical in appearance. The study reported that of the 889 women involved, 60 women from the placebo-control group and 38 of the experimental group were infected with HIV/AIDS. Twelve women fell pregnant during the study and had to be withdrawn, one woman died and twelve serious adverse effects were reported including cases of social discrimination and stigmatisation. Four women withdrew from the study completely as a result of the social discrimination. Nevertheless, the report of the study (Karim et. al., 2010) reported that the study was a success as it reduced incidences of HIV and HBV-2 infections significant.

2.0 Methodology

As part of the research training for Masters and PhD students at the University of the Western Cape, research ethics is incorporated into the methodology modules. Fifteen Masters and PhD students participated in the academic integrity course. To determine the students’ understanding of the complex issues surrounding ethics in research, the students were presented with a case study based on the CAPRISA HIV/AIDS prevention study. They were asked to critically appraise the study. The study was chosen because it had received a lot of high profile publicity in both print and electronic media, was bandied as a successful South African enterprise and generated a lot of discussion and debate.

Students were provided with media releases of the study, the scientific publication of the article as released to academic peers and some worksheets. They were asked to reflect individually on the documents provided and answer the questions on the worksheet. When completed, the worksheets were collected and a whole group reflection ensued, guided by the same questions as for the individual activity. The group discussion was recorded and then transcribed, to enable results to be compared.

The transcripts were coded using grounded theory approaches as suggested by Auerbach and Silverstein (2003). Repeating ideas were grouped into issues and these ethical issues were then grouped into themes. The themes were then used to answer the research questions cited above.

3.0 Results and discussion

The remainder of this paper will focus on the ethical evaluation of the CAPRISA study as conducted by the IKS research group at the University of the Western Cape. Where quoted, discussants are identified by two letters followed by the line numbers on the transcript. Thus if LM mentioned something on HIV, He/she would be quoted as “LM (In 204).....”. Where LM is the code for the discussant, and the line number denotes the exact position on the transcript, where the discussant made this remark.

3.1 In what ways did the study design assist or hinder ethical practice?

In the CAPRISA study, it is reported that the participants were required to apply the gel within a window of twelve hours before being involved in sexual intercourse. A second dose was to be applied immediately after sex. The gel must not be applied more than twice within 24 hours (FHI and CAPRISA, 2010B). The discussants felt that participants in the CAPRISA study would have had difficulties with adherence, especially pertaining to the rules relating to the application of the gel. Using the gel everyday regardless of
whether a woman has sex is associated with high adherence as it is easier to remember if it is part of a daily routine. Others however, (see FHI and CAPRISA, 2010B) argue that it is easier to remember to use if it is associated with sex. The CAPRISA 004 researchers reported that the decision to choose the coital (or episodic) adherence over daily adherence was taken after consultation with the participants in the sample, and also after noting that the women had husbands and partners who were seasonal migrant workers who came home about twice a month. In the review, the discussants felt that the time lapse for application of the gel before and after could turn out to be inconvenient for women, especially if they did not anticipate sex and had to comply with their husband’s wishes, which could account for the 27.8% non-compliance rate for this adherence procedure. In addition, the study does not identify whether the cases of non-compliance were widespread or were limited to specific individuals. We feel this would have been important information when comparing adherence with HIV/AIDS infection rates, e.g. was HIV infection incidence higher among those who were non-compliant or not?

The CAPRISA study (FHI and CAPRISA, 2010I) also reveals that of the 889 women involved in the study, 39 women experienced serious adverse cases and one woman died in the placebo gel group. They however omitted to describe the nature of the adversity that affected at least 4% of the sample size, and resulted in the loss of human life. Five of the women stopped using the gel, four due to genital findings (which were again not elaborated upon) and one had congestive heart failure. It appears as if there were methodological breaches and disinformation, as it appears there was insufficient risk assessment carried out before the study commenced. For example, because of the high attrition rates, it is difficult to estimate the effective sample sizes. The attrition rate has the effect of actually increasing the effective HIV infection rates for both the experimental and control groups – depending on which groups were affected by the attrition. It is important for readers and the public to be given the correct figures of those who completed the whole study. As a result, the report was found to be highly misleading as these very important issues were skimmed over and brushed aside, in the researchers’ bid to woo the media. We find the manner in which this information was withheld from the public in their intent to glorify their findings disingenuous as it gives a completely wrong picture and prevented people from asking the right questions in assessing the risks of the study.

The discussants also felt that the study infringed on the confidentiality of the participants, as the media were able to meet some of the women who participated (see Sunday Times: 25 July, 2010). These women were mostly living in rural areas, and their husbands were migrant workers, there was always the danger of stigma and discrimination because of the misconceptions that those involved in the study maybe infected with HIV. Indeed, twelve of the participants reported cases of discrimination during the study and four women withdrew – as a result of it. The researchers claim that those affected by discrimination received counselling from the study’s staff members. The study does not disclose whether the discrimination was perpetrated on the women by project staff, or community members. We believe that the social cost of this project was not adequately evaluated.

A source of methodological concern also relates to the way the young women were selected for the study. The CAPRISA backgrounder (FHI and CAPRISA, 2010A),
indicates that the candidates for the study were young women aged between 18 and 40 years old. All the young women were initially HIV-negative, as the study carried out extensive screening for pregnancy, STIs and HIV. In addition, women who used other forms of contraception were also excluded from the study. The document further points out that the young women were recruited when they visited the clinic, but it does not state the reasons for the visits in the first place. From the description of the recruitment process, it appears as if these women, who were all HIV negative initially provided a captive pool for the researchers, as they were already at the clinic for certain services when they were recruited. One cannot discount the possibility of inducement in this case. The women would have found it difficult to withhold consent, as they perceived the researchers as people who had the power to assist them with their health problems (Marshall, 2005)

As a result of the foregoing, we conclude that the methodological breaches in the study design hindered ethical practice more than it facilitated it.

3.2 How fairly did the study treat its participants?

CAPRISA 004 was designed to the most rigorous international ethical standards (FHI and CAPRISA, 2010A). It was reviewed and approved by the UKZN’s Biomedical Research Ethics Committee and by an independent ethics committee convened by FHI. In addition, data on safety, enrolment, and efficacy were reviewed at pre-defined intervals by an independent Data Safety and Monitoring Board (DSMB). The study was also conducted under the oversight of the South African Medicines Control Council.

Despite this rigor, it appears that the participants’ partners were left in the cold by the consultation process. In an interview, the researchers commented that they did not know the prior status of the women’s partners (See Sunday Times, 25 July, 2010). One of the discussants, SK (ln 110-120) commented that the article stated that 99% of the women interviewed after the study, said that they will surely use the gel “if they were sure that it does prevent HIV” (our emphasis). This implies that the women were beginning to question for themselves, the efficacy of the gel.

The use of the placebo effect on humans is generally discouraged (See Nadkarni, 2006), as it goes against the ethic of informed consent. It can be considered as a form of deception, as none of the women knew what type of gel they had been given. The researchers created an impression that the gel could be used to protect them from contracting HIV, and the women might have as a result, decided against using any other means they traditionally used to protect themselves, including indigenous knowledge they might have known, or rather they might not have taken the precautions they would otherwise have taken. Thus more than half of the women were needlessly exposed to risk.

In the case of the group using the placebo-gel, there was an added methodological problem of introducing a type one error, since the HIV status of sixty of the participants was permanently changed at the end of the experiment. The discussion participants felt that the damage attributable to the placebo effect was irreversible, so this made the research a very high risk business. KL (ln 100) commented that since these women had been HIV negative initially, the researchers might actually have scored higher successes by exhorting them to practice safer sex or total abstinence.
As a result of these observations, we feel that the research was unfair to the participants because the researchers were not completely honest with them.

3.3 How sensitive was the research to the needs of the participants?

The fact that almost one eighth of the women in the sample contracted HIV within a period of 30 months is quite worrying as it translates to slightly more than three infections per month. CAPRISA 004 (FHI and CAPRISA, 2010E) observed that the women had partners or husbands who were migrant workers and that these men came home on average once every two weeks. Such a high infection rate among people who had infrequent coitus should have been reason enough to review the intervention. It is noted in the media that the men were not involved in the intervention at all. Our argument is that the neglect of men in the intervention showed insensitivity to the culture and context of the women. Zulu culture is patriarchal and the men wield power over their women in terms of decision making, yet the study ignored these seats of power. Several Biomedical ethics experts underline the importance of understanding the participants’ culture in clinical trials. Kuper, (1999) went on to claim:

The application of ethical guidelines for research is difficult to accomplish without knowledge of the cultural context within which a study takes place ..... culture is a symbolic system representing ideas, values, cosmology, morality and aesthetics shared by individuals and groups (p227)

Indeed, several biomedical ethics researchers such as David Resnick (1998) and Nardkarni, (2001), have observed that AIDS research tends to focus inordinately on women, ignoring the men, who are commonly vilified as the culprits in the first place. If culturally, the men have the decision-making powers over the sexual conduct of their partners, surely, changing men’s behaviour should be the priority focus of these interventions. By casting the women as victims, and then focusing RCTs on them, the researchers are demonstrating their hypocrisy.

This hypocrisy is further demonstrated by the fact that participants received free condoms, treatment for STIs, and regular counselling on how to prevent HIV and STIs—measures that constitute the widely accepted standard for HIV prevention services (CAPRISA, 2010A:2). If the women presented symptoms of STI infection, surely then the men also needed to be treated as failure to treat the men would result in re-infection? In addition, the women were given condoms, ironically, the efficacy of this RCT depended on women NOT using condoms – thus it would be interesting to note how this contradiction was resolved. (FHI and CAPRISA, 2010D:1). If they were really interested in preventing or slowing down the spread of AIDS, surely they should have included the women’s husbands in the counselling sample, to enable them to provide support to their wives.

The study also indicates that pregnant women were taken off the product. If the pregnant women were taken off the study, it’s not clear whether the 889 included or excluded the pregnant samples, if so then what was the original number or the final sample on the findings?

Women found to be HIV positive during the screening process in the study, or who
acquired an HIV infection during the study, were counselled and referred to the best care and support services available in their communities, including CAPRISA treatment and research programs. In-fact, the CAPRISA factsheet (FHI and CAPRISA, 2010E) reports that infected women were given the option to join another RCT project which was run by CAPRISA and was researching HIV/AIDS treatment. In this case, (SS: 18) and (PO: 82-83) feels the damage is irreversible since the status of the person is permanently changed. Social workers have significant roles to play in community based research in HIV/AIDS. They can help communities set up community based ethics committees and link them with academic institutions. The development of a community-based research ethics infrastructure would also promote increased independence for non-academic researchers and improve their awareness of ethical issues (Ogden, 1999).

It is also noteworthy that the researchers focused on Durban which has the highest HIV-infection rates in the country, and selected rural Zulu women whose literacy level is also among the lowest in the country (See Leach, 2000), a combination of factors that makes this study unfair and unethical (BM: Ln136-138), as the researchers evidently took advantage of the vulnerability of their clients. Williams goes so far as to recommend that:

Since justice demands that the benefits of education be fairly distributed throughout the developing country in which the experiment is to take place, this means that the experiment must be postponed until any would-be sub-group of participants has a level of education that is representative of the whole population of that country. (Williams, 2000: 559)

The research design of this study was deliberately focused on exploiting vulnerable women, in situations where it was known that the research carried a high potential for type I errors.

To cap it all, clients’ rights of confidentiality and anonymity were not respected. In their articles to the press, the CAPRISA researchers identified the clinics where the study took place, effectively exposing their clients to the glare of the media. Some of the women were even interviewed on radio and by the print media and asked to comment on their feelings in participating in the study. PO: (Ln554-555) argued this could surely lead to stigmatization. One may argue that the women had given consent to be interviewed, or exposed, but as Goodwin and Pope (2003) noted, some cultures make it difficult for women to give true consent and in some cases, such information can only be given with communal (extended family) consent. As noted earlier, Zulus are a patriarchal society where right of passage is still very strongly adhered to, thus women and children are not expected to make decisions on their own, if married.

Based on the issues raised above, it can be argued that the CAPRISA study focused more on the procedural ethics and neglected to address the cultural dimension to ethics. In this respect it was unfair to the participated and may have compromised the women’s standing in their community.

**3.4 How much information was communicated to the participants to enable their recruitment?**

The CAPRISA study (FHI and CAPRISA 2010I) indicated that there were social risks
associated with the study. There were twelve incidences of social discrimination, which resulted in four women having to withdraw from the study. The report brushes over the social implications of this observation and neglects to identify the sources of this discrimination. For example, were the perpetrators of this discrimination, the husband’s extended family..... or workmates? In a closely knit society such as a rural area, such questions are very important as they highlight the kind of extra support that the participants could get from their community. Depending on the level of relationships between the perpetrators of the discrimination and the participants, such discrimination could have effects as devastating to the women as actually contracting the HIV virus.

Karim et. al. (2010) explain that the participants to the study were trained to understand the implications of the study before they signed the informed consent forms. In the light of the methodological flaws highlighted above, it is debatable whether the participants really understood what they were signing themselves for. One revealing piece of evidence supporting this observation was the fact that women who were interviewed by the Sunday Times (25 July, 2010), when asked about the possibility of going onto the next stage of the trials, replied that they would only do it if they were certain that the gel provided contained the microbicite. It seems, they only realized that some of them were receiving a placebo after the study was completed.

Nadkarni (2006) notes that researchers in previous years conducted unethical practices, this was why the Nuremberg Code (1947) and the Declaration of Helsinki (WMA, 2002) in 1964 were developed. These events led scientists to pay more attention to ethical issues in health research (p2). David Resnick (1998) provides examples of case studies of unethical research conducted in South Africa, during and after the Apartheid era.

Professional conduct in research is imperative, particularly when human participants are involved during clinical studies. The HIV/AIDS pandemic, especially the high prevalence rate in Africa stirred researchers to work towards preventative strategies for HIV infection. For researchers to conduct an ethically appropriate study in social science they need to comply with the Declaration of Helsinki which specifies that research subjects, including those in control groups should receive the best proven treatments and medical care. Other documents such as the Belmont Report and the CIOMS’ International Ethical Guidelines for Biomedical Research also agree with the protection of human subjects during a research (Resnik, D. 1998). SS: (L6, 7) corroborated that human subjects must be protected during research practices.

According to the critics the use of placebos under these circumstances violates one of the principles of the declaration of Helsinki which holds that all research subjects; including those in control groups, should receive the best proven treatments and medical care. Other documents relating to the protection of human subjects in research include the Belmont Report and the CIOMS’ International Ethical Guidelines for Biomedical Research involving human subjects (Resnik, D. 1998, p291).

The Harvard School of Public Health Bio-ethics Guidelines manual states that there is a need for social researchers and social workers to practice a conscious effort of taking responsibility in HIV/AIDS research. It is very important for science researchers to understand the ethical issues and implications when the research encompass HIV/AIDS (Jesani and Barai, 2000)
Nardkarmi (2006) argues that researchers should pay special attention to research subjects that are rendered especially vulnerable by circumstances beyond their control, such as the shackles of culture, geographical location and illiteracy.

The rural participant comes from a very cultural setting where these morals and values are respected by women. One of the discussants in the study, BM (L317-322), described how culture influences everyday decisions of Zulu women. RS (L27); SK (L35-37) and EM (L 128-130) all agreed that these rural women were not placed in an advantageous position. Without proper information, the husbands might have made decisions that they would not normally make, thus placing the lives of the families at risk. For example, SS (L18,19,20 ); SK: (L36, 37 and L48,49) argued that the use of a placebo in the study was analogous to playing GOD with human lives because the participants in the placebo sample were mislead into believing they were using an active gel. Nadkarni (2006) further argues that “it is the duty of all human beings and particularly those in positions of power like health and social science researchers, to be very conscious of how their activities involving the participation of people impact on their lives and on society” (p).

Williams (2000) concluded that peer assessment should occur in the health sector prior to the initiation of these types of research practices. She also stated that professional social workers were working towards greater ethical practices in health care, including health research; while social workers and educators have been active developing ethics in social science research (p558). Williams is especially scathing in her attack on researchers who use placebo-controlled experiments on vulnerable groups. She argues;

Otherwise the researchers should experiment upon their own extended geo-political-economic kin. Given the commercial hegemony of the rich drug companies involved, their opposition to the production of cheaper ‘generic’ drugs and the huge disparity between levels of wealth in developing countries and developed countries, the chances of benefit to the burdened group were clearly not fairly available to them. (Williams, 2000: 559)

3.5 What human safety issues needed to be addressed by this study?

According to discussant AL (In 66), the CAPRISA study has become a moral issue in South Africa as it was broadcast on radio and television, as a scientific breakthrough. This media blitz is disingenuous as it makes many people to believe that a possible solution to HIV/AIDS for women has been found, yet the study states very clearly that there is still a lot of work to be done (Sunday Times, 25th July). The researcher who was interviewed even went so far as to state that the percentage yield for success, of 39% risk reduction was too low, and the study would never be approved in Europe and the USA, unless the efficacy could be improved. Unabashed, the CAPRISA researchers calculated that;

...the level of risk reduction translates to the prevention of 1 new HIV infection for every 20 women who used tenofovir gel during the trial (Cap-D: 2). There were 39 serious adverse events, including one death (in the placebo gel group), but none of these events were related to use of the study product. Twelve cases of social harm were reported during the trial of CAPRISA 004, and four participants withdrew from further
participation in the study as a result of the social harm they experienced. (FHI and CAPRISA, 2010D: 2).

Even though the researchers claim that some adverse events had nothing to do with the research, they failed to adequately explain the social context in which these events occurred. They simply deny the responsibility of any adversity. This paper has already shown that there were too many cases of breaches to the ethical and methodological considerations (e.g. not involving partners was a cultural violation which could have resulted in social harm and adverse effects). This denialism is shown even more starkly in CAPRISA researchers’ condescending and rather patronising concluding statement;

..... all users of the product will need to know that the gel does not provide full protection against HIV. It will be important for individuals to continue practicing other proven HIV prevention methods, such as condom use, knowing one’s HIV status and one’s partners’ HIV status, and having fewer partners. (FHI and CAPRISA, 2010D: 3)

With all serious and unclear adverse events, e.g. the death, social harm, and 98 cases of new infections, we feel that the cost to human suffering is too high and we cannot justify the results of this study.

As mentioned earlier, our considered view was that the clients in this study were in no way protected. It was unethical for the researchers to reveal the location of where the research took place, including the two clinics used. Such disclosure makes it easy to identify the people who frequented the clinics at the time that the study was conducted. PO (In201) clarifies that this type of experiment has social and moral dilemmas that can dislocate the whole community. On the respect of cultural traditions of study populations and communities, Marshall (2007) recommended that a foundation of trust should be build between researchers, study participants and the local community. Researchers need to identify concerns that are culturally based and develop strategies for addressing them in a meaningful way. After all the hype and megaphone celebrations, CAPRISA concluded by commenting:

if the gel comes to market, all users of the product will need to know that the gel does not provide full protection against HSV-2. It will be important for individuals to continue practicing other proven HSV-2 prevention methods, such as condom use, knowing one’s HSV-2 status and one’s partners’ HSV-2 status, and having fewer partners (FHI and CAPRISA, 2010E: 3).

These remarks feel like an anti-climax compared to the media blitz, and claims that came in the aftermath of the research publication. These interviews and media frenzy that followed hiked up expectations and might actually have transmitted misconceptions about the real achievements of the study.

4.0 Conclusion

The IKS group review has highlighted the following concerns:

4.1 Methodological Issues

There were methodological ethical issues arising from the way the sample was identified and selected and the choice of the research design.
The IKS discussion group felt that the methodology did not take into consideration the cultural implications of the research and as a result overlooked aspects of culture which would have been crucial for the success of the project. For example, the study ignored the role of men as power brokers in sexual relationship and it is feared that this could have caused social problems for the women. The contention is that even though the gel was directed at women, the study design could have included their partners both in the counselling and as participants in a supporting capacity. In addition, attempts could have been made to assess the status of the men as well, before and after the intervention, to find out if indeed the microbisite really prevented women from getting infected. For example, if at the end more women were negative, in comparison to their partners, one could more surely conclude that the gel was protecting the women from HIV infection, since one of the unspoken assumptions in this study, was that the women contracted HIV from the men. In such a design, there would have been no need for a placebo, as direct causation could be inferred through comparison of men and women’s infection rates. Such a design would have ensured that the men understood what their partners were doing and might have lessened the social burden of the women.

Secondly, the selection of the participants broke some ethical norms. The researchers selected vulnerable women, whose partners were migrant workers, living away from home for part of the time, and also most of whom lived in rural areas. This vulnerable group has the lower literacy rates compared to their compatriots living in the urban areas. To reduce the risk and yet still run a fair research, the selection should have been focused on the Durban sample, as these women would be expected to have higher literacy and thus better understand the implications of the study.

4.2 Ethical Issues

The CAPRISA Study followed an ethical protocol that was impeccable as far as the legal requirements were concerned. However they lacked a moral ethical protocol, because they overlooked several moral, cultural and aesthetical issues.

