27TH ANNUAL CONFERENCE OF THE
SOUTHERN AFRICAN ASSOCIATION FOR RESEARCH IN
MATHEMATICS, SCIENCE AND TECHNOLOGY EDUCATION

15 January – 17 January 2019
(Venue: Southern Sun Elangeni Maharani Hotel, Durban)

Hosted by University of KwaZulu-Natal
Durban, South Africa

Conference Theme:
Research for inclusive, relevant and equitable quality Mathematics, Science and Technology Education: Promoting research-based opportunity for all

BOOK OF PROCEEDINGS

Edited by N Govender, R Mudaly, T Mthethwa & A Singh-Pillay
Proceedings compiled by M Good & L Molefe

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SAARMSTE Book of Proceedings 2019

27th Annual Conference of the Southern African Association for Research in Mathematics, Science and Technology Education (SAARMSTE)

Tuesday 15 – Thursday 17 January 2019

Hosted by University of KwaZulu-Natal, Durban, South Africa.

Theme: Research for inclusive, relevant and equitable quality Mathematics, Science and Technology Education: Promoting research-based opportunity for all


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Message from the SAARMSTE President 2019

“If you want to walk fast, walk alone, but if you want to walk far, walk together”

African Proverb

SAARMSTE was born in 1993 and in 2018 it turned 25 years old and not out! This milestone is indeed by no means a small feat and as such it is worth celebrating. On behalf of the SAARMSTE Executive committee, we would like to pay tribute to all the champions over these years of this prestigious and dynamic organisation, whose mission and vision is the advancement of research in MSTE in Southern Africa. Admittedly, had it not been for their vision, hard work and selflessness, SAARMSTE would not be where it is today. In all these years SAARMSTE emerged as a formidable and significant developmental organisation. The fact that it still ‘walks’ tall today is a testimony to the richness, depth and most importantly, the Ubuntu of the SAARMSTE research community. Of course, it should be acknowledged that SAARMSTE still exists because of the efforts of hundreds of dedicated scholars, something which has resulted in massive achievements over the years. The highlight, for instance, was that SAARMSTE as an organization was nominated as a finalist in the South African National Science and Technology Forum (NSTF) awards in 2018 and was represented by Professor Hamsa Venkat in her capacity as chairperson of the Research Capacity Building Committee (RCBC).

SAARMSTE continues to innovate and respond to the advancement of relevant and quality research in MSTE in the SADC Region and beyond. Over the years different universities have successfully taken responsibility for growing our organisation by hosting conferences. For instance, the 2019 SAARMSTE Conference will be hosted by University of KwaZulu-Natal (UKZN) and we would like to extend our sincere words of gratitude to the UKZN LOC under the leadership of Professor Nadaraj Govender. We are also indebted to all the scholars who despite their hectic work schedules generously volunteered to review short and long papers for the conference.

We are also honoured to have the following internationally renowned plenary speakers in the 2019 conference:

- Professor Robert Berry, Associate Professor in Curriculum Instruction and Special Education, in the Curry School of Education, University of Virginia and he is NCTM President;
- Professor Judith Lederman, Associate Professor and Director of Teacher Education, Department of Mathematics and Science Education at Illinois Institute of Technology, Chicago; and
- Professor Busisiwe Alant, Associate Professor in Technology Education at the School of Education, University of KwaZulu-Natal.
As an innovation for our SAARMSTE 2019 conference, in addition to our prolific plenary speakers, we have a dynamic team of panel speakers and these are:

- Science Education: Professor Elizabeth Mavhunga and Professor Jan van Driel; and
- Mathematics Education: Professor Zain Davies and Dr Samantha Morrison.

I know we will all enjoy and benefit significantly from their contributions and from the accompanying conference deliberations and discussions.

On behalf of the SAARMSTE community, I would like to acknowledge the great work done by our Executive Committee members over the past year and thank them. We are all indebted to them. I have invited, as is the practice, to each to give us a sample of some of the things they have done for SAARMSTE in 2018.

As past SAARMSTE’s president, Lyn Webb has supported the executive in many ways and co-ordinated the organisation of the Long Paper Reviews for the 2019 SAARMSTE Conference. She will remain involved with SAARMSTE events as Treasurer of the Eastern Cape Chapter.