Firstly, by not including the men into the project, they demonstrated a lack of understanding of the power dynamics that operate within Zulu society, and because of this, possibly exposed the women to unnecessary risk and social discrimination. By their own admission, some women became victims as a result of this social dimension. Sadly, by ignoring Zulu cultural implications, their beneficent actions are called into question. Robinson et. al. (2009) argue that “clinical trials tend to replicate the hierarchies of power, access to information, control and prestige that dominate the Bio-Sciences.” By ignoring the power dynamics of the Zulu culture, the researchers sought to impose their own power structure on the women. Finally the study should have incorporated an multi-disciplinary ethics team including sociologists and IKS practitioners to ensure that the rights of the women and the community were respected and protected.

4.3 Implications for IKS Research

As mentioned earlier, although IKS researchers are unlikely to be involved in randomized controlled trials, they also work with disadvantaged communities, sometimes in areas that include some social risk and taboos. There is need to be cognisant of the cultural primacy of the community participating in the research, and therefore to follow cultural protocol. It is also wise to observe the power structure and show respect to the community and to give deference to the community power differential. As stewards of indigenous
knowledge systems, the IKS group is against the exploitation of women for research purposes, especially in the case of placebo use. Women bear the brunt of vulnerability as a result of social norms, at the same time, they are entrusted the burden of transmitting the same culture to future generations. Thus women are the keepers of IKS in a real sense. The infection of 98 women who could have been protected, is thus not acceptable.

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Increasing the socio-cultural relevance of science education for sustainable development

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Socio-scientific issues should be considered in the course of students’ formal education in science as one of the ways in which science education ought to be connected to the goals of sustainable development. Approaches to education in science perpetuate a way of thinking that is incommensurable with preparing learners to develop the understandings and skills requisite for active participation in an uncertain and complex world. We argue herein that finding ways to link science education to issues of sustainable development could provide the basis for making science more relevant to learners, as well as better prepare learners for active participation in society. We raise the question: How can science education be more relevant, thereby enabling learners to deal with complex everyday issues and participate in decision-making oriented toward the goals of sustainable development?

Interest in Socio-Scientific Issues
The global population presently uses resources at a rate 40% faster than the planet can regenerate in a calendar year. As recently as around 1980, "the global community consumed resources and produced carbon dioxide at a rate consistent with what the planet could produce and reabsorb" (Global Footprint Network, What is Overshoot? section, ¶4). In essence, in the course of about 30 years we have seen a shift from sustainable living globally to a situation where we increasingly overspend the ecological resources at a faster and faster rate (sustainable living globally in 1980 did not imply equitable consumption of resources as some nations used a lot less and some used a lot
more; this is certainly true today as well). In 2009, Earth Overshoot Day was reached on September 25th. If we continue with a business as usual lifestyle and do not begin to make significant changes, then around the time children born in 2009 graduate from college the Earth Overshoot Day will be July 1st. What this means is that in the early 2030s it would take two years for the Earth to regenerate what is used in one year. Reaching this level of ecological deficit spending may be physically impossible (Ewing, Goldfinger, Wackernagel, Stechbart, Rizk, Reed & Kitzes, 2008).

Between now and the timeframe we have identified in the early 2030s, a different kind of community of practice in science classrooms is going to have to emerge. Just as a business as usual mindset, "which is destroying the economy's eco-supports and setting the stage for dangerous climate change, is no longer a viable option" (Brown, 2008, xii) within society-at-large; a business as usual mindset with respect to science education can no longer be tolerated. We concur with Sadler (2009) when he calls "for the development of communities of practice in science classrooms that prioritize socio-scientific Discourses and development of identities reflective of engaged citizenship" (p. 12).

Wackernagel (2008) asserts "many opinion leaders are trapped in the misconception that advancing sustainability is detrimental to the economy, an expense that will only be affordable at some later date. Unfortunately, later is now, and the consequences of putting off change until later is that countries, and humanity as a whole, will be unprepared for the challenge of living within the limits of our natural resources" (p. 1). He envisions those who prepare for living in a resource-constrained world will fare far better than those who do not. Moreover, he contends in an age of growing resource scarcity, the wealth of nations will be defined in terms of ecological assets. Preparing for this new economic reality will take time, making it urgent to begin as quickly as possible. Strategies will need to be simultaneously put in place to better manage and protect ecological reserves, while minimizing or reducing a nation’s demand on ecosystem services.

The world is facing almost insurmountable challenges. These challenges transcend national boundaries. The Millennium Project has identified 15 global challenges that “provide a framework to assess the global and local prospects for humanity” (Glenn, Gordon, & Florescu, 2009, p. 10). There is recognition among governments that fundamental reordering of global priorities is needed in order to implement the goals of sustainable development. This recognition was first enshrined in the Declaration of the Earth Summit in Rio de Janeiro in 1992, which placed emphasis on strategies for preventing environmental degradation and for establishing a basis for achieving sustainable balance between nature and the human economy into the twenty-first century. Ten years later, in 2002, when the World Summit on Sustainable Development (WSSD) convened in Johannesburg, it was hardly a point of dispute that not much progress had been made at the level of local communities for most global environmental issues (United Nations, 2002). With poverty deepening and becoming more widespread, and environmental degradation of essential ecosystems worsening, we can question whether the subsequent actions and recommendations of the World Summit have been able to contribute in meaningful and realistic ways to achieving sustainable development. We
believe it is important for science educators to ask: What are the implications of WSSD for science education?

In 2009, the International Council of Associations for Science Education (ICASE) sponsored a conference with the theme “Meeting Challenges to Sustainable Development in Africa through Science and Technology Education.” The conference was intended to provoke lively debate and discussion regarding the ways in which science education may be connected to issues of sustainable development. In striving for the promotion of science education for sustainable development, any such debate should include examples which highlight the value of science learning relevant to the needs of a changing society and to the needs of both boys and girls as future citizens, whatever their future career aspirations may be. Such examples would include science teaching emphasizing student learning of - and assessment strategies associated with - skills and competencies promoting problem-solving and socio-scientific decision-making. In essence, the question that arises is simply this: In what ways should science education be more intrinsically linked to issues of sustainable development? Herein we argue that answers to this question ought to provide a veritable means of making science education more relevant to the needs of learners and society. We offer the assertion that the aims of science education are intrinsically linked to one’s conception of scientific literacy. We concur with Roberts (2007) when he notes the visions of scientific literacy materialize from the contexts in which science subject matter is taught.

Roberts (2007) indicates there seem to be two visions of scientific literacy representing the extremes on a continuum, which he refers to as Vision I and Vision II. For Roberts, “a vision is a much broader analytical category than, say, a definition” (p. 730). Vision I is “rooted in the products and processes of science” (p. 730). Advocates of Vision II, the perspective from which we (the authors) emanate, stress the importance of starting “with situations, then reaching into science to find what is relevant” (p. 730). Traditionally, scientific literacy has been framed in terms of past knowledge. Such a perspective fails to capture dynamic aspects of the emergence / disappearance of new literacies (Roth, 2007). We agree with van Eijck’s (2007) notion of scientific literacy as an emergent feature of collective praxis. This notion is “grounded in a conception of knowledge as a collective and distributed cognitive entity” (p. 255). He notes that “grounding the concept of scientific literacy in a cultural-historical perspective allows the articulation of what being scientifically literate means” (p. 256).

We take the position that it is problematic for science education to be primarily aimed at promoting future success in the culture of schooling without links beyond school science to communities, society, self-and social empowerment, and / or social transformation. Sadler (2009) suggests science education should seek to accomplish more than just helping students to develop Discourses and identities enabling them to succeed in higher levels of school science; such an orientation falls far short of the aims that science education ought to assume.

Socio-scientific issues often frame social transformation concerns of many African countries. These include adequate health care, hunger, malnutrition or undernourishment,
lack of safe drinking water, poverty and un/under-employment, subsistence agriculture in small holdings, soil erosion, HIV/AIDS, deforestation, reduction of biodiversity, disease, and many other related social concerns. For a third of the world’s population, the only source of fuel for cooking is firewood. The unchecked exploitation of the forests and vegetation, particularly in the developing countries of Africa, has had catastrophic impact on the natural environment and eco-systems. Such human conditions that pertain to science education have been well documented and corroborated in various UN and World Bank publications (refer to Kyle 2006 for such sources). These human conditions offer stark and contrasting images of the ways in which people in developed and developing countries are linked to the environment. For instance, the more industrialized countries have long experienced the uneasy relationship between environmental protection and economic development. For the developing countries, it was only in the 1980s that it dawned on society that the lack of development (i.e., poverty) is just as effective in damaging the environment as is development. The fact remains, whether human societies appear to be closely tied to the environment or not, their impact upon the environment is crucial for their continued survival and success (Kyle, 2006).

One of the most pressing challenges confronting the developing countries of Africa is how to address in sustainable ways environmental and social issues central to sustainable development. How can African countries achieve the goals of sustainable development - one that meets human needs, while protecting and restoring the natural environment - when many African countries are faced with problems that appear too numerous and/or virtually impossible to overcome? Part of the answer, perhaps, lies in Annan’s (2002) suggestion in strengthening partnerships among governments and non-governmental organisations, including others in a position to contribute, such as the academic and scientific communities. Besides needing strong partnerships, what is clearly required is an active and participatory citizenry. Right now, the challenges facing effective strategies for sustainable development in Africa cannot be handled by government alone. As science educators, we must begin to find ways to take action that would seek to counteract those debilitating human conditions that persist for a significant percentage of the African population, and which prevent the achievement of the world’s goals for education. This intervention would make it imperative for Africa’s education system to embrace the principles of sustainable development, both for students who attend formal education as well as for the millions of students who never enter the place called school and yet are members of society. Both formal and informal science education has much to offer in helping to develop and strengthen student and citizen life-skills in areas that would help society progress on implementing pathways to new and more sustainable ways of living in harmony with Planet Earth.

Relevance of Science Education

One of the most discernible trends in science education worldwide is the declining number of students going into science and science-related careers. For example, in South Africa a demonstrably low percentage of all post-secondary education degrees are in mathematics, science or engineering. South Africa’s ratio of scientists and engineers to the population stands at 3.3 per 1000 compared with 21.5 per 1000 and 71.1 per 1000 in
the US and Japan respectively (National Research Foundation Report, 2005). The situation is worse in most other African countries as they struggle to address a variety of challenges with their educational systems. Collectively these challenges are regarded as a crisis of relevance. From a science education perspective, one can regard this crisis as a failure to meet the needs of both students and society in a rapidly changing environment.

Science remains one of the most important subjects in the school curriculum. But the science education curriculum has failed to excite students for at least two reasons. First, it is frequently taught as rote memorization of complex facts and abstract or meaningless data, which in a sense is antithetical to the visceral-driven way we live and interact with our world. Secondly, science educators have failed in their social responsibility to provide students and the general public with an understanding of science as it is today, especially in terms of its history, its powers and limitations (Kyle, 2006; Ziman, 2000). Students are not provided opportunities to ‘see’ the relevance of studying science at school and beyond. The teaching of science has gradually become isolated from society. Various studies have established that learners do not perceive the study of science as being relevant to their lives. This lack of appreciation of the relevance of science could be attributed to the way science is taught. The ideas and major conclusions of science play important roles in many of the decisions that humans have to take with regard to contested socio-scientific issues. But given the way science is now taught, it would hardly be surprising if any such issues are presented in ways that include moral issues. Bowers (2001) has questioned the wisdom of treating education in the sciences as entirely separate from moral issues. Science educators engaged in the STS movement of the 1980s would certainly concur. Solomon and Aikenhead (1994) capture the commitment of STS curricular innovations to social responsibility, moral responsibility, empowerment, critical thinking, problem solving and decision making. Similarly, Cheek (1992) presented a model for STS curriculum development in science, social studies, and technology education, along with a constructivist research agenda for STS education. The recommendations for a research agenda were comprehensive and insightful, yet the community of science educators engaged in STS education never really advanced the agenda. Cheek (1992) warned science educators that efforts to promote scientific or technological literacy must be more than slogans. His desire was for such efforts to translate into worthwhile research and development strategies that could move the entire debate forward in more promising directions. Regrettably, many curriculum resources were developed to support STS approaches, yet macro-structures such as regulations concerning the use of high-stakes tests can leave science teachers with feelings of being disempowered and having to teach towards the test (Tobin, 2009).

Science courses from elementary through undergraduate studies continue to be structured and taught from the perspectives of an uncritical acceptance of logical positivism, and to a large extent as a mastery of abstract concepts and principles, rarely explicitly linked to real life experiences (Kyle, 2006; Onwu, 2000). The link between science education and “real world” experiences is almost always tenuous in the minds of present day science learners. The failure of science educators to develop curricular connection between science and the day-to-day lived experiences of learners is likely to obscure and diminish the relevance of science in their lives (Onwu, 2000). Students’ dwindling interest, low
motivation to learn, and poor performance in science can all be attributed to the lack of recognizable relevance of science teaching by learners. Science education ought to move progressively towards a real world, context-based approach to the teaching and learning of science at all levels of the school curriculum (Holbrook, 2009).

**The Meaning of Relevant Science Education**

It is appropriate to try to establish a working definition of relevant science education, particularly in the context of promoting education for sustainable development. This is because notions or concepts of sustainable development are far reaching and have varying meanings / purposes in the minds of students, teachers, citizens, scientists, or politicians. An example of a curriculum policy document that explicitly acknowledges the significance of discourses other than that of orthodox science is South Africa’s national curriculum policy for natural sciences. It states that “The Natural Sciences Learning Area deals with the promotion of scientific literacy. It does this by:

- the development and use of science process skills in a variety of settings;
- the development and application of scientific knowledge and understanding; and
- the appreciation of the relationships and responsibilities between science, society, and the environment” (Department of Education, Pretoria, 2002, p. 4).

The document elaborates on each of these three aspects of scientific literacy, synthesizes their intended meaning in three broad learning outcomes, and provides an extended discussion of how the three components can be assessed. The third outcome, described as “challenging, with potential to broaden the curriculum and make it distinctively South African” (p. 10), is of special interest because it includes attention to relationships between science and traditional practices / technologies as these relate to traditional wisdom and knowledge systems. “One can assume that learners in the Natural Sciences Learning Area think in terms of more than one world-view. Several times a week they cross from the culture of home, over the border into the culture of science, and then back again. How does this fact influence their understanding of science and their progress in the Learning Area? Is it a hindrance to teaching or is it an opportunity for more meaningful learning and a curriculum which tries to understand both the culture of science and the cultures of home?” (p. 12).

In the context of schooling, relevance implies here the use of community or community-based resources and the incorporation of local issues and practices into the science curriculum (Holbrook, 2009). Thus, context or issues based learning is seen in the eyes of the student as something useful, worthwhile, meaningful and important. We believe relevant science education has much to offer in promoting intrinsic motivation for self-involvement and self- and social-empowerment.

Malcolm, Gopal, Keane, and Kyle (2009), in collaboration with two rural communities in South Africa, sought to investigate what the communities considered to be ‘relevant science education.’ The nature of the research question and the researchers’ commitment to human rights and democracy rendered transformative action research an appropriate
orientation for their inquiry. They found their initial open-ended approach was rapidly directed to action when they asked in a community meeting: "What is relevant science?" Malcolm et al. (2009) report participative processes led to conceptualisations of relevant science education centred on community development (economic and social), school community collaboration, and project-based learning. Through a series of community meetings and workshops, a project focused on sustainable agriculture, health care, HIV/AIDS, the creation of markets, and the ability to create employment was articulated. Community members were also interested in gaining access to computer skills and the knowledge such information technologies can make available to high-poverty rural communities. The idea of villagers, researchers, teachers and children learning through projects arose by interpreting the stated needs and aspirations and translating them into a design to address those concerns and be culturally congruent. The idea emerged that curriculum development should be embedded in community development, via school-community projects. It was a way of bringing together education and development, school and community, research and action, and accepting the community's observation that relevant science education would surely do something about poverty in the village.

**The Meaning of Sustainable Development**

If we were to ask the ‘person on the street’ the meaning of sustainable development we would likely hear a variety of responses, ranging from the ways in which individuals might contribute to sustainable development to current and emerging global issues. The responses might also reflect a range of emotions. This is simply because sustainable development is a complex, multi-faceted concept, which according to Ratcliffe and Grace (2003) combines aspects of environmental protection with social equity and the quality of human life. The two most commonly quoted definitions are as follows:

*Sustainable development (means) improving the quality of human life while living within the carrying capacity of supporting ecosystems.* (UNEP / WWF 1991, p. 211)

*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.* (WCED, 1987, What is Sustainable Development section, ¶1)

Sustainable development is therefore essentially about the simultaneous struggle for balance, for harmony between environmental protection and economic development. These definitions are not without their critics. They have been considered somewhat inadequate or out of tune with the process of education, particularly science and technology education (Holbrook, 2009). Be that as it may, it would be worthy to consider the meaning of relevant science education in the context of sustainable development. Thus, the two definitions derived from development principles suggest a relevant science education for sustainable development may be construed as an education that:

*...enables people to develop the knowledge, values and skills to participate in decisions about the way we do things individually and collectively both locally*
and globally that will improve the quality of life now without damaging the planet for the future. (DETR, 1990, p. 30)

One might reasonably ask, “What does this look like in practice?” In a collaborative research project oriented toward social responsibility and sustainability, Sinnes, Kyle and Alant (2010) indicate Project SUSTAIN students seem to have a very clear understanding of what they see as a socially responsible SMT education. According to the students in Project SUSTAIN, a socially responsible SMT education would have to:

- respond to the challenges in the environment where the pupils live;
- empower people and transform their lives;
- be rooted in their cultural context;
- echo the needs of the pupils, be creative, and teach pupils to become creative;
- provide democratic spaces for learning;
- teach pupils not only to understand, but to act;
- be responsive to the environmental threats and teach individuals to act in a way that does not destroy the environment; and
- teach pupils to act responsibly.

Thus, a relevant science education for sustainable development is that which is intended within the school curriculum to maximize the socio-cultural relevance of science education in helping learners to achieve the goals of sustainable development.

Some Remaining Issues: Socio-scientific Issues and the Curriculum

Over the past 100 years or so, science has been progressively inserted into the school curriculum. Yet, its original purpose (that of preparing students for University studies) has remained the determinant of the content and pedagogy (Holbrook, 2009). Many science educators have asserted the science content for learning still carries a strong conceptual tone characterizing science preparation for an elite group, ignoring the wider complex of socio-cultural and political factors that influence the ways schooling is structured for the benefit of some students more than others.

Scientists have come a long way from the ivory tower and many scientists nowadays are well aware of societal needs and constraints associated with the nature of their inquiry. Research activities have emerged focusing on sustainability sciences and interdisciplinary research groups are working on such issues as health care, sustainable agriculture, food security and food production. However, even though it has become important to demonstrate the value of research, this value is often still expressed in economic terms. How can we incorporate societal issues and a focus upon present-day innovative research agendas in science and technology education? Where in the curriculum should socio-scientific issues be located and how can the curricular support for such teaching be provided? These are some of the challenges as we strive to create opportunities for interdisciplinary learning in the sciences. On March 5-6, 2009, the first in the series of Biennial Conferences on Human Security in Africa transpired with a focus upon how agriculture, education and health can be leveraged to enhance human security in Africa.
The resulting edited volume offers a valuable first step toward addressing the issues of importance while offering recommendations for policy formulation and implementation (Obasanjo, Mabogunje, & Okebukola, 2010). Getting the balance right between a sufficient number of students going on to scientific and technological careers and providing all students with enough motivation and knowledge of science and technology to appreciate the importance of those subjects in society is perhaps the major educational issue facing all countries today (Holbrook, 2009).

We believe the aims of school science need to be examined with respect to sustainable development. We have implied that science education for sustainable development is essentially the province of science teachers and science educators. However, in practice, the situation is not always that obvious. Although consideration of socio-scientific issues involves many facets, some writers have argued that given their particular educational background science teachers are not necessarily well equipped to teach about society and social issues. Rather they are better placed to focus more on the features of the scientific enterprise and the strengths and limitations of science. While there may be some considerable sympathy for that view, Ratcliffe and Grace (2003) have suggested that the subject structure of the curriculum could give rise to two extremes:

- Learners consider socio-scientific issues in lessons other than science, essentially for developing skills of reasoning, communicating and analysis, and yet not necessarily appreciating the strengths and limitations of scientific processes and content in addressing the issue. Thus, science lessons can be seen as devoid of social context and unrelated to topical sustainable development issues say.
- Learners consider socio-scientific issues in science lessons, used in developing skills of reasoning, communication and analysis and appreciating the strengths and limitations of scientific processes and content in addressing the particular issue. Thus the demands on the science teacher or educator and the science curriculum become integrated and all-embracing.

Because socio-scientific issues straddle the formal curriculum, the issue of the extent to which socio-scientific issues are the province of science education or humanities education is always a point of debate and discussion. However, given the need for both students and citizens to be able to participate in socio-scientific discourse, the question arises: In what ways should science curriculum be connected to issues associated with sustainable development, particularly in Africa, so as to make science teaching more relevant, meaningful and accessible to learners?

O'Donoghue (2010), grounding his work in Bhaskar's Critical Realism, searches for a more refined lived world perspective for engaging modern science as a source of object congruent tools to mediate difference by probing cases of situated learning and change. "We have now reached a stage that the conditions of our times are cut through by risk and fear for future sustainability. This is driving a curriculum of fearful alienation and wrath with little chance of redemption because the necessary change is complex, contested and unclear. Critical realism redirects an ontology of intergenerational being in the world, potentially allowing us to reduce the current ontological terror at the heart of problem /
issue-centred environment and sustainability education, pointing to a methodological move from taking problems to children to a curriculum of engagement in sustainability practices for the common good O'Donoghue, 2010, p. 63).

Interestingly enough, a consistent message from proponents of cross national science achievement surveys, such as TIMMS, is that science education will be transformed by implementing norms and standards that assess students’ technical knowledge and engaging them in such cross-national comparisons of science achievement. Such views have come under criticism and are currently being challenged. For example, Kyle (2006) argues that such international comparisons tend to invoke a narrow image of science by emphasizing more the technical interests of the empirical-analytical sciences at the expense of the practical and emancipatory interests of the hermeneutic-interpretive sciences. Moreover, it neglects the fundamental issues of the place of science in the larger social context and fails to acknowledge the political situatedness of science. In essence, students and citizens alike have been denied access to the social and political process of science. Similarly, O'Donoghue (2010) addresses the situating primacy of cultural practice for meaningful learning with epistemological access in modern curriculum settings. He notes an inadequate sense of the primacy of the mediating cultural preconditions in meaning-making interactions that appear to have produced a pedagogical barrier of cultural exclusion, the reification of concepts ordered in detached hierarchies accompanied by a process reduction in science (empiricism as the scientific method). He asserts the latent exclusion of being in the world has constituted science as a field of detaching exclusivity where expert communities of practice mediate the induction of others. Currently, expert mediation to induct modern African children is failing with scientific abstractions proving of little relevance and the field being inaccessible to all but the elite.

Drawing on the experiences of community activism for sustainable development (e.g., Malcolm et al., 2009; O'Donoghue, 2010), we argue for the introduction of novel pathways that link science education to the goals of sustainable development. If formal education is about eliciting and expanding upon the existing knowledge and life experiences that learners bring to classroom situations, then a universal image of science as opposed to a contextual one of science has to be untenable. Learners come into the science classroom with different background experiences and worldviews. Education in science must be contextualized and linked to the life world experiences of the learners, while taking into consideration issues of locality, interest, and cultural values. Thus, engagement with sustainable development issues will only become meaningful when students see the issue as relevant and important. Such an education in science will facilitate the emergence of a far more reflective, relevant and insightful science education provision for sustainable development.

**An Agenda for Action**

In order to integrate the goals of sustainable development into science education, there is a need to widen our vision beyond the content and process aims of science teaching and learning, and expand our view of the goals of science education. What is needed is a shift
of emphasis of science education from one bound by subject matter headings - from learning science as a body of knowledge to learning science linked to contextual realities of life and living. An important reason for this shift is the apparent isolation of many science curricula that are quite divorced from such a perspective.

Greene (1995) emphatically states the main point of education in the context of a lived life is “to enable a human being to become increasingly mindful with regard to his or her lived situation - and its untapped possibilities” (p. 182). Science is a human activity. The values of science are therefore human values. As Bronowski (1956/65) posits, the strengths of science and its safeguards rest predominantly on principles of freedom, notably, free inquiry, free thought, free speech and tolerance, all of which are the hallmarks of respect of human rights, freedom, and democracy. Learners ought to be afforded the opportunity to exercise such principles in the process of learning science. It is through experiencing such an education in science that they are also able to embed themselves in what is referred to as a “web of human relationships” (Arendt, 1985, p. 183), thus enabling the teacher to integrate issues of sustainable development, free speech and critical discussions into the curriculum.

In reflecting about the appropriate curriculum for relating science education and issues of sustainable development, we are drawn to the publication, *Beyond 2000*, a Nuffield Seminar Series report that has proved influential in shaping some of the directions of the UK science curriculum. The outcome of *Beyond 2000* spells out the aims of the science curriculum, which includes that students should be able to:

- appreciate why the important ideas and explanatory frameworks of science are valued;
- appreciate the underlying rationale for decisions (for example about energy use, or medical treatment or ) which they may wish or be advised, to take in everyday contexts, both now and in later life;
- understand and respond critically to, media reports of issues with a science component;
- feel empowered to hold and express a personal point of view on issues with a science component which enter the arena of public debate, and perhaps to become actively involved in some of these;
- acquire further knowledge when required either for interest or for vocational purposes. (Millar & Osborne, 1998)

Such aims resonate with our vision of the very ways in which science education can be connected to issues of sustainable development. They also imply that the teaching approaches should be consistent with giving students opportunities to experience the hermeneutic or interpretative sciences in the context of their formal schooling, in ways that are self-involving, transformative, and emancipatory (cf. Kyle, 2006).

Although researchers and policy makers may not always agree as to the appropriate content in science education for sustainable development, the balance of appropriate curriculum content is dependent upon the perspective of any society’s purposes or goals.
of science education (Law et al., 2000). Tilbury (1995) provides support to this integrative approach of linking the discipline of science education to contextual realities of life and living relevant to the learner. The societal and personal well-being priorities have some overlap with science education for sustainable development. With this inclination for relevance, there is an increasing recognition that science education should be fostering engagement with goals of sustainable development in various domains such as health and environment, poverty alleviation and economic prosperity, conservation of nature and erosion eradication, stewardship and civic responsibility (cf. Kyle, 2006).

Conclusion

In conclusion, for too long science education has been disassociated from the contextual realities of life. This leads us to ask, "Why have science educators not regarded education as a primary means of investing in human resources and for promoting development?" Science education classrooms ought to be permeated by socio-scientific themes, if indeed we wish to prepare future citizens able to deal with complex everyday issues. This is not a modest goal. We must begin to prepare students who will act as informed and responsible citizens when faced with issues related to sustainable development. After all, the goals of sustainable development are premised on a scientifically literate citizenry.

On December 24, 1968, Frank Borman, Jim Lovell and Bill Anders – the three person crew of Apollo 8 – were the first people to orbit the Moon, they were the first people to lose complete contact with their own planet, and on their fourth orbit Commander Frank Borman rolled the aircraft away from the moon to complete a navigational fix and as the windows tilted toward the horizon there was a sudden view of the Earth, rising. They were the first to see the image later to become known as "Earthrise." That image of Earth rising in the vast darkness of space over the landscape of the Moon has offered inspiration to everyone who has seen the picture for over 40 years now. Seeing our home from space, realizing it is the only home we have, and that we had better care for our planet offers the inspiration to do so. The image from space spawned environmental movements and awakened a public consciousness with respect to the fragility of a planet that seems so immense to the residents who live there, but so small when viewed from the close proximity of its natural satellite.

McKibben (2010) aptly declares, "But we no longer live on that planet" (p. 2). He notes that in the four decades since that magnificent picture, Earth has changed in profound ways. He asserts "we imagine we still live back on that old planet, that the disturbances we see around us are the old random and freakish kind. But they're not. It's a different place. A different planet. It needs a new name. Eearth" (p. 2). Are we ready to take up the challenges of this new planet? In the process, science educators must contribute in meaningful ways to creating the infrastructure for the world that comes next. After all, that is what educating for sustainable development is really all about.

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Effective teaching of science: why what matters is the teachers’ classroom language

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Abstract

The choice of which language to adopt for learning and teaching remains an issue for heated political debates in many countries perhaps on the fact that students learn better in...
their first language. In science education research, the attention so far given to role of the language of instruction has been only with regard to the impact of levels of student proficiency in the language, especially where students have to learn in foreign languages. While clear benchmarks or indicators for satisfactory proficiency for successful learning to occur still remains elusive, this article, presents critical analyses of findings in research studies of students’ difficulties with everyday English words common in science texts and in the classroom language typical of science teachers to highlight the general difficulty of the language of science texts and as used by science teachers during classroom instruction. Implications for effective science teachers’ classroom practice and research on language in science education are considered.

**Introduction and Overview**

“What kind of science can a child learn in the absence, for example, of basic language competence and an attendant inability to handle concepts?” (Achebe, p. 162)

Africa is the only continent in the world where formal education is generally conducted in instructional languages that are foreign to most learners and their teachers. The continent has in this regard been balkanised into Anglophone, Francophone and Lusophone states, to refer to the European (former colonial) languages, English, French and Portuguese respectively. In the special case of Tanzania, the balkanisation may be referred to as a ‘Swahiliphone’, for the special reason that Swahili, the mandatory language of primary school education but - though unofficially - also used widely in secondary and higher education, is neither a local language nor the first one to all students and their teachers. Swahili is therefore also a foreign language to most students and teachers in Tanzania; it however is an African language. A common argument has been that all the foreign languages of European origin were retained at independence as the official as well as classroom instruction languages for economic and political reasons. It is also an acceptable argument that the retention of the languages must have been dictated by circumstances that were prevailing at the time in respective African countries. In the case of Kenya, although English was adopted on the recommendation of the first Education Commission popularly known as the Ominde Commission, the logic may have been that at the time,

...English was [already established as] the language of the entire secondary education system, of university, in large part, of the press, and of many other sectors; it was also the language of much creative writing, and of effective public debate, whether in ...scholarly writing and so on. It was for the time being, the main language of communication with outside ideas, whether in East or West, or indeed in other parts of Africa... not...that this was desirable or that it ... be perpetuated or protected... this was a fact. (Ogot, 2003, pp. 171 – 172; italics my addition)

While this same argument may have been used in adopting French and Portuguese in the respective African countries at their attainment of independence, the case for Swahili in Tanzania was purely a political one. Arguably, adoption of Swahili as the language of formal education in Tanzania in 1967, several years after independence, was so that the country became fully liberated from colonial influence (Kadeghe, 2003). The
current state of Swahili in Tanzania is such that the logic as so far presented, for adoption of English in Kenya, but in reference to Swahili is very relevant. In other words, all arguments should be for adoption of Swahili as the sole instructional language at all levels of education in Tanzania (Brock-Utne & Holmarsdottir, 2003; Brock-Utne, 2005; Prah, 2003; Roy-Campbell & Qorro, 1997). The global trends in the popularity of English (Newsweek, August 20/27, 2007) and need for easy international communication would be the major issues in the ongoing debate for the need to adopt English instead, as the instructional language at all levels of formal education in Tanzania. In the African countries where English, French and Portuguese are already the languages of formal education, it is apparent that they may continue to be used at all professional and academic levels because of their global presence and attractiveness in international communication. With Swahili also being a generally foreign language even to most Tanzanians, it follows that most students and their teachers in Africa will continue to use foreign languages as instructional languages in formal education. Hence, the requirement for the students in African countries to achieve proficiency in whichever is the classroom language of instruction, as a necessary first step for effective learning of school subjects to occur will continue. More than students who learn in their first languages therefore, and at least at the initial stages of learning, students in Africa will continue to experience greater difficulty due to the double task of learning two new things - language of instruction and for example, science - at the same time. Despite the assumption by many (including teachers) in multilingual societies, that once proficiency in the instructional language has been achieved, then students’ would be able to understand everything taught them (Rollnick, 1998, 2000), learning of most school subjects, including science requires more than simple proficiency in the language of instruction (Wilson, 1999). In this chapter, the focus is on the instructional language as used by the science teacher based on the role of language in all learning (Vygotsky, 1986) including school science (Scott, 1998) and the now well recognized need for teacher intervention in the learning of school science (Driver, 1989; Hodson & Hodson, 1998; Hodson, 1999). The chapter is in three main parts. Firstly, the components and nature of the language of instruction as used in science texts and by science teachers in classrooms are discussed. Secondly, a critical review of research-based evidence of possible universal difficulty of this language is presented. Thirdly, the approaches to going round the difficulty and foreignness of this language via, in particular, effective classroom use of language by science teachers and necessary research on language for/in science education are considered. The particular focus on science teacher’s language is because this author regards the science teacher as the foremost resource in students’ effective learning of science. However, based on the variety of resources or sources of school science knowledge to the student, the term ‘science teacher’ is considered to embrace and subsume the term, ‘science texts’ as a resource or an alternative source of the ideas of school science. Hence, teacher’s (classroom) language as used in this chapter refers to the science teacher’s oral language as well as the language of science texts. Although the instructional language in particular focus in the discussions in this chapter is English, these discussions are meant to generally apply to any instructional language in use.

The Components and Nature of Science Teachers’ Language

The classroom instructional language the science teacher and in science texts has
two parts: technical component and non-technical component.

The Technical Component

The technical component is made up of technical words or terminologies specific to a science subject, for example, ‘chromosome’ in biology, ‘capacitance’ in physics, or ‘anion’ in chemistry. Such terms may also be referred to as technical terms, scientific terms/terminology, science terms or simply science words. Technical words as originally argued by Gardner (1972) “…include such things as physical concepts (mass, force…) names of chemical elements, minerals, plants, organs, processes, apparatus etc.” (p. 7). The technical/science words are everyday words deliberately used as science words (Miller, 1999) and have new (scientific) meanings in addition to their everyday meanings (Sutton, 1992; Wellington, 1994). The new and different meanings everyday words acquire when used as science words, and/or when they become science words make them resemble words in a new, different or foreign language, though with fixed meanings. Regardless of the base language, the meanings of these words must be as known in the international science community circles. Therefore, apart from representing science concepts (Murphy, 2002), science words are also representations of words in a different and/or foreign (science) language.

The Non-Technical Component

The non-technical component of the science teachers’ classroom language is made up of non-technical words. It is this part of the science teachers’ classroom language that may be referred to as the medium of classroom instruction or interaction as separate from the technical terms. This component of the science teachers’ classroom language thus becomes recognisable to be the same as the language in which a science text book is written. Gardner (1972) used the following sentence to illustrate examples of non-technical words: that “gas molecules display random motion; we may predict their behaviour from theoretical considerations: the actual volume of the molecules may be neglected” (p. 7). The four words: random, predict, theoretical and neglected, though not ‘technical terms’, remain key words in the sentence, with regard to the understanding of the behaviour of the gas molecules, on the assumption that the meaning of the (technical) term molecule is known to the learners. In science education research literature relevant to this article, it is words like these that in particular, have been referred to as ‘non-technical words in the science context’ (Wellington & Osborne, 2001). This apparently has been to distinguish them from the metarepresentational terms (Wilson, 1999) and logical connectives (Gardner, 1977), two other groups of words, considered here as distinct categories of non-technical words. The non-technical component of science classroom language of instruction/interaction therefore consists of three categories of non-technical words, namely non-technical words in the science context, metarepresentational terms and logical connectives. Highlighting the boundaries between these is of interest.

The ‘non-technical words in the science context’, as part of the language typical of science subjects, may be considered to constitute a language characteristic of school science. For example, the word ‘diversity’ is more common in biology, ‘reaction’ is more
in chemistry than in physics, just in a similar way ‘disintegrate’ would be more acceptable as a standard word when referring to the concept of decay of an unstable nucleus in physics. The words ‘diversity’, ‘reaction’ and ‘disintegrate’ are recognizable as words also commonly used in everyday language, but become “specialist language” (Barnes, Britton & Rosen, 1986, p. 46) only when used in science to constitute the register of the science subject. Each of these words embodies certain concepts important to the process of learning specific science subjects; this is unlike when everyday words are used as science words, when they become distinct science concepts as already considered here.

The metarepresentational terms specifically, refer to the non-technical words that signify thinking; these include metalinguistic and metacognitive words as defined next. According to Wilson (1999), “metalinguistic verbs are words which take the place of the verb to say (e.g. define, describe, explain, argue, criticize, suggest), while the metacognitive verbs are words which take the place of the verb to think (e.g. infer, calculate, deduce, analyse, observe, hypothesize, assume, predict)” (p. 1069). Evidently, metarepresentational (metalinguistic and metacognitive words) terms constitute the same words which are associated with learning and ‘talking science’ (Lemke, 1990), such as observe, hypothesize, experiment, classify, analyse, conclude, deduce, interpret, define, investigate, and infer. It is these words, often used in examinations to indicate the content as well as the structure and emphasis required by the examination questions that Bearne (1999, p. 62) and Bulman (1986, p. 188) have respectively, recognised as the “key terms” or “operative words”. The value of these words therefore is in the fact that knowledge of their meanings may enhance students’ understanding of the demands of the questions and to accordingly, design the correct responses (Bulman, 1986); students’ understanding of the meanings of these words may also be expected to enhance their classroom participation (Rodrigues & Thompson, 2001).

Logical connectives, according to Gardner (1977), are “words or phrases which serve as links between sentences, or between propositions within a sentence, or between a proposition and a concept” (p. v). Examples include conversely, if, moreover, because, therefore, in order to, consequently, by means of, since, etc. The importance or functional value of logical connectives as may be evident from these examples, is that they are words that, according to Fensham (2004), “are commonly used in the oral or written discourses of science to link observation to inference, theory to explanation, hypothesis to experiment, experiment to findings etc” (p. 202). Again, students’ understanding of the meanings of these words would enhance their classroom participation as well as the understanding of the processes of learning science, including science teachers’ classroom language.

General Difficulty of the Science Teacher’s Language

Research studies have shown that all categories of words that comprise the entire/total science teacher’s language are generally difficult.

Difficulty of Words in the Technical Component of the Classroom Language
George (1999) has recorded that the general difficulty of school science, hence science content as is well known world over, vary in extent, depending on the specific circumstances in different countries. In this article, this general difficulty is argued on the foreignness of science words/language or technical terms used in science. While most arguments of the difficulty of school science have always made a claim on the difficulty of the science content matter, the foreignness of science to learners is also a very important factor as can now be explained. The fact that any science word has a meaning different to that in everyday language is one reason such words can be viewed as representations of a different, new or foreign language. The use of these words therefore comes with a way of speaking very uncharacteristic of the common/dominant culture; the science words/language therefore also represents a different culture – the (foreign) science subculture. Science words may therefore be considered to have a triple identity (conceptual, cultural and linguistic).

The origin of the general difficulty of technical words interchangeably referred to as science words, science terminology or science content is this aspect of general foreignness. The foreignness of the science words may also explain the gap that exists between the students’ world and the world of science they are meant to learn (Lemke, 1990; Jones, 2000). Yet this general difficulty of science words/content is only part of the difficulty of words that comprise the science teacher’s instructional language.

As revealed in the reviews of empirical research in the next section, all categories of non-technical words, just like with the science words, are also generally difficult; evidence is presented that the general difficulty of non-technical words is irrespective of the linguistic and cultural circumstances of the science learners.

**Difficulty of Words in the Non-Technical Component of the Classroom Language**

In this section, a critical review of the general difficulty of all categories of non-technical words in the science teacher’s language, with the distinctive focus on the influence of students’ proficiency in the language of instruction (English) on levels of students’ understandings of the words is conducted. This has been done in the order, non-technical words in the science context, metarepresentational terms and logical connectives.

**Student Difficulties with Non-Technical Words in the Science Context**

With regard to non-technical words used in the science context, there have been several cross-national studies, all of which have been based on Paul Gardner’s pioneer study (Gardner, 1971). In this first project that was conducted in Papua New Guinea, (Gardner 1971, 1972), Dr. Paul Gardner studied the accessibility of 599 normal English words using a sample drawn from secondary school students in Forms 1-4 for whom English was not the first language. Tests were administered in the form of multiple-choice items. Examples of the four common formats in which the words were represented are given here for the word ‘effect’:

1. A **synonymous** expression without context e.g.

   ‘Effect’ can mean
2. The word appears in a sentence describing an everyday event, e.g.

Which of the following sentences used the word ‘effect’ correctly?

a) The teacher could not effect the work of the pupils
b) The effect of heat on water was that it boiled
c) It took considerable effect to move the large rock
d) He thought his smiling would effect everyone

3. The word appears in a non-science context stem, e.g.

Putting the car brakes on had no ‘effect’. This means the car

a) stopped
b) did not stop
c) went faster
d) skidded

4. The word appears in a science context stem, e.g.

If you were asked to find the ‘effect’ of adding acid to a metal, this would mean you would try to find

a) the reason for adding the acid
b) what happened
c) how long the reaction took
d) the quantity of acid used

The study was not to compare but just to detect levels of difficulty the non-technical words presented to students of science. In the analysis, items were summarised in three ways:

- Alphabetical order: list containing all words tested in alphabetical order, with a brief description of the item, and the percentages correct, for each form level, and for the total sample.

- Level of difficulty: words were grouped into difficulty levels on the basis of the percentage correct in the total sample. Level 0 words were items on which the scores were 100% correct; level 1 words appeared in terms on which 90-100% were correct; level 2 words represented 80-89% correct and so on.

- Test item list: presented all items used in the project: the percentages selecting each distractor within each form level and within the total sample were shown for each item.

In this first study, three words: disintegrate, random and spontaneous stood out as the most difficult to the students, more to the Form One students with only 10-19% of the
sample scoring correctly on these words. As a summary, 31%, 26% and 25% of the whole sample scored correctly on the words *spontaneous, disintegrate* and *random* respectively.

Two other studies by Gardner using the same design and for the same objectives were conducted using the same test items in Victoria, Australia (Gardner, 1972), and later in the Philippines (Gardner, 1976). While in both cases, participants were drawn from class levels/Forms I, II, III, and IV, all the participants were science students who used English as their first language in the case of Victoria, while those who participated in the Philippines study were students who learned science in English as their second language. Both studies revealed similar trends in the understanding of the non-technical words, with differences that were a reflection of relative linguistic circumstances specific to each of the countries. If comparisons on the levels of performance were made, it could be concluded that the second language sample (Philippines) did poorer, i.e. encountered more difficulties with the non-technical words in the science context, than the first language sample (Victoria).