Hamsa Venkat and the Research Capacity Building Committee worked with Mdu Ndlovu, Pauline Hanekom and their broader LOC team at Stellenbosch University to arrange another highly well-received Research School in Western Province in June 2018. Mercy Kazima, Busi Alant and Judith Bennett participated as external expert facilitators. A stand-alone early career scholar strand was instituted for the first time in 2018. Both doctoral researchers and early career scholars offered very positive evaluations of the Research School. The Research School has broadened its base of support across Southern African institutions and further afield. Planning is already underway for the 2019 Research School.

Audrey Msimanga and Washington Dudu kept the Chapters up to date with events and activities. Chapter activities included several well-presented and attended colloquia – Eastern Cape; North West Province; Namibia; Zimbabwe; Swaziland and an emerging Zululand chapter symposium. Additionally, Washington assisted with monitoring the review process of long papers.

Fred Lubben, Editor of AJRMSTE, has negotiated a very favourable contract with Taylor & Francis going forward. He has also compiled an electronic Special Issue in 2017/18 of the best articles published in AJRMSTE in the last 10 years. Along the way, he continues to regularly orchestrate Writing Workshops during the year and has coached developing researchers into becoming published authors.

Tulsi Morar has kept SAARMSTE finances in check, so that we can celebrate achieving the milestone we set ourselves three years ago. SAARMSTE is becoming self-sustaining through his vigilant eyes.

Carolyn Stevenson-Milln makes sure the wheels turn smoothly. She has once again run the online paper submission and registration for the conference and deals with queries and requests with a quiet efficiency – and sense of humour. Additionally, Carolyn has assisted with the programme for the SAARMSTE 2019 conference.
The theme of this year’s conference is: “Research for inclusive, relevant and equitable quality mathematics, science and technology education: Promoting research-based opportunities for all”.

The theme for the panel discussion is: “Should Southern African MST Education research prioritize focus on studies that can feed directly into development initiatives”?

We look forward to discussing, debating and sharing ideas and experiences in the warm and nurturing environment of the SAARMSTE family.

Allow me to extend a warm welcome to all of you to the warm and beautiful Durban!

Kenneth Mlungisi Ngcoza
Reviewing Process for SAARMSTE Long Papers 2019

All 6000-word long paper submissions were reviewed by at least two external reviewers.

Reviewers were selected from the list of reviewers for the accredited African Journal for Research in Mathematics, Science and Technology Education (AJRMSTE) published by Taylor & Francis. Other recognised researchers in the field of Mathematics, Science and Technology Education were also approached to be reviewers.

The reviewers’ decisions and developmental comments were considered by members of the Review Panel. Where there was consensus, the reviewers’ recommendations were accepted by the Panel. Where consensus was not reached, the Review Panel appointed at least one other reviewer and all reviews were taken into consideration before a decision was made.

In cases where papers were accepted with conditions, authors were guided to make changes in order to have their papers accepted, or to provide a compelling argument for no further revision.

Long Papers that were re-worked and re-submitted by authors underwent a final review and edit process before being published in the accredited Book of Proceedings.

Kenneth Mlungisi Ngcoza
SAARMSTE President
The SAARMSTE Review Panel thanks the following long paper reviewers for their time and expertise:

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Guidelines for paper submission and presentation at SAARMSTE 2019

**Long paper:** Maximum of 6000 words, (including references), for a 30 minute presentation followed by 15 minutes Q & A. Long papers are equivalent to journal publications utilising the same criteria as AJRMSTE articles; and are reviewed accordingly.

In accepting a Long Paper for presentation at the SAARMSTE conference, the Review Panel presumes that:

1) The paper is original and has not been published elsewhere;
2) Permission will be granted by the author for the accepted long paper to be published in the accredited Book of Proceedings;
3) At least one of the authors will register and attend the conference to present the paper;
4) First authors may only present one long paper at each conference.

Long papers are fully peer reviewed and thus attract DHET subsidy

**Short paper:** Maximum of 1500 words, (including references), for a 20 minute presentation followed by 10 minutes Q & A. Short papers should highlight preliminary findings and significance of the research. Short paper submissions could be the first draft of a journal article consisting of: abstract, introduction literature review, methodology, results and conclusions. Authors are encouraged to submit short papers for development of an article at the post conference workshop.

After acceptance of the 1500 word short paper, authors may elect to develop their research further into a 3600 word paper which will NOT be reviewed but, after consultation with the editor, could be published in the Book of Short Papers, but will not attract subsidy.