Although several subsequent studies have been conducted (Oyoo, 2004), the only Farell and Ventura (1998), Prophet and Towse (1999) and Oyoo (2000) studies have not used the four-test design, or mainly English first language (L1) samples. The Farrell and Ventura (1998), Prophet and Towse (1999) and Oyoo (2000) studies on the other hand, focused on different categories of learners at different levels of schooling. Farrell and Ventura (1998) for example focused on non-technical words as used in a specific school science subject – physics. Prophet and Towse (1999) compared performance on these words in different countries and by first and second language learners simultaneously, drawn from a developing country (Botswana in Southern Africa) and a developed country (United Kingdom). The Oyoo (2000) study also drew its sample from both first and second language learners, but from Kenya and England (United Kingdom, UK).

The types and trends in the findings in all the studies of students’ difficulties with every day words presented in the science context have been very similar irrespective of design and gender. The trends in the difficulties encountered by students have also been regardless of whether a student learns science in English as the first or second language. A summary of the types of difficulties is now provided,

Students selecting words whose meanings were opposite to those intended in the studies. For example, *negligible* for *a lot*; *random* for *well ordered*; *initial* for *final*.

For many words, the students lacked the required comprehension and often confused words with others in the same semantic field, e.g. *detect* with *project*; *isolate* with *insulate*; *reference* with *referred*; *theory* with *fact* or *belief*.

It was also common that students confused words with ‘graphologically’ similar (Gardner, 1972), i.e. ‘look-alike’ (Cassels & Johnstone 1985, p. 14) or ‘phonetically’ similar (Gardner, 1972), i.e. ‘sound-alike’ (Cassels & Johnstone 1985, p. 14), ones e.g. *complex* with *compound*, *consistent* with *constituent*, 460
component with opponent, detect with protect; accumulate with accommodate; diagnose with diagonal; proportion with portion.

The study by Pickersgill and Lock (1991) detected no difference between the understanding of non-technical words in science by males and females; no difference between the verbal reasoning ability of males and females, but found a positive correlation between a student’s score on a verbal reasoning test and on a test of understanding of non-technical words in science. The finding on verbal reasoning, 1) may be taken to imply that proficiency in the language of instruction may enhance better understanding of scientific concepts; 2) could also be a reflection of the different levels of intelligence and/or relative aptitude towards the subject. These explanations were not considered in the study. In all the four-test format designed studies, it was noticed that the best performance has been in the test where the words were presented in the science context and the lowest performance was on the synonym test. Pickersgill and Lock (1991, p. 77) who used a first language sample have explained this as follows:

… In the sentence, science and non-science format questions, the word under test is placed in a context which may carry sufficient information to give a cue or trigger to the student. In the synonym format this information is missing and it may be the absence of such cues which leads to the poor performance on this type of question compared with others.

According to Marshall, Gilmour and Lewis (1991), the better performance in the test that had the words in the science context stem was because it is in this science context that the students first learnt the words; they concluded this by making comparisons with the Cassels and Johnstone (1985) study that used an exclusively first language sample:

… although Cassels and Johnstone (1985) regard the words in this test as normal English, the results of this study indicate that for the Papua New Guinea students, this is probably not the case. For approximately 20 of the words the results would seem to indicate that students acquired the meanings in science classes. (Marshall & Gilmour 1991, p. 334)

In the Marshall, Gilmour and Lewis (1991) study, an additional observation was that the words were easier when presented in the science context stem to students in Papua New Guinea, themselves English second language learners, than was the case in the United Kingdom studies by Cassels and Johnstone (1980, 1985). This confirms that everyday words have different meanings when used in the science context. This may be justified in the fact that although these studies claim an overall improvement in the relative scores in the higher (older) classes, a scrutiny of scores on the items does not reveal a linear trend. Scores on individual items were either better or worse in the higher or the lower class levels. The greater difficulty that the synonym type test presented even English first language samples indicates that the non-technical words may not have been those common in the world outside the school (Ariza, Webb & Marinaccio, 2007; Mason & Mason, 1996; Rolstad, 2005).

**Student Difficulties with Metarepresentational Terms**

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No empirical study in the literature has specifically reported students’ difficulties with metarepresentational terms. Reference to confusion caused by two everyday words *describe* and *observe* (Cleghorn & Rollnick, 2002; Peacock, 1995; Clark, 1997) may be taken as evidence of the possible difficulty of the two words; *describe* and *observe* belong to this group of non-technical words. However, the difficulties students encounter with these terms may be argued on the fact that low outcomes in science examinations have been alleged to have its origin in students’ poor understanding of these terms. Comments in the Kenya National Examinations Council (KNEC) Reports of 1990 through to 2002, in the subjects: chemistry, physics and biology for example, would suffice in this regard. In Kenya, English, a second language to learners and teachers alike, is used in all teaching and assessment. Evident in the following comments, students’ low outcomes in these subjects may, among other reasons, have been consequent on their having encountered difficulties with the meanings of these words. Comments about poorly performed chemistry paper revealed students’ difficulties with the words: *explain, comment, describe*

Teachers should make a deliberate effort to explain to their students what certain terminologies mean when used in questions. Such terminologies include, *explain, comment, describe* etc. This is because the kind of answers … indicated that the…candidates did not even understand what the questions were asking. (KNEC 1992, p. 97)

Students’ difficulties with *define* and *distinguish* are suggested in the following comment on performance on the physics examination question: *Distinguish between ductile and brittle material.* As reported in KNEC (1990), “the candidates could only *define* the terms but could not *distinguish* between them. Teachers should teach the candidates to differentiate between the terms *distinguish* and to *define* and such other terms used in physics (p. 41). Further evidence of student difficulty was reported with regard to *describe* and *account* on the 1997 and 1998 biology examinations, where it was apparent the students had encountered problems in the theory and practical papers because they lacked an adequate understanding of the meanings of the words. In Oyoo (2004, p. 199), the following students’ opinions have been recorded in support of these reports.

Student 1: If you don’t understand the meaning… of the words used in the topic … when these words are used in an exam, you will fail the paper because you do not know the word meanings.

Student 2: Lack of knowledge of the meanings of the words leads to time wastage during examinations because one takes a lot of time fumbling with the word meanings and then end up failing the exam just because of the meaning of a word.

In a first language context, Rodrigues and Thompson (2001) have reported a teacher’s reasons for explaining the meanings of these words to students during teaching on the basis of the fact that otherwise, students would confuse between the meanings of these words. Since confusion between the words has been a common source of students’ difficulty with everyday words as already reviewed above, these words may also be
difficult in first language contexts.

**Student Difficulties with Logical Connectives**

As Gardner (1977a) reports about the only major study conducted so far of students’ difficulties with logical connectives, his was “a project set to identify the more commonly used logical connectives in science, and to measure junior secondary students’ difficulties in comprehending the connectives” (p. v). The connectives that emerged as difficult are the ones common in science texts and in science teachers’ classroom talk (oral language); this is evident in the following groupings of related connectives (Gardner, 1977b).

Several connectives which indicate *inference* are difficult: *and so, consequently, hence, it follows that, therefore, and thus.*

A second group contains connectives involved in *generalisations:* *commonly, frequently, in general, occasionally and often.*

Several difficult terms signal *similarities, comparisons* and *contrasts:* *alternatively, as, at the same time, conversely, in contrast, in fact, in turn, much like, nevertheless, similar to, similarly and unlike.*

Several *apposition terms* are difficult: *for instance, i.e., in these examples, namely, that is and viz.*

Some students are unfamiliar with *additive* terms like *again, also, further, furthermore, in addition and moreover.*

Overall, three connectives: *conversely, if, and moreover* were found to be extremely difficult (mean item facility at Form IV less than 30 per cent).

Gardner (1977b, p. 11)

Although the study used an English first language sample, the emergence of a large number of difficult connectives, implies that teachers’ classroom language could be a challenge to all learners, irrespective of their linguistic backgrounds, if the connectives are used with no appropriate measures taken to assist students’ understanding of the connectives.

**General Difficulty of the Science Teachers’ Language – A Summary and Analysis**

The general outcome of the review is that students encounter similar types and trends in difficulties with these words of the science teachers’ language irrespective of whether they are females or males (their gender). The types and trends of the difficulties encountered are also irrespective of the students’ linguistic circumstances i.e. whether they learn science using their first language or not. The overall outcome of the review therefore is that the total language of instruction as may be used in science texts or by the science teacher (technical as well as non-technical words as broadly defined in this
article), present difficulties to students irrespective of their linguistic and cultural backgrounds. In other words, in addition to the difficulty to students of the words that have been referred to simply as non-technical words in the science context (Gardner, 1971), students also encounter difficulties with metarepresentational terms (metalinguistic and metacognitive words) and logical connectives. Despite the fact that these words comprise the entire non-technical component of the classroom (English) language of instruction/interaction, this overall outcome has now made it more apparent that science teachers’ language is generally a challenge to the all learners. The extent of this challenge to students who learn in English as their second language may be dependent on the students’ relative levels of general proficiency in the language of instruction. General proficiency in the language of instruction, for successful learning of science to occur is a necessary first step for meaningful learning in that language (Achebe, 1990).

The need for some level of proficiency in the language of instruction as a prerequisite for all learning, by those who have to learn in a foreign or second language therefore need not be overemphasised. Since the larger percentage of participant students in the studies reviewed here had English as their first language, what has now become apparent is that generally, there is need for caution in explaining students’ difficulties in learning science on their perceived levels of proficiency in the language of instruction. The general difficulty of the science teachers’ language in itself is therefore a strong support for the assertion that “every day words when used in a science context cease to be mere English words” (Marshall & Gilmour, 1991, p. 334). Consequently, what now needs to be emphasised, perhaps more than has been the case, is the fact that that learners need to be appropriately/contextually proficient in the language of the science classroom. The general difficulty of all categories of words in the language of the science teacher, whether written or oral, technical or non-technical therefore presents the linguistic face of the difficulty of school science. Drawing on the nature and functional value of these and other words that comprise the science teachers’ language, it becomes apparent there are other factors that influence students’ understanding of these words in addition to the students’ proficiency in the (English) language of instruction. Especially on the already fact that these words may also be representations of particular science subjects as well as embodiments of science concepts, students’ general ability or aptitude for science may also be expected to impact on the levels of understanding of the words.

**Addressing the Foreign Language Problem in Science Classrooms**

To reiterate, the role of language in all learning (Vygotsky, 1986) and the need for teacher intervention in successful learning of school science (Driver, 1989; Hodson & Hodson, 1998; Hodson, 1999) are now well established. Language, either as text prepared or presented by the teacher or science teachers’ own classroom talk, is therefore unavoidable in learning science. We should expect that students’ understanding of the meanings of all words in this language when used as science words and/or in science context would result in enhanced students’ understanding or internalisation of the concepts taught. Appropriateness of this language to the level of schooling and general background of the learners (as the teacher may be expected to know), may therefore be of utmost importance.
Teachers’ Approach to Classroom Use of Language as addressing the foreign language problem

Although teacher intervention in enhancing students’ understanding of the technical/ science words, or science terminology, is what has often been regarded as science teaching, the general difficulty of the science teachers’ language has suggested the need for equal attention to the meanings of the non-technical words as broadly defined in this chapter. The types of difficulties students encounter with words that comprise the teachers’ language have suggested aspects of teachers’ approaches to use of language in classrooms (vocabulary) that, though may not be receiving explicit attention, may serve as major sources of students’ linguistic difficulties when learning science. As implicit in the reviews of students’ difficulties with words in science teachers’ language, the classroom steps include need for checks on talking speed, pronunciation, audibility and language level (vocabulary). As becomes apparent from the discussions of these that follow, these aspects clearly form a necessary checklist for effective communication in classrooms to be generally observed by teachers. This is especially in light of the general difficulty of the science teachers’ language as has now become apparent.

Speed of talking and pronunciation

A teachers’ speed of talking may be a potential source of students’ difficulties with learning even in very well planned lessons. Depending on students’ ability and linguistic circumstances, teachers’ fast speech may result in students not understanding or recognizing words used during teaching. Related to the speed of talking is the way words are pronounced during teaching. While in fast speech words used may not be pronounced distinctly and/or correctly, incorrect pronunciation would possibly make students to confuse these words with similar ones, or even fail to recognize the words altogether like the case was in the following case.

A little boy was doing his math homework. He said to himself, “Two plus five, that son of a bitch is seven. Three plus six, that son of a bitch is nine…” His mother heard what he was saying and gasped, “What are you doing?” The little boy answered, “I’m doing my math homework, Mom” “and this is how your teacher taught you to do it?” the mother asked. “Yes,” he answered. Infuriated, the mother asked the teacher the next day, “What are you teaching my son in math?” The teacher replied, “Right now, we are learning addition.” The mother asked, “And are you teaching them to say two plus two, that son of a bitch is four?” After the teacher stopped laughing, she answered, “What I taught them was, two plus two, THE SUM OF WHICH, is four”. (McGown, 2004; Italics, my stress)

Although this episode was at a lower school level, as evident in the reviews presented in this article, this also happened even to pre-university level students. Difficulties as a result of failure to recognize words have been in students’ confusion between sound alike words e.g. consistent with constituent, component with opponent, detect with protect; accumulate with accommodate; diagnose with diagonal; proportion with portion (Cassels & Johnstone 1985), and consistent with constant and parameter
with \textit{perimeter} (Farrell & Ventura 1998).

\textit{Audibility}

Word recognition may not be a problem only when the speed of talking is fast or words are pronounced poorly. This may also be the case if the talk is not clear or loud enough as may be particularly necessary in large class sizes characteristic of schools in some populations, or depending on teaching arrangements. As may be expected, students not yet comfortable with secondary school level language of instruction or yet to attain appropriate level of proficiency in the language of instruction would be additionally disadvantaged by a teacher’s fast talk, poor pronunciation and inaudible speech.

\textit{Language level (vocabulary)}

With regard to other components of teacher’s classroom language, teachers’ use of vocabulary not appropriate to the levels they are teaching may result in students’ difficulties with the classroom language. Logical connectives, for example, may be especially difficult to many students. As so far pointed out here, the only study so far of students’ difficulties with these words, had only first language learners (Gardner, 1977a). Hence, it can be expected that students who learn in a second/foreign language, and perhaps of different and possibly lower levels of proficiency in the instructional language, would have more problems with these words. What may be considered an obvious implication of this is that teachers’ classroom language could be a greater challenge to the learners who learn in a second/foreign language, depending on their levels of proficiency in the language.

The importance of metarepresentational terms in examinations as already pointed out in this article, highlights the need for learners’ to possess good understanding of the meanings of these words. The difficulty of these words, particularly during examinations/assessments or in solving problems (Bulman, 1986), may therefore be expected if science teachers do not emphasize the meanings during teaching. In particular, explicit or implicit use or reference to terms may be sources of students’ difficulties with the content of lessons and even assessment tasks. It is important to note that although science teachers’ would use metarepresentational terms - metacognitive and metalinguistic words – only when solving numerical questions (problems), they would only minimally explain the words’ meanings (Oyoo 2006). However, teacher sensitivity to students’ language difficulties while learning science, with regard to making explicit or implicit references to these words may need to be judged on individual student’s circumstances. The implication of this for teachers is that they need to carefully consider when to make explicit or implicit references to words during their teaching (Wilson, 1999).

In addition to the approaches so far suggested here, different approaches may be necessary depending on teachers’ levels of knowledge and sensitivity to students’ general learning needs, including linguistic competence. The most important argument for the need for attention to how science teachers use language has been based on the nature and functional value of each category of the words that together make up the language as
used in science texts and by the science teachers. Apart from some of these words being themselves science concepts, others are representations of particular science subjects. Yet some of them embody science concepts as well as concepts necessary for the understanding of the processes of learning science, for example ‘filtration’, ‘distillation’ etc. Arguably, therefore, no word should be avoided during teaching, for the simple fact that

... the learners are progressing with the learning and will most likely meet the same words at a higher level. The teachers should just uplift the level of vocabulary of the students. They should explain the meanings of these difficult words whenever they are used in class to avoid confusion in the understanding by the students. (Oyoo, 2004, p. 203)

While this opinion may be considered in reference to the entire non-technical component of the classroom language, it is generally applicable to circumstances where learning is in a foreign language other than the learner’s first language. It is also generally applicable to circumstances where the learners’ levels of proficiency in the instructional language are perceived to be lower than may be the appropriate standard for the school level. The benefit of this approach is in the fact that students’ competence in the instructional language will facilitate their understanding of the concepts taught. Another argument (reproduced immediately below) represents the often-neglected voice of the student – the main stakeholder in all teaching - in favour of non-avoidance of any words, including those deemed difficult. Learning the meanings of difficult words also, would perhaps enhance their subject-related self-esteem.

Student: We also should know the difficult words relevant to the subject so that when we meet the words, like ‘anomalous’ then we just know that it is [means] ‘unusual’. So the teacher should provide the other possible meanings and this should be all the time. (Oyoo, 2004, p. 204; my addition)

The implication on teachers is that they need to be vast in the subject matter content and vocabulary in the language of the classroom as well as of the learning context, including the learners’ cultural backgrounds. The non-technical words are generally unavoidable in the characteristic teachers’ classroom talk and students may generally not be expected to discover the meanings of these on their own. This is especially argued based on 1) the possible changeability of the meanings of words used in the instructional language depending on the context of use, and 2) the fact that the meanings of science words must be known in the science education community circles. The teachers also need to observe the triple identity of the science words so as to be able switch between these during their offering of explanations in the classrooms. While teachers should be well aware of these issues, more information need to be sourced via more research as discussed in the next and last major section of this chapter.

**Further and New Focus in Science Education Research as addressing the problem**

This review has explicitly laid out the fact of the general difficulty of all words that comprise the *language of instruction* typical of science classrooms and texts, an outcome
that may have conveyed the reality of the centrality of the language of instruction to science learning. As argued at the beginning of his article, the attention that has been given to language issues in learning of science has in the main been with regard to the learners’ proficiency in the language. Further, interpretations of the findings in studies in this area (Peacock, 1995; Peacock, Cleghorn & Mikkila, 2002) have been with a view to benefit the improvement of science texts as learning resources for primary science. The teacher as the foremost learning resource in school science at all levels and teacher’s instructional language as a tool have been out of general focus in international science education research. Hence, an urgent need exists for new focus in and more research on the manner of science teachers’ use of the language of instruction in classrooms with an emphasis on how this may influence students’ understanding and retention of science concepts via enhanced knowledge of word meanings. The role and place of language in all learning (Vygotsky, 1986) is now well established, and the need for this new focus in science education research is justifiable on the need for teacher intervention in learning of science and everyday words when used in the science context as has been argued.

A focus on teachers’ classroom use of language is now argued to be generally urgent, including in countries where non-English language background (NELB) learners are in the minority (Ariza, Webb & Marinaccio, 2007). In such countries, the teaching of science has gone on with the expectation that students will understand and learn when teachers present the content in scientifically appropriate ways. In other words, there has been little consideration on these students’ literacy, language, and cultural understanding (Lee & Fradd, 1998). While this tendency might be responsible “in part for the under-representation and alienation of diverse students in science” (p. 13) in these countries, similar assumptions in the countries where students learn in a second or an additional language may have adversely impacted on levels of students’ outcomes and attitudes towards science. The argument here for the general need for more studies on the impact of the manner of teacher intervention in enhancing students’ understandings of the language of the science classroom hence science concepts, may be justifiable on the observed similarities in science teachers’ classroom approaches including use of words/language. Although literature in this area is still scanty as so far observed (Yore & Treagust, 2006; Yore, Hand & Bisanz, 2003) there is adequate evidence in the few reports so far in circulation regarding teachers’ classroom approaches during science teaching.

In the Bleicher, Tobin and McRobbie (2003) study of experienced teachers in Australian and American contexts for example, the teacher participant clearly controlled “the discourse in a linear, unyielding one-dimensional push to reach a satisfactory conclusion to cover the topic of the day” (p.234). In this same study, that the students as well as the teacher indicated in a follow-up interview that they preferred the approach since it led to the completion of the syllabus in time would be a window into the constraints to effective practice teachers face in classrooms. While the elaborate presentations of teachers’ approaches to explaining science in classrooms by Ogborn, Kress, Martins and McGillicuddy (1996) may be considered specific examples of science teachers’ approaches found in the United Kingdom (Yandell, 2003), they may be recognized to represent examples of teachers’ approaches in explaining science in any other country of the world today. Abagi, Cleghorn & Merritt (1988); Cleghorn, Merritt &
Abagi (1989), Cleghorn (1992); Cleghorn & Rollnick (2002) and Abdi-Kadir and Hardman (2007) would present the situation in primary school science classrooms in Kenyan and South African contexts in particular as well as in classrooms where English is a second language to both students and their teachers. The need for more research will need to be based on recognition of the triple identity of the nature of science words/concepts, and be founded on the following three issues. Firstly, recognition of the science teacher as the foremost resource in learning science (Driver, 1989); secondly, the general purposes of teacher use of language in science classrooms (Scott, 1998). Thirdly, the fact that the greater percentage of talk in many classrooms including those of science, across a wide range of teachers and across countries, comprises that of the teacher (Barnes et al, 1986; Barnes & Todd, 1995; Edwards & Mercer, 1987; Wilson, 1999; Bleicher, Tobin & McRobbie, 2003). This commonality in science teachers’ classroom approaches may be more support for the argument for more research in the teachers’ use of instructional language in classrooms. The general existence of science teachers’ classroom approaches to classroom talk serves to challenge any assumptions about the existence of culturally determined approaches to teaching of school science.

**Conclusion**

In contexts where where most formal education is conducted in instructional languages, usually foreign to most learners and even the teacher, the impact of language on learning is not new. However, the attention that has been given to the language of instruction has been with regard to the need to make learners proficient in it. Hence, the apparent assumption that once proficiency has been achieved in the instructional language then the students’ meanings would just come through. This may be evidence of the possibility that communicating objective knowledge by means of language has traditionally been taken for granted by educators (von Glasersfeld, 1998). While proficiency in the language of instruction is necessary for social interaction in the classrooms, learning science involves more than mere social interaction; it also involves deliberate formulation and sharing of ideas (Wilson, 1999). The instructional language needs therefore to be appropriate in all respects. The reason why even students who have attained acceptable levels of proficiency in the language of instruction have often been found unable to follow classroom discussions with ‘good’ science teachers of science thus becomes apparent. In many cases, this occurs when both the learner and the teacher know the meaning of a word (e.g. everyday word used in science context or as a science word) and each assumes that the other shares the same meaning. The consequence has been breaks in communication, poor understanding of the scientific concepts, and poor science outcomes. Although it has been possible to educate science teachers on the contemporary effective teaching approaches for enhanced learning in science, the role of language has not been really a focus. This is because education of science teachers in Africa has often depended on research findings in (English) monolingual societies – mainly Australia, United Kingdom and United States to America - to inform local approaches to how we prepare our teachers. In these monolingual societies, the identity of language has in the main, been taken as static. Hence, despite the larger volume of research in these societies so far (Fensam, 2004; Harlen, 1999), studies on language for effective science education may only be beginning to consider the impact of the language of instruction on enhanced learning in science classrooms (Kinchin, 2005; Yandell,
In this chapter, the objective has been to suggest an approach to the use of language by science teachers, appropriate to the general international science education community, which may lead to an enhanced understanding of the scientific concepts. It will be of particular relevance to contexts where science is learnt in a foreign language (like is the case in all countries in Africa) because of the language proficiency requirement as a necessary first step in learning in that language. This chapter is the outcome of sustained literature reviews of cross-national research and the distinctive view of science as a distinct language, foreign to all learners irrespective of their first language.
References

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The use of cartoons in shifting students towards greater autonomy in planning investigations

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Abstract
This design-based study reports on the use of cartoons in stimulating students to plan scientific investigations. Despite curriculum imperatives in South Africa and worldwide for students to have more autonomy in scientific investigations, investigations remain largely teacher controlled with students having only limited opportunities in planning investigations. This design-based study explored how cartoons can be employed in a Grade 9 class in a Black township in prompting students to plan scientific investigations. This innovation followed a continuous cycle of design, enactment, analysis and redesign, synonymous with design-based research. The findings suggest that a cartoon having a dialogue between characters on a scientific concept, accompanied by a prompt sheet is an effective support mechanism in planning investigations. To a large extent students were able to write a plan which included a statement of the problem, a formulation of the hypothesis, identified variables, apparatus to be used, a step-by-step procedure for conducting the investigation, and a description of how the collected data would be analysed to address the stated hypothesis.

Key words: scientific investigations; cartoons; practical work; autonomy; planning; prompt sheet

Background
Practical work in the school science curriculum is an area which has received much attention in the curriculum reform initiatives which have taken place worldwide. For example in the UK, the new national curriculum required that much attention be apportioned to scientific investigations and this was detailed in Attainment Target 1 (Department for Education and Employment, 1999). Also in the USA, the American Association for the Advancement of Science (AAAS) and the National Research Council (NRC) have endorsed science curricula that actively engage students in an inquiry-based approach which require them to do investigations. This new emphasis on the hands on
inquiry approach was in stark contrast to the traditional laboratory approach associated with older curricula where students often slavishly followed teacher directions and procedures without much thought (Hodson, 1993). A similar approach to practical work is promulgated in the South African science curriculum (Department of Education, 2002) which advocates student autonomy in scientific investigations as it specifies at the 9th grade, the student apart from “conducting investigations and collecting data” and “evaluating data and communicating findings, also ‘plans a procedure to test predications, or hypotheses, with control of an interfering variable’” (p. 17). Implicit in this new approach to practical work is the notion that students will have more autonomy in their learning.

In recent years there has been increasing research interest in learner-centred inquiry-focused learning environments. These studies have revealed that despite curriculum imperatives for students to have more autonomy in doing investigations, they remain largely teacher controlled. In a survey of science education in the United States conducted in 2000 by Horizon Inc. for the (National Science Foundation (NSF) it was shown that only 12% of teachers indicated students were asked to design or implement their own investigation (Smith, Banilower, McMahon & Weiss, 2002). Scientific inquiry continues to be presented in teachers scripted labs where students follow directions to confirm textbooks answers (Trumbull, Scarano & Bonney, 2006). Furthermore, a finding of the AKSIS (ASE-King’s science investigations in schools) project conducted in the United Kingdom, showed that teachers found that students experienced particular difficulty in planning investigations (Watson, Goldsworthy & Wood-Robinson, 1998). These findings are similar to that of a study conducted by Bradley (2005) with a sample of Australian junior secondary science students, where low levels of student-initiated activities were found in science practical work. The situation is even more desperate in South Africa’s township schools which where designated for Black students in terms of the previous Apartheid government’s Group Areas Act. Here factors such as a lack of laboratory resources, the presence of large classes and a lack of teacher competence result in students have had only limited experience of doing practical work. At such schools where practical does take place, it tends to be dominated by teacher demonstrations and a cookbook approach where students merely followed the teachers’ directions (Seopa, Laugksch, Aldridge & Fraser, 2003; Rogan & Aldous, 2005) and in general, students have only limited autonomy in choosing the question, formulating a hypothesis and in planning (Author, 2007). There is therefore a need to shift students towards greater autonomy in all stages of the investigation, especially in formulating the investigation question and planning the investigation.

Using a cartoon in science investigations

This study explores how concept cartoons accompanied by a prompt sheet can be used in addressing this need. The concept cartoons, which are cartoon-style drawings showing different characters arguing about everyday situations, are not meant to be humorous but are designed to provoke discussion and stimulate thinking (Webb, Williams & Meiring, 2008). Cartoons have been used in a variety of ways in science education. These include enhancing motivation in science learning (Heintzmann, 1989; Keogh & Naylor, 1999;
Perales-Palacios & Vilchez-Gonzalez, 2005), identifying students’ alternative ideas and thereby remedying misconceptions (Kabapinar, 2005; Keogh, Naylor, & Wilson, 1998; Stephenson & Warwick, 2002), and provoking argumentation (Webb, Williams & Meiring, 2008). The notion of using a cartoon to stimulate investigative inquiry appears to be plausible, as a cartoon provides a context and purpose for investigating (Stephenson & Warwick, 2002). A concept cartoon depicting alternative frameworks of understanding can be used as a stimulus for students to explore their own ideas which may or may not be represented on the cartoon. Following this exploration of alternative ideas on a scientific phenomenon, a prompt sheet comprising of questions may be used to facilitate students’ thought processes on the planning stage of an investigation (Harlen, 2001). Research conducted on the use of prompt sheets has reported that they help students structure their work and support them in decision-making (Akkus, Gunel & Hand, 2007; Gabel, 2001; Watson et al., 1998). This is especially the case during the planning stage where students can be prompted in defining the variables which form the focus of the investigation, and other variables which need to be controlled (Gomes, Borges & Justi, 2008).

Against this background the following research question is formulated:

Can a cartoon accompanied by a prompt sheet support students in planning scientific investigations?

**Methodology**

This study is located with the paradigm of design-based research which is considered an important methodology for understanding how, when, and why educational innovations work in practice. This methodology is directed at the study of learning in context through the systematic design and study of instructional strategies and tools (Brown, 1992; Collins, 1992). I considered this design appropriate as it enabled me to frame my understanding of teacher experiences of using cartoons in facilitating the planning of investigations. Furthermore, design-based research involves flexible design revision and place through continuous cycles of design, enactment, analysis and redesign (Cobb, 2001; Collins, 1992) and my research following a similar pattern.

Reeves (2000) cited by Peterson and Herrington (2005) sums up what researchers seem to agree on regarding the function of design-based research. He lists the critical characteristics of the approach as:

- addressing complex problems in real contexts in collaboration with practitioners;
- integrating known and hypothetical design principles with technological affordances to render plausible solutions to these complex problems; and
- conducting rigorous and reflective inquiry to test and refine innovative learning environments as well as to define new design principles.

Reeves (2000) proposes the following design-based research stages: (a) Analysis of practical problems by researchers and practitioners, (b) Development of solutions, (c) Evaluation and testing of solutions in practice, and (d) Documentation and reflection to produce design principles. I adopted and adapted these stages in guiding my research. This is illustrated in the diagram below (Figure 1).
Sample and context

This study was carried out at a high school situated in a densely populated township. The area was previously designated a Black township under the Group Areas Act, which demarcated residential areas for race groups. The school has 900 Black students. The pass rate for the Grade 12 national exit examination in the previous year was 55%. The school fee was R 400 with a 40% collection rate. The teachers were all employed by the national department of education. The average class size is 41.

The school does not have a science laboratory. A few chemicals and equipment are stored in a classroom. These include six test-tubes, two beakers, a measuring cylinder, five small bottles of chemicals, and a circuit board with missing electrical components. Miss Kekana (pseudonym), the Natural Sciences teacher and her class of 42 Grade 9 students (13-14 years) formed the focus of this study. Grade 9 was considered significant as it is the first grade in the South African school science curriculum where students are expected to do open investigations, which includes planning the investigation. Miss Kekana has ten years’ experience teaching Natural Sciences. She possesses a teaching degree with Natural Sciences and Mathematics as her majors. I became acquainted with her when she attended a professional development programme in science education which I offered at the University of Johannesburg. One of the competencies which this programme aimed to develop in teachers was the teaching of scientific investigations. At the end of the programme, the teachers were invited to participate in a research study on the use of cartoons in facilitating the planning of investigations by students. Miss Kekana was one of the teachers who agreed to participate and this paper reports on the cycles of design, enactment, analysis and redesign of this innovation.

Data collection and analysis

Data were collected through classroom observations which informed me on how the cartoon supported students during the planning stage of the investigation, and interviews with Miss Kekana whereby she shared her experience of using the cartoon. The lessons were video-recorded and the interviews audio-recorded. My data analysis was largely framed by the stages of design-based research elucidated in Figure 1. Data collected during the enactment stage of the cartoon was analyzed to understand and explain the
effectiveness of the cartoon in supporting students in their planning of the investigation. At the same time I tried to identify from the collected data difficulties students encountered in their planning. This analysis enabled me to reflect upon the viability of the cartoon, and consider refinements which needed to be made to this innovation.

Findings

The findings of this study are structured according to the staged-process described in Figure 1 above.

Stage 1: Analysis of the problem

Miss Kekana told me that her students lacked the experience and expertise in planning investigations. She believed despite the curriculum requirement for students to be able to plan investigations, students needed much support in this regard. She explained this as follows:

Although the curriculum specifies that learners should be given more responsibility in doing things, I believe they still need to be told what to do. They need a lot of direction. It is not that I don’t have confidence in their ability, but they lack the practice of doing it. It is unreasonable to suddenly spring it upon learners that they must design an investigation on their own. They need guidelines on what is required. For example, they should be given a list of apparatus they can use, and then they can plan around that.

A particular problem she identified in planning was the identification of variables. In targeting this problem she had given students exercises whereby they would be given investigations problems to identify variables and formulate a hypothesis on the problem. An example of such an exercise which she showed me was:
For each of the following investigations, formulate a hypothesis, and identify the independent, dependent and control variables:
1. The effect of temperature on a magnet’s strength.
2. How does the surface on which a car moves affect how fast it moves ?
3. Does the sun heat salt water and fresh water at the same rate ?
4. What amount of water is best to grow tomatoes ?

She indicated that despite her efforts, the overwhelming majority of students found this work difficult and confusing. She explained this as follows:

It is very frustrating because despite spending much time on this, my students continue to make mistakes. A problem is mainly they mix up variables. The hypothesis is not clear, and they therefore cannot know how to do it (the investigation).

Miss Kekana was quite eager to try out a new approach with her Grade 9 class.

Stage 2: Development of a cartoon to address problem
At the initial visit to the school, Miss Kekana informed me that the topic she was about to commence with was heat transfer. I presented her with the idea of using a cartoon as a support mechanism for students in planning investigations. She was amenable to the idea and it was decided that a cartoon would be developed on this topic. Though discussion we agreed the cartoons would meet the following criteria:

- They would relate to some real-life experience/observation of the students.
- They would target a scientific phenomenon on the topic of heat transfer.
- They would depict alternative ideas on the scientific phenomenon.
- They would be visually appealing.
- They would use language which is accessible to students.
- They would include characters students could relate to.

The justification for the above criteria was that the cartoons should hold the interest of the students and they should engage student thinking on a scientific phenomenon related to the topic. These criteria to a large extent agreed with the features of a concept cartoon suggested by Keogh, Naylor and Wilson (1998).

I developed a cartoon which addresses heat transfer from two liquids of different volumes. It refers to two characters, Betty and Sipho who are in conversation over whose cup of tea, the one cup being full and the other half-filled will cool faster on a cold day (Figure 2).

![Figure 2: Cartoon on heat transfer from two liquids at a different volume](image)

The students after looking at the cartoon were going to be asked to write a plan for this investigation. They would be supported in this by means of a prompt sheet focusing on different aspects of an investigative plan, namely defining the problem, formulating a hypothesis, identifying variables, choosing the apparatus, deciding on the experimental procedure, describing how the data would be collected and recorded and finally how the collected data would be analyzed and interpreted to address the hypothesis that was
initially framed (Appendix A).
I developed the prompting questions myself and asked Miss Kekana to scrutinize them and make changes where she saw fit. I asked her in particular to consider the readability of the questions as all the students were English second language speakers. She did not make any changes and believed the prompt sheet was going to be “a good guide in steering students in the right direction”.

Stage 3: The enactment of the cartoon and prompt sheet

The class of 42 students were seated in groups of 6. This was the second lesson on the topic “Heat Transfer”. In the first lesson, students became acquainted with the concept of heat, and learned that heat was a form of energy which moved from an object at higher temperature to one at a lower temperature. At the start of the lesson Miss Kekana told the students they were going to plan an investigation on the “cooling of full and half-full cups of tea”. She handed out copies of the cartoon (Figure 2) and asked students whether they supported Betty or Sipho in asserting which cup of tea will cool faster. Of the 42 students, 28 agreed with Betty that her half-filled cup of tea will stay hot longer, 10 agreed with Sipho that his full cup of tea would stay hot just as long, and 4 students were undecided and would not commit themselves. The students then each received a prompt sheet (Appendix A). Miss Kekana asked students to read through it and invited them to ask her questions should they not “follow what needs to be done”. The students were encouraged to engage in discussions within their groups, but were told to “come up with your own plan”. Miss Kekana was confronted with many questions from students, mainly seeking clarity on the prompting questions on the prompt sheet. They appeared to have difficulty with most questions on the sheet, but especially those which related to the variables, and the data analysis and recording. It was clear the lesson had not unfolded as was planned. In the post-lesson interview Mrs Kekana reflected that the students “were very unclear about the types of variables”. Although she had spent much of the lesson responding to students on this she believed the students still felt “uncertain of themselves”. An examination of the prompt sheets clearly indicated this as 35 of the 42 students had incorrectly identified the variables or not attempted a response. Only 10 students had progressed to the section on writing up a step-by-step procedure. It became apparent that an additional support would need to be provided for students.

Stage 4: Refining the innovation by including additional support

It was decided to develop a dialogue between Betty and Sipho to accompany the cartoon. This dialogue (Appendix B) would serve as a further support mechanism for students as it would highlight key aspects being referred to in the prompt planning sheet. For example, students would be supported in identifying control variables through a conversation taking place between the characters, where Betty suggests:

We will need to do two experiments. The one with half the cup of tea, and the other with the full cup of tea. We must use the same tea for both. They must be at the same starting temperature. The cups must be identical. These are called the control variables.
In a similar manner the dialogue draws the attention of the students to other stages in planning, such as hypothesizing, recording and analysis.

**Stage 5: Enacting the refined innovation**

In the following lesson, Miss Kekana handed out new prompt sheets together with the dialogue sheet to accompany the cartoon. Students appeared to work more independently in responding to the prompt sheet. There were fewer questions from students, compared to the previous lesson. When student were unsure of themselves Miss Kekana referred them to the cartoon and dialogue. She asked them to:

Go and read what Betty and Sipho said about independent and dependent variables again. Once you know what dependent and independent variables are. That's what I want you to put in there. So go and read the cartoon were they tell you and explain about independent variables and dependent variables. Read the cartoon again. If you're still not sure what that is, then put up your hand.

This appeared to work well as students who took this advise engaged more closely with the dialogue. As the students were completing their prompt sheets, Miss Kekana moved around the class listening in on group discussions taking place. She frequently stopped and asked students to explain an entry on their prompt sheet. When she learned that students had made an error or omitted something in their design she asked them to “have a look at this again” or “think about what Betty and Sipho are proposing”. At the end of the lesson Miss Kekana collected all prompt sheets, and asked students whether they had coped with this activity. Students almost unanimously agreed that they had coped much better this time around. After the lesson I interviewed Miss Kekana about the innovation. She indicated that having the dialogue to accompany the cartoon had made a significant difference to the manner in which students responded to the prompt sheet. When questioned on how the prompts had contributed to learning she remarked that it created an awareness of what students needed to consider when planning:

Okay I think the prompts were very good and very useful. And sort of reflected a thought process that you have to go through. Sort of verbalized what you would be thinking. The process of planning and it sort of explained, sort of explained the basic concepts like variables, independent analysis and so on.

She also mentioned that the dialogue between Betty and Sipho helped engage students in the scientific discourse and believed this may encourage students to use scientific language when speaking.

What was good was here were “cool” characters talking science in the science language. This help popularize it for them (students) and break the barrier of science being intimidating.

From the prompt sheets it was evident most students were able to take their cues from the cartoon dialogue to respond adequately to the prompting questions. I analyzed the prompted sheets for the extent to which students were able to plan the investigation,
using a rubric (Figure 3) which was an adaptation of the Science Inquiry Observation Scale used by Villanueva and Webb (2008) used in a South African study. The rubric assessed four areas in relation to planning an investigation: stating the investigation problem, formulating the hypothesis, identifying the variables and designing the experiment by outlining a step-by-step procedure. The scoring is based on a 4-point scale from zero to three describing a continuum extending from situation where a student makes no attempt at planning to a case where a student completely meets the requirements of planning. After scoring the prompt sheet using the rubric, I asked a researcher in science education to do the same. The reliability in scoring was confirmed as there was a high percentage of agreement in our scoring.

<table>
<thead>
<tr>
<th>Stating the investigation problem</th>
<th>Formulating a hypothesis</th>
<th>Identifying variables</th>
<th>Design the experiment</th>
<th>Analysis and interpretation of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearly and correctly states the investigation problem</td>
<td>Vaguely, but somewhat correctly states the investigation problem</td>
<td>Incorrectly states the investigation problem</td>
<td>No attempt</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Clearly identifies the independent variable and the dependent variable. All controlled variables are listed. The relationship between the variables is evident.</td>
<td>Hypothesis is testable, and addresses the stated problem</td>
<td>Hypothesis is testable, but needs to be more clear and concise</td>
<td>Hypothesis is complete, testable, and addresses the stated problem</td>
<td>Hypothesis is either not testable or does not connect to the stated problem</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Variables are stated, but a clear relationship between the independent and dependent variables is not evident. Some controlled variables are listed.</td>
<td>Variables are stated, but a clear relationship between the independent and dependent variables is not evident. Some controlled variables are listed.</td>
<td>Variables are not clearly stated. The relationship between the variables is unclear or not discussed.</td>
<td>Variables are stated, but a clear relationship between the independent and dependent variables is not evident. Some controlled variables are listed.</td>
<td>Variables are not clearly stated. The relationship between the variables is unclear or not discussed.</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Procedures are outlined in a step-by-step fashion that could be followed by anyone without additional explanations. All relevant materials are listed.</td>
<td>Procedures are outlined in a step-by-step fashion, but there may be 1 or 2 gaps that require explanation. Major materials are listed.</td>
<td>The procedures outlined are incomplete or not sequential. Some or all the materials list is missing or incomplete.</td>
<td>The procedures outlined are incomplete or not sequential. Some or all the materials list is missing or incomplete.</td>
<td>The procedures outlined are incomplete or not sequential. Some or all the materials list is missing or incomplete.</td>
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<td>3</td>
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</table>
Figure 3: Rubric for scoring the investigation plan

An examination of the student responses to the prompt sheet revealed students to a large extent were able to successfully plan the investigation. Quantitative data in support of this is shown in Table 1.