**Snapshot paper:** Maximum of 1500 words, (including references), for a 10 minute presentation followed by 5 minutes Q & A. Snapshot papers should be based on emerging research, not necessarily with results, but with a framework of: abstract, introduction, literature review, methodology and the way forward.

**Symposium / panel paper:** Maximum of 1500 words, (including references), for a 90 minute team discussion around issues where different points of view, approaches, debates or analysis of the same problem are presented. The paper should contain details of each speaker’s contribution and how these come together to create a forum for debate. This is not a forum for the presentation of multiple short papers. The emphasis is on exchange of ideas and discussion.

Short papers, snapshots and symposia/panel papers are not fully peer reviewed and thus do not attract DHET subsidy.

In future only the Book of Proceedings will be published in hard copy. All other submissions will be available electronically.
MATHEMATICS EDUCATION LONG PAPERS
ABSTRACT
Many South African, grade R children fail to develop early number concepts that are a prerequisite for mathematics learning in the first grade. The same children may also enter formal education without adequate cognitive skills that are known to support mathematics learning. This paper theorizes that mathematics vocabulary, logical reasoning and classroom engagement (as output of the cognitive skills known as ‘executive functions’) are important skills for early number concept development. Although multilingual classrooms can be utilized for rich learning opportunities, they may also add to children’s ‘linguistic maze’. A theory of translanguaging describes how children can access various linguistic features or different autonomous languages, to maximize communication. The paper extends the theory of translanguaging to the domain of early number concept development and presents a hypothesis, suggesting that, together, an elaborated mathematics vocabulary, logical reasoning, and skills of executive functions significantly contribute to early number concept development. We make suggestions for improving underperforming young South African children’s mathematics understanding, specifically regarding expansion of their linguistic code, enhancing classroom engagement, and developing logical reasoning skills.

Keywords: maths vocabulary, classroom engagement, logical reasoning, number concept development, kindergarten, translanguaging, code-switching, individual differences

INTRODUCTION
In South African foundation phase (elementary) school education, one of 11 official languages is used as medium of instruction up to the third grade. From the fourth grade, instruction is only in English or in Afrikaans. If switching between different languages of instruction after the first four years of schooling (grade R to third grade) is not challenging enough in itself, many children in South Africa grow up in multilingual households, situated in multilingual communities (Setati & Adler, 2000; Henning, 2016). What is more, some children attend a school where the medium of instruction is different to the home language. Henning (2012) has referred to this as the multilingual maze in which young learners have to navigate their way in a smorgasbord of different languages spoken by their peers and their teachers. Henning and Dampier (2012) discuss the linguistic liminality of first grade classrooms in South Africa, where young children move from one linguistic, code-specific environment, to another and for a time remain “betwixt and between languages of learning”
(p.100). Added to this is the different social registers of children who come from middle class homes, and their peers, who come from working class homes, many of which are homes of dire poverty (Spaull, 2015). An extreme form of what sociologist Basil Bernstein referred to as a linguistic restricted code (Bernstein, 1971) is observed in homes in rural areas especially, where this (often very rich in colloquialisms) code is not used across different communities, though it may have powerful local currency. In the same vein, an elaborated code is observed in middle class homes, where children have access to a variety of ‘restricted’ codes and can cross between different language registers and local speech genres, including how families engage in number talk (Levine & Baillargeon, 2016), when priming their offspring for formal education in the preschool years.

Exacerbated by the various factors that may enable or obstruct their learning of vocabulary and syntax of early mathematics learning, when children enter school they also encounter a dense language-rich mathematics curriculum (South Africa. Department of Education, 2011). Making matters worse, in grade R teachers often begin to introduce English terminology (Mashiya, 2011) in an effort to prepare early graders for English as target medium in grade 4: They engage in the practice of code-switching (Cantone, 2007; Macaro, 2005), or of trying to make meaning across different languages in what has been termed ‘translanguaging’ pedagogy (Garcia, & Wei, 2014; García et al., 2017; Lewis et al., 2012; Otheguy et al., 2015; Park, 2013) in early grades.