Table 1: Student scores per component of science investigation planning

<table>
<thead>
<tr>
<th></th>
<th>Level 3</th>
<th>Level 2</th>
<th>Level 1</th>
<th>Level 0</th>
<th>Average score per component of planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigation problem</td>
<td>30</td>
<td>10</td>
<td>2</td>
<td>0</td>
<td>2.67</td>
</tr>
<tr>
<td>Hypothesis</td>
<td>26</td>
<td>8</td>
<td>6</td>
<td>2</td>
<td>2.38</td>
</tr>
<tr>
<td>Variables</td>
<td>22</td>
<td>10</td>
<td>8</td>
<td>2</td>
<td>2.24</td>
</tr>
<tr>
<td>Design experiment of</td>
<td>20</td>
<td>15</td>
<td>7</td>
<td>0</td>
<td>2.31</td>
</tr>
<tr>
<td>Analysis and interpretation of data</td>
<td>19</td>
<td>9</td>
<td>11</td>
<td>3</td>
<td>2.05</td>
</tr>
</tbody>
</table>

Table 1 shows that the average score for all component of planning was above 2. In terms of the rubric a score of two for a component signified that a particular response was correct but incomplete. A score of 2 is therefore considered satisfactory, and it may be concluded that students were able to successfully plan the investigation.

**Discussion**

The findings of this study suggest that a cartoon is an effective support mechanism for students to plan scientific investigations. Design-based research was appropriate as it enable me to explore an innovation in trying to address both a national and worldwide problem of students not being able to plan scientific investigations. The initial enactment of the cartoon revealed that students needed further scaffolding in planning. It was
decided to write a dialogue which perhaps would have taken place between the cartoon characters Betty and Sipho. The classroom observation showed how students under the guidance of the teacher took cues from the dialogue to respond to the questions on the prompt sheet. Miss Kekana had a positive perception of this innovation and indicated that it was an effective mechanism in shifting students towards greater autonomy in planning investigations.

Furthermore, Miss Kekana remarked that the cartoon engaged students in the scientific discourse. This was also evident from the discussions which were taking place within the groups as students appeared to be “borrowing” phrases from Betty and Sipho. Language is central to scientific endeavor and science learning. Many scholars have suggested how the language of science with its own specific genre often serves as a barrier to the learning of science (Brown, 2004; Gee, 2004; Lemke, 1990; Varelas et al., 2002; Wellington & Osborne, 2001). Students often experience alienation from science due to the distinctive grammatical features and language structures of scientific language which are quite different from everyday language. The cartoon accompanied by the dialogue was therefore invitational to students as they could perhaps relate to the characters depicted. The issue of scientific language could perhaps form the focus of another study on cartoons.

The particular group of students in this study had a very limited background in scientific investigations, in particular the planning of investigations. Using design-based research a support mechanism was developed to accommodate them at this level of competency. However, if students are to progress to higher levels of autonomy, teachers need to offer less support at early stages and focus more on particular types of support suited to the autonomy stage. This notion of withdrawing some teacher support as students become more competent at doing investigations is similar to that expressed by Gabel (2001) in her model for a scaffolded inquiry. A similar framework is presented by the NRC (2000) in the National Science and Education Standards guide for teaching and learning inquiry. This issue of withdrawing support and how this affects autonomy could be investigated in another study where students initially would be scaffolded in planning through a cartoon and then asked to plan without this support. The present study focussed on the planning stage of an investigation, as research has reported on the difficulties student experience in planning investigations. Future studies could explore how this innovation may be used in supporting students through all stages of an investigation.

What is of significance in this study is the context in which this innovation was investigated, namely a disadvantaged school. Practical work requirements are not being met by a large portion of disadvantaged schools where Physical- and Natural Science is being offered. The science experience of students at these schools is therefore largely content-based. Students at such schools have been deprived of some of the mentioned benefits to science learning associated with practical work. This study shows that if cartoons can be developed and made available to such schools where students have a scant expertise and experience in scientific investigations, competence in planning investigations can be gradually developed.
References


and Higher Education, Vancouver, Canada.


Appendix A: Prompt sheet for planning investigation

PLANNING THE INVESTIGATION
1. Investigation problem
What are you going to investigate?
________________________________________________________________________

2. Investigation variables/hypothesis
What will you change in this investigation? (Independent variable)
________________________________________________________________________
What kind of effect will you observe? (Dependent variable)
________________________________________________________________________
What should be kept the same? (Controlled variables)
________________________________________________________________________

Predict what you think will happen (Hypothesis)
Try to write this as an if-then statement:
If........................................................................................................................................
......................................................
......................................................
......................................................
......................................................

3. Designing the experiment
List the apparatus and materials you will need?
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

What precautions will need to be followed?
________________________________________________________________________
________________________________________________________________________

List step-by-step what you will do. Refer to how you will set up the apparatus, what you will measure, how you will measure and the number of measurements you will take.
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
4. Data collection and recording
How will you record your observations and measurements. You may choose to draw a table to record your data. Draw the table with column headings.

5. Data analysis and interpretation
How will you make your data meaningful to you? Will you draw graphs and/or do calculations.

How will you label the axes on the graph? How will you interpret the graph and/or calculations in accepting or rejecting your hypothesis?

Appendix B: Dialogue between Betty and Sipho on planning the investigation
Betty: I think the amount (volume of the liquid) affects how quickly it cools. But these are just guesses (hypotheses). Let’s investigate it. What do we need?
Sipho: Two cups of tea and a thermometer.
Betty: Yes, but it has to be a fair test.
Sipho: What do you mean by this?
Betty: We will need to do two experiments. The one with half the cup of tea, and the other with the full cup of tea. We must use the same tea for both. They must be at the same starting temperature.
   The cups must be identical. These are called the control variables.
Sipho: Okay so we will have different volumes (independent variables) and investigate how the volume affects the time taken for the tea to cool (dependent variable).
Betty: What will it cool to?
Sipho: Not sure, but I think it will be room temperature.
Betty: The thermometer shows 25°C, so the tea will need to cool to this temperature. The
starting
temperature is the temperature of the hot tea.

Sipho: I think we are missing something. We want to know how quickly it is going to cool. So we need
time.

Betty: We will need to use stopwatches.

Sipho: We also need to put our results somewhere *(recording)*. How about using a *table*?

Betty: Maybe we can draw a *graph* to see this more clearly *(analysis)*.

Sipho: Great! Let’s do it.

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**A critical analysis of classroom discourse and co-construction of knowledge relative to the preparation and production of an African staple food**

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**Abstract**

While several studies worldwide have shown that learners encounter great difficulties with many scientific concepts only a few have been concerned with helping teachers to develop instructional approaches that can ameliorate such difficulties e.g. through co-constructing such concepts with their learners. In response to Learning Outcome 3 of the new South African curriculum calling for the integration of science and indigenous knowledge, the Science and Indigenous Knowledge Systems Project (SIKSP) at the University of the Western Cape mounted a series of argumentation-based workshops to help teachers implement the new inclusive curriculum. This paper focuses specifically on how the workshops were used to assist 12 science teachers develop an understanding of how a staple African food known as gari is prepared and produced. The workshops involved training in argumentation, collaborative laboratory activities and discussions in the co-construction of knowledge. The findings based on an analysis of the data derived from completed worksheets and audio/video recordings showed that the teachers found the new instructional approach to be informative and useful on how science and indigenous knowledge can be integrated in the preparation, production and preservation of gari. The implications of the findings for instructional practice are highlighted in the paper.

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**Introduction**

There is a resurgence of interest in the cultures of indigenous peoples throughout the world and part of this interest focuses on indigenous foods (Whyte, Hudson, Hasell, Gray, & O’Reilly, 2001). With this increased interest comes the danger that preparation of traditional foods may not be undertaken by people versed in the correct methods or that contemporary adaptations of traditional techniques may negate practices which had produced safe food for centuries. The work described here sought to obtain information concerning a traditional African staple food
processing techniques in order that they could be documented and analysed from a contemporary food safety standpoint. Gari eaten in western, central, some provinces in South Africa, Asia, many tropical and sub tropical regions of the world is derived from the Cassava plant, *Manihot esculenta*. Beyond the rhetoric of the new South African curriculum most teachers lack necessary knowledge and skills on what Indigenous Knowledge Systems (IKS) stands for or how to enact in their classrooms an inclusive curriculum which embraces science and IKS. It is for this reason that a series of workshops was mounted as an exemplar to introduce different aspects of IKS into the science classroom.

A group of science teachers involved in this study is currently being trained as facilitators for effective implementation of classroom discourses in their classrooms (Siseho & Ogunniyi, 2010). The video and audio archives of lectures, workshops, classroom-based activities and focus group interviews form part of the process used to assist the teachers in implementing the new science curriculum in South Africa published by the Department of Education (DOE, 2002). The curriculum urges teachers to develop critical process skills in their classrooms as a means to facilitate conceptual understanding among learners. According to the new curriculum, “process skills refer to the learner’s cognitive activity of creating meaning and structure from new information and experiences (Siseho & Ogunniyi, 2010). Examples of process skills include observing, making measurements, classifying data, making inferences and formulating questions for investigation.” Argumentation-based instruction developed in the larger study has been found to create a positive learning environment which has enabled learners to actively participate in discourses and to engage in high-level process skills needed in science e.g. formulating hypotheses, prediction, application and decision making (Ogunniyi, 2007; Ogunniyi & Hewson, 2008).

One of the argumentation models that have been frequently encountered in the current literature in science education is Toulmin’s (1958, 2003) Argumentation Pattern (TAP). The TAP consists of a claim—an assertion or belief about a subject matter; data—evidence to support the claim; warrant—the statement that links the evidence to the claim; backings—underlying assumptions to the claim; qualifier—the conditions necessary for the claim to be valid; and rebuttal—a statement made to invalidate a claim. Although the TAP has been useful in clarifying classroom discourse it is not free from criticisms such as: the inconsistent way in which the validity of an argument has been presented; the assumption that all arguments can be subjected only to a strictly logical forms of reasoning at the expense of equally important practical reasoning; the inconsistency in its inclusion of backings, rebuttals and qualifiers for the warrant but not the data, thus turning a simple argument into a compound one; the assumption that amassing bits and pieces of evidence is sufficient grounds for a given claim; etc (Van Eemeren et al, 1996). However, despite these weaknesses the TAP has provided some useful hints about how to assess arguments in a given context. A number of studies have simplified the structure of the TAP to make it more applicable to the field of science education (e.g. Erduran et al, 2004; Simon et al, 2004; Osborne et al, 2006). These studies have done this by classifying classroom discourses in terms the complexity of the arguments involved such as: non-oppositional; arguments with claims or counterclaims with grounds but no rebuttals; arguments with claim or counterclaim with grounds but only single rebuttal arguments with multiple rebuttals challenging the claim but no rebuttal; etc (Siseho & Ogunniyi, 2010).

**Purpose of the study**

Learners need to be taught the norms of social interaction and to understand that the function of their discussion is to persuade others of the validity of their arguments” (Osborne, 2010). Teachers’ instructional practices are essential for supporting learners’ conceptual development
and critical process skills needed in scientific inquiry. If teachers are trained to develop high-level argumentation skills, they are likely to use such skills later in their instructional practices. The purpose of the study therefore was to examine possible impact of argumentation-based activities on teachers’ ability to critically analyze a classroom discourse and co-construct knowledge relative to the preparation and production of gari, a staple African food. In pursuit of this aim, we sought answers to the following questions:

1. How effective are argumentation-based laboratory activities on the teachers’ ability to analyze classroom discourses and co-construct knowledge about the preparation and production of a staple food known as gari?

2. What sort of arguments do the teachers use while forming tasks on the preparation of gari?

3. What levels of the TAP are evident in the teachers’ argumentation as they work on classroom discourses and co-construct knowledge about the preparation and production of the staple food?

Method

The study involved 12 science teachers who were exposed to a series of bi-weekly three-hour workshops underpinned the TAP for a period of six months. The teachers were assigned selected readings based on the works of scholars on the Nature of Science (NOS) and IKS (e.g. (Abd-El Khalick & Lederman, 2000; Aikenhead & Jegede, 1999; Garrouette, 1999; Ogunniyi, 2007a & b). The first one and half hour block was in form of a lecture on socio-scientific topic such as environmental pollution, genetically modified food, energy conservation, the building of atomic power station at the west coast of Western Cape province, etc. They were also introduced to the controversies that ensued among early natural philosophers and scientists from the 20th century to the present period with respect to the nature of the atom, etc. The purpose additional reading assignments was to create the teachers’ awareness about how scientists go about constructing knowledge in their various fields and to show teachers how to reflect the same thing in their classrooms (Siseho & Ogunniyi, 2010). After the six-month workshops, the teachers were introduced to the argumentation-based laboratory activities. The teachers were confronted with several tasks among others to: (1) perform sensory analysis on the gari by evaluating the following: flavour and taste, texture, smell (aroma), appearance – both in colour, shape and size; (2) critically evaluate the methodologies (A, B, C as per appendix 1) of the process flow chart for the indigenous production of gari and reflect upon various process steps (e.g. washing, drying, fermenting, etc); and (3) determine whether there are comparable processes of indigenous food production in South Africa. Activities began with individual tasks, followed by small group tasks and finally whole classroom discussions and summary. This was to mimic real scientific inquiry where scientists often work as an individual, present, argue their own case to a small group, and finally publish a scientific paper for public consumption. The last 30 minutes of the three-hour block was used to identify the teachers’ arguments in terms of levels depicted in Table 1 below.

Table 1: Toulmin’s Argumentation Pattern (TAP) in classroom discourse

<table>
<thead>
<tr>
<th>Claim</th>
<th>A statement or belief about a phenomenon whose merits are in question.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>Facts or evidence used for supporting a claim.</td>
</tr>
<tr>
<td>Warrants</td>
<td>Statements used to establish or justify the relationship between the data and the claim</td>
</tr>
<tr>
<td>Backings</td>
<td>The implicit assumptions underpinning the claim.</td>
</tr>
<tr>
<td>Qualifiers</td>
<td>Conditions governing the claim.</td>
</tr>
<tr>
<td>Rebuttals</td>
<td>Statements which show the claim to be invalid.</td>
</tr>
</tbody>
</table>
To reinforce their argumentation skills the teachers were then given some assignment for the next workshop. All the lab sessions were recorded using both audio-video-tapes. The transcribed materials were then analyzed in terms of the modified Toulmin’s Argumentation Pattern (TAP) shown in Table 1 above. Since a greater detail of the argumentation-based instruction used in the study has already been published (Ogunniyi, 2007a & b and Siseho & Ogunniyi, 2010) it will not be repeated here. The classification of the teachers levels of argument were carried out by two independent team members. Their scores were then correlated using Spearman Rank Difference formula. The correlation stood at 0.94. This indicates a high correlation agreement between the two. It suggests a strong face, content and constructs validity of their classification.

Findings

Given that the study involved several activities on processes of producing and preserving a congeries of indigenous foods, only two of these activities will be presented here as an example of the challenges faced by teachers in using argumentation-based instruction to exemplify the scientific basis of the processes involved. The result presented here is based on Activity D4: Small group task and Activity D5: Whole class discussion. The former required the teachers to realize their disagreements, discuss their arguments with other members within the group, reflect on the arguments to reach consensus and tabulate the arguments as Claims, Evidence and Warrants. In the latter, group leaders would then present their agreed claims, evidence and warrants to support their arguments. The findings shown in Tables 2-4 below present an agreed summary of what transpired in Groups 1-3 (each group consisting of four members) in the classroom during activity D4 and D5. For reasons of anonymity, the 12 teachers were given pseudo-names.

Table 2: Group 1 teachers’ arguments as they attempted to predict critically evaluate and reflect upon the various methodologies on the process flow chart for the indigenous production of gari.

<table>
<thead>
<tr>
<th>Names</th>
<th>Claims</th>
<th>Evidence</th>
<th>Warrants</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Group 1) Rose</td>
<td>Method A</td>
<td>• Natural process used i.e. crushing by hand, drying on rocks.</td>
<td></td>
</tr>
<tr>
<td>Alan</td>
<td>- It is the most likely process in rural areas to produce powdered gari.</td>
<td>• Not a fine product;</td>
<td></td>
</tr>
<tr>
<td>Phil</td>
<td></td>
<td>• No grating;</td>
<td>• Based on product quality, high fibre content;</td>
</tr>
<tr>
<td>Masdah</td>
<td></td>
<td>• Natural process retains higher nutritional value;</td>
<td></td>
</tr>
</tbody>
</table>

Here below is an excerpt of Group 1 leader presentation transcribed verbatim from the video.

Rose: “I ... Alan, Phil and Masdah are in group 1 and I’m just about to share with you the claims that we had made. We are certain that Method A is the methodology that was used to compare the cassava that we had tested and that was based on the fact that we had ...um... descend from the critical control points that were essential to produce a product of good quality, product that was safe as well as a product that was able to be stored for a lengthy period of time. Related to the quality, we found that in methodology A, the sorting, the peeling, the washing- those critical points were addressed...um...but also we looked at the fact that: the product that we had sampled was not fine, it still had granules in it and its for that reason that we did not choose method B and C because there was no grating, we are assuming that there was no grating that took place. We again for...um...product safety with methodology A, because of the steeping, fermenting, they’re all vital in the removal of cyanide content of the cassava... within the cassava ...sorry... and to reduce the...
moisture also, we found that...more natural process in methodology A as the hydrolytic process used in the other two...umm...methods as opposed to crushing by hand as well as the use of the rubric dryer in B and C as opposed to drying on rock which is also a natural process, minimized the loss of nutritional value, so we are looking to higher sugar, protein and macro-nutrients within a more natural product. The solubility...we are saying that because it is of critical control points for drying, packing and sorting. There is reduction of macro-organisms activity and as a rebuttal in our argument; we are saying that we cannot make informed decisions if we do not have samples of all three processes A, B and C. And we couldn’t test for the nutritional value as we don’t have the necessary apparatus available to us, so we are saying that...um... we assume that the nutritional value will be higher if we are utilizing a more natural indigenous process”.

Table 3: Group 2 teachers’ arguments as they attempted to predict critically evaluate and reflect upon the various methodologies on the process flow chart for the indigenous production of gari.

<table>
<thead>
<tr>
<th>Names</th>
<th>Claims</th>
<th>Evidence</th>
<th>Warrants</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Group 2)</td>
<td>Method B</td>
<td>Hard, dry product that</td>
<td>• Roasted products will be</td>
</tr>
<tr>
<td>Eddy</td>
<td></td>
<td>looked as if it was</td>
<td>dehydrated;</td>
</tr>
<tr>
<td>Ruti</td>
<td></td>
<td>roasted.</td>
<td>• Granular shape indicates</td>
</tr>
<tr>
<td>Lorna</td>
<td></td>
<td></td>
<td>grating</td>
</tr>
<tr>
<td>Ciwu</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- the necessary basic steps</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>were present</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Here underneath is a passage of Group 2 leader presentation transcribed verbatim from the video

Eddy... Myself, Ruti, Ciwu and Lorna we first of all I think with the first group, they spoke about... for example the reasons why they have chosen A, we had a difficulty in making that decision from the premises they were moving from because...um... [clears throat] the discussion in the group was that basically was...um...the productivity which was taking place here, is it a small productivity or is it productivity on a large scale. So, I think we then basically moved from the premises that there’s productivity on a large scale and that’s why we have chosen methodology B. So everybody was getting that one... [Laughs]...so the reason why we have chosen Method B we’ve looked at the end product, the end product itself is a very dry product, for example if methodology A was followed, we agreed that for example to use methodology A you won’t get a dry product as is. In example 1, basically I don’t know if it is sufficient to substantiate the claim there because if, you look at dry fruit, dry fruit is still going through all these roasting and all that, so if it comes out there’s still a certain amount of moisture in there and the product that we looked at there was almost no moisture there, it was hard, it was solid and also the texture of it, and those were the reasons we have...ummm...used as evidence to state our claim which is what basically is methodology B. Our warrant in this case is a roasted product for example going through on that; temperature exposure will be dehydrated and if you look at the product is...it has moved from the original colour to a more darker colour so in our case, it was exposed to a higher temperature.

Table 4: Group 3 teachers’ arguments as they attempted to predict critically evaluate and reflect upon the various methodologies on the process flow chart for the indigenous production of gari.

<table>
<thead>
<tr>
<th>Names</th>
<th>Claims</th>
<th>Evidence</th>
<th>Warrants</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Group 3)</td>
<td>Method B-</td>
<td>Granular</td>
<td>• Produce powders</td>
</tr>
<tr>
<td>Rob</td>
<td></td>
<td>Not powder form</td>
<td>• Drying process</td>
</tr>
<tr>
<td>Dan</td>
<td></td>
<td>Fibres present</td>
<td></td>
</tr>
<tr>
<td>Sima</td>
<td></td>
<td>No smell</td>
<td></td>
</tr>
<tr>
<td>Bren</td>
<td></td>
<td>Quite dry</td>
<td></td>
</tr>
</tbody>
</table>

Here underneath is an extract of Group 3 leader presentation transcribed verbatim from the video

Rob: Now we have decided that, based on the figure 1, to go with Methodology B and with bases on the original product that we had, which was not to find the white one but rather the creamish one
which was bigger in texture, granular form, that is why we went for Method B because it shows um...the product was granular, it was not powder form, there was fibres present in the sample that we had, we couldn’t pick up a smell in the fermentation process. Methodology B points out that the fermentation process, there is a dry process, they use clay baskets, they won’t talk about leaving it in water therefore the end product is quite dry, that is the one that we had originally whereas methodology A and C points out that in order to obtain a fine powder form, you remove the fibres that why we went for B, that is our warrant, A and C both produces the powder product, even the drying process was different. The backing is that um...the seeding process is optional in methodology B and that is where the fibres are optionally present. Today we had a look at the one sample that we’ve got which is the powderish one, which is fine in texture and for me that is a rebuttal that it cannot be methodology A because the product that we had was granular, bigger in size than the white fine product. These were the two samples that we had and we compared the one with the other one.