Against this backdrop, disadvantaged children, with limited knowledge of the language of instruction in grade 4 education, which is already being inserted in code-switching fashion, face a host of linguistic barriers, one of which is the lack of vocabulary as a translanguaging device. Such devices, argue the theorists of this pedagogy (Garcia et al, 2017), assist young learners in identifying the meaning of the message that a teacher, or a mediating tool such as a textbook or a worksheet, may wish to convey in another language. In the setting where we conduct the present research in South Africa, most working-class children and disadvantaged children have yet to develop a stable set of linguistic tools with which to mediate mathematics concepts, while translanguaging. In many South African classrooms, children learn English mathematical terms incidentally at the same time that they are being instructed in their African home language. The effect of this practice on early number concept development has not yet been adequately researched.

LINGUISTIC CONTEXT

Children, from an early age, come to understand the world by conceptualizing what they are experiencing (Barner & Baron, 2016). They observe and perceive their environment, interact with one another and slowly build a repertoire of experiences and observations to create mental ‘copies’ or representations of objects, properties, people, events, ideas and sounds in their minds (Barner & Baron, 2016; Gopnik & Meltzhoff, 1997). These representations of reality constitute ways of storing individual versions of reality. Young children with sufficient exposure to rich discussions about various topics are likely to develop an expanded vocabulary and discourses early in life, compared to children who may have less verbal interaction.
Teachers of young children note that they initially use language without a clear understanding of the specific meaning of a word, using words as ‘placeholders’ (Carey, 2009) for meaning until they grasp the meaning. For instance, young children may say “yesterday I will go to school” or “tomorrow I went to the zoo” which shows that they have limited understanding of order of events – or perhaps do not know the exact meaning of the words ‘tomorrow’ or ‘yesterday’ and also have not yet developed language tense structure of verbs (Behrens, 2001). When two-year-old children copy a familiar string of sounds, such as “onetwothree,” they don’t initially know what these sounds signify, until they learn the exact meaning of the individual words as numerals, denoting quantity. Until then, words such as ‘tomorrow’ or ‘onetwothree’ serve as placeholders for concepts of time, or for the counting nouns - one, two and three.

Gradually, placeholder words acquire meaning when children map them semantically, draw analogies, and make inductive inferences (Zaitchik et al., 2016). They begin to theorize their own experiences (Gopnik & Meltzoff, 1997). At first, young children may not explicitly understand concepts for which they have started to ‘use’ words, but by means of an inductive process of conceptual change, they begin to make sense of the words they know. When they connect familiar experiences and observations with their existing word knowledge, they complete individual semantic mappings.

It is not only current behavioral science scholars and neuroscientists who study concept development. In the 1930s Lev Vygotsky described this ‘moment’ of mapping word form onto semantic substance as “sense that becomes objectivized in words” (Kozulin, 1990, p.8). When mapping has been achieved, children can express their understanding by representing their concepts by means of language. Vygotsky considered the importance of the functional use of signs (Kozulin, 1990, p.154) in a language: He argued that language represents reality symbolically, but also creates reality. As children increasingly represent their reality using signs and symbols, they construct new knowledge, because signs and symbols (together with tools such as models or materials) mediate learning semiotically (Henning, 2012; Henning & Ragpot, 2015). In this way they construct a network of interconnected concepts that contributes to their understanding of the world in which they live. A part of such a reality is mathematical (Henning & Ragpot, 2013). They begin to ‘make their world mathematical’ – and natural language is one of their semiotic means to do so.

In some communities of the world, children learn in a colloquial code, with “number talk” (Levine & Baillargeon, 2016) that is, in the Bernsteinian analogy, ‘restricted’ (Bernstein 1971), and, moreover, also bilingual, or translingual (Lewis et al., 2012), or ‘code-switched’. They encounter number talk in a mix of languages, with numerals in one language, adverbs, prepositions and adjectives in another, and in some cases with pronunciations that are colloquial in the extreme. Garcia and Wei (2014) argue that this does not withhold them from having one, translanguaged idiolect - meaning that children do not use different linguistically determined structures when they make meaning, but converge different, socially categorised languages mentally to construct understanding.
In this paper, we argue that children’s language skills in general, and maths vocabulary in particular, are likely to play a role in explaining why they struggle to succeed in maths. Their exposure to mathematical discourse in their pre-school years is sometimes varied, so that teachers and children often do not understand each other, with teachers having access to an ‘elaborated’ language of mathematics and children having their own ‘motswako’ (the Setswana word for a ‘stew’) of a restricted linguistic code for mathematics. They often have an idiolect of already mixed languages that have been acquired at home, in day-care centres and in preschools. In such a translanguaged state of meaning making, there are many linguistically pre-structured role-players in number concept development. For instance, number concepts are influenced by the lexical properties of language, such as inversion and power transparency (Dowker & Nuerk, 2016). Some languages, for example, German and Afrikaans, invert the order of tens and ones; for instance, in Afrikaans 13=three ten, 14=four ten, 21=one and twenty, 32=two and thirty. English follows the same pattern up to twenty (for instance, 14=four ten, 15=five ten) after which the units and tens are switched (21=twenty one, 38=thirty eight). Already in the counting nouns there could be cause for some confusion in the forming of a child’s number concepts, if one takes the view that idiolect is an individual mental phenomenon.