After group presentation, Sami (the workshop facilitator) summarized the whole class presentation and the asked questions about the purpose of fermentation in the production of gari as shown below:

Sami: Ok, thank you very much. Now the whole class will join in to see whether group A or B, the first group their reason was sufficiently cogent to be able to say is group A, they say the indigenous one takes...um...looks at it in a way that it doesn’t destroy some of the ingredients…um… and whether they are justifiable on that basis to say that’s why therefore A. The other 2 groups are viewing B from a different reasons…right...so...what is left for us is to be able to see whether we can agree with the reasons given by group 1 that because of the indigenous one. I thought they were going to emphasize the issue of nutrition…um… and that they look at the issue of fermentation when it is about 3-4 days of fermentation but they didn’t give reasons what might be the implications of that vis-à-vis the products of gari, what is the purpose of that fermentation? What is it supposed to do?

Rose: It’s the encouragement of the micro-organisms growth so that they can …um… the reactants that they cause between the cyanide and the micro organisms, it actually neutralizes the cyanide.

In his capacity as the project director Bola took over from Sami to interrogate the presenters further. The excerpt below provides only a slice of the discourse that followed:

Bola: Alright, so...you assume that the micro-organisms will have been able to digest the fibres as well as reducing the fibres and also dismantling the finer contents so that they can flow out with water, that is an assumption here so that is their own valid reason, they need to link their claim with that evidence. The fact that it was deeper in water for 3-4 days and then of course the question will pop in later of dangerous sifting by hand and not by destroying the whole material together. It’s a very fibrous root as you know; it can be very, very fibrous so the need to know it might also be ideal for digestion.

Ciwu: Ok...um...I think that part, I understand the purpose of micro-organisms in terms of the conversion of cyanide by in terms of fibres themselves which are more cellulose and...um…those micro-organisms don’t necessary attack, break down the cellulose fibres.

Bola: Do they have to break it down actually? Considering they have to digest cellulose.

Ciwu: Those that produce cellulose bacteria they will do so but I don’t know how much that process, it’s an assumption.

Emma: There’s an indication…yes…that the fermentation takes place over a longer period of time and that should allow the natural process to take place 3-4 days.

Bola: So we are talking of millions of bacteria multiplying, so all of them “walking and cooking” in the industry so there’s an element of validity in that sense, but the other case I must wait until it is mentioned by other people. Any other view why you think group 1 taking methodology A might be justified? Yes, Ciwu.

Ciwu: Can I just say a point on what Doc said over there was the multiplication of bacteria. I read an article that 2000 million bacteria are able to reproduce within 12 hours so within 48 hours already…sorry…3-4 days, you would have quite a bit of micro organisms that work there, so
definitely will ensure a better fermentation and a safer product.

**Alan:** But then in methodology B, its 5 days.

**Bola:** We’re coming to that now...so let’s now go to group B, Eddy’s group, their own argument is that....

**Rob:** Are we finished with this one here?

**Bola:** For now yes.

**Rob:** She was talking about the quality...the nutrients in the product itself, its exposed to high temperatures, that’s something maybe I can support them on that and that claim also, but with regard to the nutritional quality of the food, if we go that route, then I can support A.

**Bola:** Ok, so the point you are saying is that you can provide it as an additional evidence that the higher... most of the thing you put in a claim...a very high temperature so you add to a 200˚C sometimes, but the local people would not have been able to generate that heat...intensive heat...there is no doubt that its very hot. Do you know the difference between sea salt and ordinary salt? Sea salt is produced and dried by the sun and its much better salt than the one in the cave because the other one is put in a hot oven and that’s why many people...it’s not advised...to people who are health conscious don’t want to use ordinary salt because of the extremely high temperatures in which it has gone through and people with cancer are discouraged to take normal salt and people with high blood pressure are discouraged from taking it because of the process. So first of all food quality it’s safer but the side effect is that it destroys the nature of the food, it changes the structure of the food itself. So these are some of the breakdowns but nevertheless, your point is made. Let’s go to group 2...your major reason is the...in terms of intentional fibre, if I got it correctly.

**Bola:** It could last much longer, ok, so that your focus as evidence is that it’s an assumption, further evidence shows that it would be able to last longer, it was well dehydrated like the ones we have here, I don’t know how old that one is but the one I got the other day was more than 5 years already...so I mean and none of you has mentioned rivers, which is very terrible with starch and littering food. This one doesn’t go with rivers, no matter how long a gallery estate, you’ll never find a river, something must be in there maybe... [Sigh]...it gets its moisture from atmosphere.

**Dan:** I think that when something is fermented it makes it a bit acidic.

**Bola:** Because of the alcohol content...this gets alcohol or alkaline content is retained and create a colour of detergent...and also has a good taste and they put it in a liquid then they run away from it or they lay their eggs on that and do it willingly, these are some of the...where there is no right or wrong answer to see a reason because that one wanted to develop my learners: what are the reasons they are giving? Can we support their reason? And in science not everything is always right or wrong. Two views will even be complimentary to each other alright...so group 3, in defence of their own position if i got it correctly is relating to the issue of preservation as well.

**Ciwu:** It was optional that we were also looking at the texture.

**Bola:** Plus sifting, what is the advantage of sifting?

**Ciwu:** It’s to make a more a more final product, sifting if it’s optional, then we’ll be leaving the fibres or whatever that was there and that’s what we saw in the product.

**Bola:** In terms of the appetite or whatever, what is an advantage of a sifted product?

**Ciwu:** More proteins.

**Eddy:** If you look at sugar, the ordinary one that we use, the white sugar versus the brown sugar. The white sugar is more refined, processed one versus brown sugar is high in nutrition or the better quality one, less refined. So when we looked at the two samples, what stood out was, the one was very fibrous, the cream one and therefore i would say that one was less refined, it didn’t go through the sifting process.

**Bola:** Alright. Thank you. What levels of argument have we seen so far in the 3 groups? Claims and claims...counter claims? Alright...any level 2?

**Rose:** we have claims so that’s level 2

**Bola:** Ok. Any level 3 any rebuttals, grounds...anyone with a rebuttal to make it level 3 in all this?

**Rob:** I think Bola stopped the groups before they could come up with any.

**Bola:** ok, let us hear what the rebuttals are

**Rose:** In our discussion, we attempted to provide a rebuttal in that, we mentioned that we can’t make an
informed decision since we don’t have any sample for all the three methodologies and also that we
could not test for nutritional value as we don’t have the apparatus. We believe that is our rebuttal.

Bola: Ok alright, you are saying in other words, they’re just assuming that the one is better quality than
the other though they didn’t do full tests so you couldn’t make such claims, so that’s trying to
counter or rebut the position that indeed this one is more nutritious than the other. Any other
rebuttal? Yes Ciwu…

Chris: I think we’ve made a point that the normal assumption understanding of cereals and so forth, when
you can see fibres, the presence of fibres themselves indicates the high level of protein and is
nutritional. In itself I don’t need to necessary have instruments to actually measure it.

Bola: So you are referring to the presence of certain things are suggesting that fibres are there, there’s a
good product.

Ciwu: And therefore even the 5 days to 3-4 days because the other one says 5 days and the other 3-4 days
which is not much difference therefore, the product indicate that 5 days was sufficient to break up
the fibres that are present in the product,

Bola: Because you can still see the fibres

Ciwu: Yes, because I still have the fibres in the product so the question of having to say it was 5 days, it
doesn’t warrant the evidence that we have and that the difference is significant.

Bola: Then we have to test, we will not do the full test, other than just predicting because we are only
predicting that one is likely to have this, still retain protein, the fibre we can see as one of them but
that of protein, we have to see whether any of any protein is there by full test and other
mechanisms. We haven’t gone beyond, there’s a tree. We haven’t gone beyond whether now we
will be having more rebuttals. The more rebuttals, the more we are, moving up 4, 5, and 6…yes…

Ruti: Um… in our discussion we looked at these processes and we decided they were all valid processes
as they could come up with a dry product and since we didn’t have the knowledge of varieties of
cassava and the different methods used to produce them. We said that each of these processes will
probably have valid ways of making curries but they were relevant to different varieties because of
their different properties in terms of moisture, texture or whatever...

Bola: So, the whole assumption is that each one leads to a valid product which is valuable but in terms
of dryness, they all end on something but it probably ‘they are not of the same taste, quality as
well but then they serve different purposes

Eddy: Then also coming up with a decision in terms of the product itself and in terms of the process
itself, there were no guidance given in terms of production whether it was a small scale
production. These are suggestions and the product we had in front of us maybe in a small scale
maybe associate it with A because there is no big machinery involved there or associate it with B
because they’re talking about pottery drying there so maybe with those as I’m saying that making
a decision in terms of the product itself, in terms of which process is that you have to take a stand
and say it’s a small product then you can go with A or B or whether a big scale product then you
can go with C.

Bola: Ok, so that’s your argument. So we are not informed whether they used the modern methods
addition or whether it’s a large scale production or just an excuse. In other words we need
additional information other than this table in order to be able to make judgment or right decision,
that’s also better. Yes Dan.

Dan: Ok, when I look at the sequences of steps, I think method A and method C will not result in curie.
It will not result in giving something green like starch. If you look at method A after washing,
nothing is talked about crouching first, you steep the whole cassava first, even the san were talking
about, you are steeping the whole cassava and not get broken down so you steep the whole
cassava. The next step after steeping before you crouch for 4 days, which by normal biological
process will be fermenting or it will be getting soft in 3 -4 days. After that time you crouch, so
then method C, after washing, you steep it for 48-72 hrs at room temperature then you sift, to sift i
think you sift something when it is in grain, if grain so that the grains can pass through the holes of
the grater, so that is contradictory. The process there you will not be able to find the final product.
If you follow that manner, you will see that A and B more further to the end product.

Bola: That’s good and valid points as well

Eddy: When I look at A, the first step is actually, the size production of cassava before you go to washing
and stepping. You can ...the first stage as you could...your size production where you could break
up cassava pieces before you wash it and then it goes to the sifting and fermentation.
Bola: So you assume that the height you need something to break it down to make it smaller?
Eddy: before it goes to fermentation
Dan: But that’s optional, then the crouching is after the steeping, breaking into finer things then the reduction in size that one is different from the crouching because crouching because crouching later on
Bola: But will the whole cassava now because of the fermenting even if you can squeeze it in your hand it becomes very soft because I’ve seen casual like that and so soft in your hand so you don’t need too much effort to play with that one even in your hand it can be crouched because of the fermentation process, that’s why the assumption is like that. It’s a very soft material now after the fermentation. All the points you’ve mentioned are important. There are still a lot of bakkies here, in other words assumptions, there are a lot of assumptions here, I believe in that this smaller size it was at the crush somehow, but it has come to such an extent that crushing is very simple, you can use your hand, store whatever it is to crush it. Isn’t it? That’s the assumption.
Dan: But if it did go to that level then it will not produce grains
Bola: You have lumps than grains. My own concern is that 3-4 days, we’re not told the dates after that, before you start sifting it, fermentation period even before the crouching and the drying we don’t know the time interval alright, that’s the major problem that i have and somebody who has been in that area before it takes a while for it to really get to drying it. Talking about fermentation, the watering here ferments it to hydroxyl gas, when you take the one that has been pressed down it’s still wet with washy-mushy, and something as a little bit dry but water is likely gone now. Between the intervals, it would have to see how many days of drying in a little bit. The drying would have been on rocks or on surfaces with high temperatures now because that one cannot dry in 3-4 days, it might take some days that time is crucial even if you say it would be in the sun for several days...4 days – 5 days that would have helped us. I think it’s an assumption that: of course it depends on the season of year, is it a rainy season or hot season or is it a windy day and so on. There are a number of rebuttals here which could have taken the argument higher and it will be striking on those things that are missing. Actual it’s now starting to back it. In other words because you don’t know you just assume that because you see grains. If I increase the pressure, what happen to the temperature? Things can boil at low temp, if I increased the pressure...so those are assumptions that scientists have, they are called backings. Certain things will happen if I do this, if then...you run to that one because information is given. You can’t talk grains unless there are ways of seeing them. By the time you see them, they are just light weight, they are crumpy, and you can see now all the fibres but I’ve tried this thing before. It’s a bit wet, it’s not dry like the one in front of me now, it’s still wet but now you can tolerate it in your hand. If you squeeze it you’re not likely to get water but it’s still wet. It takes quite some days sometimes a week or 2 depending upon how much sunlight is available. The only advantage is that the sunlight make natural drying, it will not be like putting it in a tin then in 2 or 3 hrs. It comes out almost red or if you put it in a big basin and you just flip flap, that’s what women usually do. The content is very hot but it’s not hot like you put it in the industrial oven which goes at temp of 1000-2000˚c that produces gold, that hot temperature. Food being thrown into that kind of environment is no longer the kind of food that you want to eat. The structure has been changed, whether now it’s still good for human consumption or for commercial purposes it’s alright.
Ciwu: Specifically for food, they mostly use rotary dries
Bola: If they had mentioned that here it would have helped us to know what kind of dryer they used because the one that uses mostly wind...because what the women do is certainly throwing to the wind. How those do not fall in the ground I still don’t know. I mean it flies in the air just like that and then within a matter of 15 minutes that one is ready, another one is poured in and then they throw it up.
Ciwu: They do that sump as well, you mill it first then you do that
Bola: So how it’s very dry and then it depends how you keep it dry after that and keep it away from moisture. Alright, I think we are making some progress now, for that its showing us how much we can do because we are doing two things at the same time. In the meantime, we are looking at argumentation as well.

Discussion
Since the purpose of the study was to examine possible impact of argumentation-based activities on teachers’ ability to critically analyze a classroom discourse and co-construct knowledge relative to the preparation and production of gari, a staple African food we will now attempt to enumerate the key elements, as we see them and interrogate the findings with literature. From the data presented above in table 2-4, teachers carefully studied the process flow charts and identified critical control points essential for product quality, safety and storability. As espoused by Bencini (1991) all three groups presented valid arguments on the principle of preservation and processing of cassava to say that cassava is fermented to remove cyanide and produce the desirable flavours. Group 2 in table 3 of the TAP argued in their evidence that the dry product appeared to be roasted. This valid statement that made Group 2 to choose method B is affirmed by Steinkraus (1983) that gari is roasted to destroy enzymes and microorganisms, to drive off cyanide gas, and to dry the product. Preservation is achieved by heating during roasting. Low moisture content inhibits recontamination by bacteria. Packaging is needed, especially in areas of high humidity, to retain the low moisture content.

Related to the issue of quality, Group 1 argued that in methodology A, the sorting, the peeling and the washing were critical points which were addressed sufficiently. On the same issue of hygiene, Flach (1990) asserts that fresh cassava is a moist, low-acid food that is susceptible to bacterial and fungal growth. Hygienic practices, especially in the early stages of processing, should therefore ensure minimal contamination. Washing should be carried out thoroughly to avoid contamination of the final product with peel, sand, and so on (Vasconcelos, Twiddy, Wetby & Reilly, 1990). Drawing from the video transcription, Group 3 presentation emphasized on the granular texture, the powdered form and the white colour vis-à-vis the cremish colour and a bit on fermentation as critical control processes. In his study, Scott (1992) contends that fermentation must be properly controlled, as too short a period will result in incomplete detoxification and a bland product which eventually will compromise product quality, safety and shelf-life. Too long a period will give the product a strong sour taste. Both over- and under fermentation also badly affect the texture of the final gari. If too much liquid is pressed from the grated cassava, the gelatinization of starch during subsequent roasting is affected and the product is whiter. If sufficient liquid is not removed, however, the formation of granules during roasting is affected and the dough is more likely to form into lumps. The ideal moisture content is 47-50%, and this is assessed visually by experienced gari producers (Vasconcelos, Twiddy, Wetby & Reilly, 1990).

During the whole class discussion and dialogue Rob, the leader of Group 3 shifted from method B to A and back to B later in the conversation. Rob was quoted in the transcription on page 6 saying …but with regard to the nutritional quality of the food, if we go that route (referring to Alan in an earlier conversation), then I can support A. Through dialogical argumentation learners articulate their reasons for supporting a particular claim and then strive to persuade or convince others about the truthfulness of such a claim (Ogunniyi & Hewson, 2008). In this particular case, argumentation-based activities manifest that dialogue creates a lot of anxiety as new data arise or when more divergent views are brought forward. This proves the point that when individuals begin to externalize their thoughts and verbalize their fears and misgivings as espoused by Ogunniyi (2007a) they tend to expose their intra level of argument and try to find an anchor.

In his capacity as the project director Bola took over from Sami to interrogate the presenters further. By so doing, Bola played the role of a teacher by creating opportunities for critical comments such that the several subjects were able to externalize their doubts, clear their
misgivings or misconceptions, reflect on their own ideas and those of their peers in order to arrive at a clearer and more robust understanding of the topic than would have otherwise been the case.

By argumentation practices we mean adding complexity to claims, elaborating justifications, co-constructing arguments, offering rebuttals or adding modal qualifiers (Lima-Tavares, Jimenez-Aleixandre & Mortimer, 2010). A point in case is on page 7 when he asks the whole class at what levels of argument have they been so far in the 3 groups? Rose interrupted that they had claims so that is level 2 and he continued to probe “Ok. Any level 3, any rebuttals, grounds...anyone with a rebuttal to make it level 3 in all this?” as espoused by Erduran & Osborne (2004).

There was a unanimous agreement among the teachers at the end of the whole class session that the argumentation-based laboratory activities helped them to clarify their views as well as enhanced their understanding as they co-constructed ideas about how gari was produced and prepared for storage. In terms of the TAP, the teachers’ arguments ranged between levels 0, 1, 2 and 3 i.e. one step further to a similar earlier study (Siseho & Ogunniyi, 2010). In the final analysis it became evident that the teachers had begun to develop some skills in argumentation-based laboratory activities which hopefully they would be able to implement in their classrooms. At this stage the teachers have been able to put up arguments with or without claims or counterclaims with grounds and few rebuttals challenging the claim. However, the teachers still have a long way to go in using an argumentation-based lesson confidently in their classrooms.

Conclusion

The didactic representation for ratifying a dialogical argumentation-based dissertation is a communicative model arising out of the succession of seminars and has been conducted successfully based on empirical evidence (e.g. Ogunniyi, 2007a &b). The outcome of the didactic schema was the realization of some level of cognitive synchronization on the part of the participating teachers on the basis of credible evidence and warrants. During the classes of dialogical argumentation, individual teachers experienced cognitive arguments in terms of the conflict between their worldview and that of science. However, as they got involved in the discourse and listen to the views of others they begin to find answers to their puzzles. Although certain claims and grounds may be rebutted at each stage of the argumentation processes (individual task, small group task and whole class discussions), individuals and groups are persuaded to reach some level of consensus where feasible especially where claims and grounds adduced by others seem convincing. According to Kwofie (2009), once cognitive harmonization has been attained, the individual could be described as having reached cognitive optima.

The levels of argumentation are determined at each stage of argumentation (individual, group and whole class) to establish whether or not the teachers are developing high-level argumentations skills. Higher incidences of rebuttal of claims and grounds by colleagues involved in the argumentation discourses could lead to the attainment of high level of argumentation (e.g. Simon, Erduran, & Osborne, 2006; Ogunniyi, 2007a &b). Preliminary findings emerging from this study show that the teachers have begun to increase their conceptual understanding as well as developed some elementary high level argumentation. Similarly, the teachers appeared highly provoked to use dialogical argumentation in their classroom practice. However, in terms of the TAP, teachers’ arguments varied largely between 1, 2 and 3, that is uncomplicated claim versus counterclaim with no grounds or rebuttals and claims or counterclaims with few grounds and limited rebuttals. What emerged from this short study is that teachers have started appreciating the value of argumentation not only as a useful instructional strategy but also a tool for exposing the significant aspect of co-constructing scientific concepts.

References


Cognitive Skills and Strategies: Shouldn’t Greater Emphasis be Placed on Them in Education Courses?

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Abstract
Two aspects to the learning of any topic are knowledge of subject content and competence in cognitive skills and strategies. Many students’ difficulties in learning and applying chemical knowledge are associated with their being not sufficiently competent in a few widely applicable cognitive skills and strategies. This paper first identifies some of the cognitive skills and strategies that are important for the effective learning of science and then discusses the performance of matric and first-year university chemistry students and matric physical science teachers in some questions used by us to test competence in cognitive skills and strategies. The results indicate that about 70% of the students and teachers lack competence in the required cognitive skills and strategies, and that many who have the competence to use the strategies do not recognize the necessity for doing so. The results also suggest negative attitudes and lack of self-confidence in problem solving. There is therefore a need for the explicit training of students in cognitive skills and strategies. Such training should be integrated with the teaching of subject content.

Introduction
Two important aspects to the learning of any topic are:

- Knowledge of subject content
• Competence in the cognitive skills and strategies (also called intellectual skills and strategies or thinking skills and strategies) needed for the effective learning, storage (in memory), retrieval and application of content knowledge.

The main purpose of this paper is to try to justify, both by theoretical reasoning and by empirical evidence, the need for the simultaneous training of students in the cognitive skills and strategies needed for the effective learning of any topic along with the teaching of subject content.

The term *skill* denotes the ability to do something well and hence *cognitive skill*, a skill associated with the mind, may be considered to be the ability to perform mental activities/operations well. Cognitive skills may be considered to be the basic “building blocks” of all mental activities. The term *strategy* denotes an overall plan of action for executing some task and a *cognitive strategy* would deal with the planning, guiding and execution of a cognitive (mental) task such as learning, problem solving and decision making. Cognitive strategies are generally “broader” than cognitive skills and the execution of a cognitive strategy would generally need competence in many cognitive skills.

Competence in cognitive skills and strategies is important for many reasons. It is needed for effective learning in education courses, and is particularly important for the performance of higher order mental tasks such as analysis, synthesis and evaluation (Bloom, 1956). Such competence also seems to be the most important factor determining the Intelligence Quotient (IQ) of a person (Hunt, 1995; Alloway and Alloway, 2010). Competence in cognitive skills and strategies can also be expected to foster positive attitudes, increase self-confidence, simplify learning and promote ability to solve problems encountered in our daily lives.

There are many types of cognitive skills and strategies and they have been classified in different ways. Detailed classifications are given in the books by Marzano *et al* (1988) and Jones and Idol (1990). Simpler classifications are given by Beyer and Presseisen in their articles in the excellent book edited by Costa (2001).

**Objectives of the Paper**

The main objectives of the paper are to:

• identify some of the cognitive skills and strategies that are particularly useful in the study of physical science;

• briefly outline the criteria that must be satisfied by questions designed to test competence in cognitive skills and strategies;

• discuss some of the questions that have been used by the authors to study the competence of university students, matric students and matric teachers in cognitive skills and strategies;

• discuss the results of the study.

• emphasize the need and importance of training students in cognitive skills and strategies.
Important Cognitive Skills and Strategies

Some cognitive skills and strategies (Marzano et al, 1988) that are particularly important in physical science courses are:

*Cognitive skills*

- Mathematical skills
- Knowledge organization skills
- Information processing skills
- Three-dimensional visualization skills
- Reasoning skills (particularly direct proportion and inverse proportion reasoning)
- Analysis skills
- Synthesis skills.

*Cognitive strategies*

- Clarification and clear representation of problems
- Identification and sharp focusing on the goal
- Identification and use of principles for deductions
- Transformation of information in statements into equations
- Tabulation of the steps in the solution
- Proceeding step-by-step with the solution.

Criteria for Designing Questions

Two important criteria must be satisfied by a question if it is to test competence in cognitive skills and strategies. These are:

- lack of knowledge of subject content (e.g. concepts, principles) should not be the cause of any difficulty;
- the solution to a question must not be known to the respondents (to prevent recall of answer).

To satisfy the first criterion, all the concepts and principles needed to answer a question must be provided in the question itself, and these concepts and principles must also be as simple as possible, and not difficult to understand. To satisfy the second criterion, the questions used must be unfamiliar to the respondents. Selvaratnam and Mazibuko (1998) have elaborated on these criteria.

We have done a significant amount of research, at North-West University, on the cognitive aspects of learning and using scientific knowledge. This includes the development of models for problem solving (Selvaratnam, 1990) and explanations
Questions Testing Cognitive Skills and Discussion of Performance

Six questions that test competence in some widely applicable cognitive skills are given in this section and students’ and matric physical science teachers’ performance in them will be discussed. The importance of the skills will also be pointed out.

**Question 1**

For a non-ideal gas, the variable physical quantities are related by the equation \( p^{1/2}V = kT^2 \), where \( k \) is a constant. For this gas, at constant \( T \), will \( pV \) be a constant?

**Question 2**

A gas obeys the equation \( pV = kT \). Derive the equation that shows the relationship between the density \( d \) of this gas and pressure \( p \) and temperature \( T \). (Note: \( d = m/V \))

Questions 1 and 2 test competence in two important **mathematical skills** that are essential for dealing with equations. The understanding of equations and ability to use them for calculations and deductions is very important in physical science and all quantitative sciences.

**Question 1** tests ability to deduce correctly the information provided by the equation \( p^{1/2}V = kT^2 \). This equation shows that when \( T \) is kept constant \( kT^2 \) will be constant and therefore that \( p^{1/2}V \) (and not \( pV \)) will be constant. About 85% of the 73 matric physical science teachers from 50 Dinaledi schools who were tested with this question (Selvaratnam, 2010b) and about a half of the 300 first year university chemistry students who were tested (Drummond, 2003; Drummond and Selvaratnam, 2009), thought incorrectly that \( pV \) was constant. These teachers and students did not know to deduce the information organized in the simple equation \( p^{1/2}V = kT^2 \). **Question 2** tests ability to combine the two simple equations \( pV = kT \) and \( d = m/V \). Though this is not a difficult task, about 35% of the 73 teachers tested were unable to answer this question.

Lack of competence in the cognitive skills needed to deal with equations will be a serious limiting factor in the learning of the quantitative aspects of any course. This is mainly because equations organize knowledge unambiguously and concisely and are hence easier to remember, manipulate and use. There are many advantages in using equations as frameworks for learning, organizing, storing (in memory) and using knowledge for calculations and deductions (Selvaratnam, 1998b). Many students and teachers do not recognize the usefulness of equations for making deductions. Since equations are storehouses of knowledge, they should be used not only for calculations but also for deductions.

**Question 3**
The questions concern the figure given, where the arrowed lines represent the X, Y and Z axes and the box is cubic.

(a) Is point F at a higher level, same level or lower level than point A?

(b) Which face of the cube is opposite to face HGCD?

(c) Will the angle ADH (labelled \(a\) in the figure) be \(90^0\), less than \(90^0\) or greater than \(90^0\)?

(d) Will the angle ABF (labelled \(b\)) be \(90^0\), less than \(90^0\) or greater than \(90^0\)?

This question tests *three-dimensional visualization skills*. It tests ability to visualize three-dimensionally the drawing of a cube (drawings are always two-dimensional). About 15\% (average performance in all parts) of the 73 Dinaledi teachers tested were unable to answer the question correctly despite the fact that the cube is a simple structure (Selvaratnam, 2010b). In a similar question given to first year university students, about 35\% had difficulty (Drummond and Selvaratnam, 2009). Since three-dimensional visualization of two-dimensional drawings (e.g. drawings of the structures of molecules and internal structures of solids) is important for understanding many aspects of chemistry and physics, any lack of competence in this cognitive skill will handicap learning.

**Question 4**

Three men need 12 hours to tile the floor of a house. How many hours will be needed by four men, working at the same rate, to tile the floor of a house?

This question mainly tests *inverse proportion reasoning skills*. Though this is a familiar type of problem encountered in our daily lives, about 60\% of the 73 teachers tested were unable to solve it correctly (Selvaratnam, 2010b). In a similar problem given to students about 70\% of them had difficulty. Most of the erring teachers and students gave the answer as 16 hours, even though this contradicts “common sense” (four men should *not* need more time to do a task than three men). This suggests that the principle (inverse proportion relationship) that has to be used to do the calculation is not first identified. Direct proportion reasoning and inverse proportion reasoning are of fundamental importance not only in science but also in our daily lives. It is important, therefore, that students are repeatedly trained to ensure that they become competent in them.
Question 5

Consider the following two statements: All mammals are warm-blooded animals; Animal A is warm-blooded. Would it be true to conclude from the two statements given above that A is a mammal? Explain your answer.

This is a question in symbolic logic. From the two statements given it cannot be concluded that A is a mammal. Perhaps the simplest way of showing this is to represent pictorially all the information given in a Venn diagram, as shown below. This diagram shows clearly that A can be warm-blooded without it being a mammal. About 60% of the 73 teachers tested were unable to answer this question (Selvaratnam, 2010b).

Questions on Cognitive Strategies

Many questions on cognitive strategies have been used by us to test competence of many groups of students (and also some teachers). Seven of them are given below, together with a discussion of students’ and teachers’ performance.

Two types of difficulties associated with the use of a strategy for problem solving are:

- Lack of recognition of the need for the use of a particular strategy;
- Lack of competence in the cognitive skills needed to execute the strategy.

A method which has been suggested (Selvaratnam and Mazibuko, 1998) for distinguishing between these two types of difficulties involves comparison of students’ performance in a “standard” question with that in a “hint” question. The only difference between a standard question and a hint question is a hint in the latter question that suggests the strategy that should be used to solve the problem. Twelve questions have been used in one of our studies (Drummond and Selvaratnam, 2008) to test cognitive strategies using standard and hint questions, and the hint form of seven of these questions are given below. The standard questions were the same but did not have the hint.

Question 6

Atom A is heavier than atom B but is lighter than atom C. Atom D is lighter than atom A but is heavier than atom B. Atom B is heavier than atom E. Which atom is the heaviest?

Hint: Use the information given in the data to arrange the atoms in the order of increasing masses on the line given below, before answering the question. The first piece of information (atom A is heavier than atom B) has been indicated in this line.
This question mainly tests whether students use the important strategy of clarifying the problem and representing it clearly, as the first step in its solution. The question involves the comparison of five items of information to decide which atom is the heaviest. To remember five items of information in our working memory (short-term memory) and compare them mentally is a difficult task (Johnstone, 1997; Eggen and Kauchak, 2007). The solution will be much easier if the items of information are coordinated together in a line diagram, as suggested in the hint. The answer may then be obtained easily from the line.

In the standard question, 60% of the 300 students tested solved the problem correctly. Of these, about 25% showed, in their answer scripts, the arrangement of the atoms in a diagram. Since it would be difficult to answer this question without some sort of arrangement to compare the data given, it is likely that the successful students arranged the data in one place, though they did not show this in their answer scripts. In the hint question, there was a significant improvement in student performance. Of the students who failed the standard question, 25% were able to answer the hint question correctly. This suggests that these students had the ability to represent the information given on a line, but failed because they did not recognise the necessity for doing this. Despite the suggestion in the hint to arrange all the data on one line, about 30% of the students did not do so. They may either have had language difficulties that resulted in their being unable to carry out the simple instructions given or they lacked self-confidence which prevented them from trying to proceed with the instructions. There is therefore a need for checking, and then ensuring, whether students are able to carry out simple instructions and tasks, without assuming that they can do so. A similar question, with the hint, was tested on 73 matric physical science teachers from about 50 Dinaledi schools. About a half of them were unable to answer the question (Selvaratnam, 2010a).

**Question 7**

A substance has a melting point of -25°C and a boiling point of 85°C. Is this substance a solid, a liquid or a gas at -10°C? (Note: Any substance exists as a solid below its melting point and as a gas above its boiling point.)

*Hint:* Use the diagram shown below that indicates the melting point, boiling point and the different phases of the substance, to answer the question.

This question, like Question 6, checks whether students recognise the importance of a
clear pictorial representation for successful problem solving. The solution to this problem is easy if we represent the melting point, boiling point and phases of the substance in a diagram, as shown in the diagram given in the hint question. The diagram shows that the substance will be a liquid at \(-10^0C\).

In the standard question, only about 40% of the 300 students tested solved the problem correctly. Their performance in the hint question, which had a diagram relating the melting point, boiling point and phases of the substance, was much better. About 30% of the students who gave incorrect answers in the standard question were successful in the hint question. These students understood the diagram and were able to use it to deduce the correct answer. About 40% of the students, however, were unable to deduce the answer from the diagram, even though the diagram is fairly simple. This suggests the need for training students in very basic intellectual abilities, such as how to obtain information from diagrams (particularly from diagrams that are unfamiliar) and also on how to represent information as diagrams. This question did not test students’ ability to draw a diagram from the data provided, which is a more difficult task. Training in these skills is important, not only because it would lead to more successful problem solving, but also because it would build up the self-confidence of students. A similar question given to 73 matric physical science teachers showed that about 30% of them were unable to answer correctly (Selvaratnam, 2010a).

**Question 8**

3.00 g of phosphorus pentachloride (vapour) are heated in a closed 1.00 dm\(^3\) container at 300°C. It then partially dissociates according to the equation

\[ \text{PCl}_5 \text{(g)} \rightleftharpoons \text{PCl}_3 \text{(g)} + \text{Cl}_2 \text{(g)}, \]

to give 0.50 g of Cl\(_2\). Calculate the density of the *gaseous mixture* present in the vessel after dissociation.

(Note: Density is defined as the mass per unit volume. P = 31.0; Cl = 35.5.)

**Hint:** Calculate the density of the gaseous mixture \((\Delta_{\text{mixture}})\) by using the equation

\[ \Delta_{\text{mixture}} = \frac{m_{\text{mixture}}}{V_{\text{mixture}}}, \]

where \(m_{\text{mixture}}\) and \(V_{\text{mixture}}\) are respectively the mass of the mixture and the volume of the mixture.

This question tests whether students start the solution with the defining equation for the required quantity, \(\Delta_{\text{mixture}} = \frac{m_{\text{mixture}}}{V}\), where \(\Delta_{\text{mixture}}, m_{\text{mixture}}\) and \(V\) are respectively the density, mass and volume of the mixture of gases in the vessel. Since, by the law of conservation of mass, mass does not change during any chemical reaction, \(m_{\text{mixture}} = 3.00\) g. From the data \(V = 1.00\) dm\(^3\) and therefore \(\Delta_{\text{mixture}} = 3.00\) g / 1.00 dm\(^3\) = 3.00 g dm\(^{-3}\). Although the solution is easy, only about 30% of the first year university students answered the standard problem correctly. The answer scripts showed that about 30% of the erring students used the defining equation for density for the calculation but they substituted incorrect masses: some substituted 0.50 g (the mass of Cl\(_2\) given in the data), and some added or subtracted the masses (3.00 g and 0.50 g) given in the data. A few students even multiplied the mass of each gas by its molar mass! It appears from these answers that many students try to solve problems by merely manipulating the data given; they do not try to get a picture of the problem and identify the principles needed for the
solution. Student performance in the hint question was much better, about a quarter of the students who failed the standard question were successful in the hint question. These students’ failure in the standard question may therefore be attributed to their not using the strategy of starting the solution with the defining equation for the required quantity. A similar question, without the hint, given to 73 matric physical science teachers from about 50 Dinaledi schools showed that about 40% of them had difficulty (Selvaratnam, 2010a).

**Question 9**

The mole fraction of a gas A in a mixture of two gases A and B is 0.20 when the pressure is 200 kPa. What will be the mole fraction if the pressure is increased to 400 kPa?

(Note: (a) the gases do not react with each other; (b) the mole fraction of A is, by definition, equal to the moles of A divided by the total moles.)

This question, like Question 8, tests whether students focus on the relevant defining equation for deductions. The defining equation shows that mole fraction depends *only* on the moles of substances present in the mixture. Since moles of substances do not depend on pressure, mole fractions cannot depend on pressure. The mole fraction therefore will not change when pressure changes and its value will therefore be 0.20. Only about 10% of the students and 15% of the teachers tested recognised that mole fraction does not depend on pressure. About 30% of them thought that mole fraction would be doubled (i.e. they implicitly assumed that mole fraction is directly proportional to pressure) and about 15% thought that it would be halved. Since mole fraction is a concept that may be unfamiliar to students, its defining equation was included. This question was not given as a hint question. Students’ and also teachers’ performance in this question again illustrates that most of them do not focus on the goal to solve problems. It is our experience that many students merely manipulate (add, subtract, multiply, divide) the data given, without much thought or understanding, in their attempt to obtain the solution. Often students seem to think (incorrectly) that two quantities have to be either directly proportional or inversely proportional to each other.

**Question 10**

The volume of 1.00 kg of water (which is a *liquid*) is 1.00 dm$^3$ at a pressure of 100 kPa. When the pressure is doubled, its volume will be

(a) 0.50 dm$^3$  (b) 1.00 dm$^3$

(c) 2.00 dm$^3$  (d) the volume cannot be calculated from the given data.

Select the correct answer and briefly indicate your reasoning.

*Hint:* Decide first whether there is an equation that relates the volume of a *liquid* to the pressure. Is volume inversely proportional to pressure, for a *liquid*?

This question tests whether students use the important strategy of first identifying the relevant laws and principles and then use them to solve problems. It concerns the variation of the volume of a *liquid* with pressure. Since the volume of a liquid decreases slightly with increase in pressure, response (d) will be strictly correct. Response (b) was also taken as correct because the volume decrease is very small. In the standard question, only a quarter of the students selected the correct response. Of the students who chose
incorrect responses, about a half of them thought that volume of water is inversely proportional to pressure. The other half seem to have merely manipulated the data. Student performance in the hint question was much better: about 20% of the students who chose incorrect responses in the standard question chose the correct response in the hint question. These students therefore recognised, when prompted to think about it in the hint, that volume of water is not inversely proportional to pressure. Their initial error was probably because they rushed into the solution without identifying the principles involved. The probing question in the hint “Is volume inversely proportional to pressure for a liquid?” did not, however, help the other students. They did not make an attempt, or were unable, to identify the principles involved and apply them. They again seem to have merely manipulated the data given, without much thought and mental effort.

**Question 11**

A closed vessel contains a mixture of two gases A and B at a temperature $T$ and pressure $p$. The mass of A is 1.2 g and the total mass of A and B is 2.0 g. The gases do not react with each other. What will be the mass of A present in the vessel if the pressure is doubled from $p$ to $2p$?

This question, like Question 10, tests whether we recognize that to solve any problem it is necessary to first identify the principles that need to be used to obtain the solution. The problem involves a basic physical quantity (mass) which will therefore not depend on any other quantity. Mass of A will therefore not depend on pressure and hence it will remain unchanged at 1.2 g. Despite its simplicity, about a half of the 73 matric teachers tested had difficulty. Most of them thought incorrectly that mass will be doubled when pressure is doubled. Their error was probably due to their not attempting to identify the principle that needs to be used for solving the problem. Though no principle relates mass and pressure, most teachers implicitly assumed (probably without much thought) that mass would double when pressure is doubled.

**Question 12**

Use the equation $t = k/N$ (where $N =$ number of men employed to do some task, $t =$ time needed to do the task, $k$ is a constant), to calculate the time needed for four men to do some task if three men need 12 hours to do the task.

This question was used to check whether the important strategy of proceeding step-by-step was used for obtaining the solution. To calculate the time ($t$) needed by four men ($N = 4$) to do some task, using the equation $t = k/N$, the value of $k$ must be known. Since this is not given, the first step in the calculation must be to calculate $k$ using the data given. Using this value of $k$, the required time can then be calculated (answer is 9 hours). Though this is an easy calculation, it was surprising that about 45% of the 73 matric physical science teachers tested could not do it. Their answer scripts showed that the main reason for their difficulty was their attempting to do the calculation in one step, by applying the given equation just once. The equation has to be applied twice and this requires step-by-step reasoning.

**Importance of Cognitive Skills and Strategies**

Cognitive skills and strategies are the “tools” of all mental activities. Competence in them is therefore essential not only for meaningful and effective learning in classrooms and
education courses but also for success in our daily lives.

First we consider learning in classrooms and education courses. Competence in cognitive skills and strategies will help to simplify the organization, storage (in memory), retrieval and use of knowledge. It will promote more meaningful learning and also help avoid errors during problem solving. We illustrate the usefulness of cognitive skills and strategies by considering the topic “equations” as an example.

The use of equations, mainly because they are concise and organize knowledge unambiguously, is in our experience the best method for storing and using quantitative knowledge. To do this, however, requires competence in the cognitive skills and strategies that are needed to perform the following operations: identify the information organized in equations (see Question 1 in this article); transform quantitative statements into equations; manipulate and rearrange equations; combine equations (see Question 2) and use equations for calculations and deductions.

To illustrate the importance of cognitive skills in the effective organization of knowledge, consider the ideal gas equation \( pV = nRT \), where \( p \) = pressure, \( V \) = volume, \( n \) = amount, \( T \) = temperature and \( k \) is a constant. This equation incorporates Boyle’s law \( (pV = k) \), Charles’ law \( (V = kT) \) and Avogadro’s law \( (V = kn) \). It is therefore not necessary to remember the equations, statements and graphical representations of these three laws because they can be deduced from the equation \( pV = nRT \), provided that one has the needed cognitive skills. Just remembering the equation \( pV = nRT \) is sufficient; memorizations of the three laws are not necessary. This would simplify learning because just one equation has to be memorized.

Competence in cognitive skills and strategies is also needed for making deductions from equations. To illustrate this statement, consider the question, “How does the density of an ideal gas depend on pressure?” To answer this question, one should make use of the following strategy: derive the equation that relates density and pressure and then use this equation for making the deduction. This strategy is very widely applicable and is much better than the use of verbal reasoning for deductions.

Now we consider the positive influence competence in cognitive skills and strategies will have in achieving success in our daily lives. Increased competence in them will lead to an improvement in intellectual abilities (IQ), increase self-confidence, foster positive attitudes and help us to solve problems encountered in daily life.

**Conclusions**

Increasing the competence of students in cognitive skills and strategies should be an important learning outcome in all educational courses. This would lead not only to more efficient learning in classrooms but also to an increase in their self-confidence and ability to solve problems encountered in their daily lives. Many research studies, as illustrated in this paper, show that most students do not have sufficient competence in the cognitive skills and strategies needed for learning efficiently. There is therefore a need for the explicit training of students in cognitive skills and strategies and to ensure that they are competent in them. Such training should be integrated with the teaching of subject content knowledge.
References