Secondly, languages like Sesotho and isiZulu (two of South Africa’s official languages) are transparent in the structure of number names. Children who speak Sesotho and isiZulu, for instance, can easily generate number names after they have learnt number words from one to ten by following a very simple and transparent rule. In isiZulu yishumi nanye (11) means ten and one and yishumi nambili (12) means ten and two. In Sesotho leshome le motso o mong (11) means ten and one and leshome le motso e mmedi means eleven and one. However, some isiZulu and Sesotho number names are extremely long and can overload children’s working memory. For instance, the eight-syllable word isishiyagolombili (eight in isiZulu, an agglutinative language, such as Finnish ) is rather difficult to remember vs. the one syllable word eight or agt (eight in Afrikaans); or the eight syllable leshome le motso o mong (11 in Sesotho) compared to the three syllable eleven in English or one syllable elf (11 in Afrikaans).

Dowker and Nuerk (2016) highlights that conceptual preparation of lexical concepts also influence number concept development. Because of children’s, often limited (and mixed), language exposure, they develop a restricted, colloquial code of language with the implication that they often hear maths vocabulary without being able to connect the word to a nonverbal conceptual referent. On the other hand, children may be unable to explain an already existing concept, due to a lack of vocabulary that is shared by the ‘school space’, but which is understood in the (restricted) ‘street space’. Non-English speakers may only be able to employ a placeholder isiZulu word for a number concept, while they may be required to present their work in English. According to the translanguage protagonists, teachers should encourage switches between languages (Park, 2013; Kleyn, 2016; Garcia et al., 2017).

We, as many others, claim that together with early number concept development, supporting cognitive skills like an elaborated maths vocabulary - in a discourse of a single language and not considering the influence of a child’s idiolect that criss-crosses more than one language - contribute
to early number concept development. Other skills include logical reasoning and active classroom engagement, which is mediated by executive function skills. First, we describe a five-level model of the development of early number concepts and then discuss possible contributing cognitive skills.

EARLY NUMBER CONCEPT DEVELOPMENT

While most young children develop number concepts at approximately the same age, such as learning the counting list at the age of two, followed by the concepts of ordinality, cardinality and decomposability and relationality, some children struggle to understand concepts and others grasp mathematical ideas without difficulty. This is evident in some six-year-old children who grasp only the principles of counting, while others have already developed an understanding of the cardinal principles (de Villiers, 2015; Henning et al., 2018). Much research (e.g. Desoete, 2015; Dowker, 2005; Perpura et al., 2017) has been conducted to explain these individual differences, to find out which cognitive skills support number concept development in the early grades, and which skills will best predict number concept development.

Literature suggests that there are two non-symbolic core number processing systems which form the foundation for number concept development, although there is continued debate about discontinuity and continuity from innate systems or core number knowledge to advanced number knowledge. These systems, namely the approximate magnitude system (AMS) and the object tracking system (OTS) (Feigenson et al., 2004), provide individuals with an innate sense of number and are affected by limited visual, attentional, and working memory (Hyde, 2011). The approximate magnitude/number system (AMS/ANS) encodes approximate representations of numerosity and is used to compare and combine magnitudes (Spelke & Kinzler, 2007). Approximate representations are not limited to visual arrays but also include, for example, sound (Feigenson et al., 2004). The object tracking system (OTS) encodes exact representations of small quantities (Dehaene, 2011; Carey, 2009; Spelke & Kinzler, 2007; Wynn, 1990). Hyde (2011, p.6) claims that “the two core number systems do not operate in isolation from other cognitive and perceptual limits”, but numerical representations depend on “what else the brain is doing”.

Most mathematical cognition researchers would agree with Fritz et al. (2012, 2014) that children develop early number concepts hierarchically, with the ANS/AMS and OTS as possible foundation. At around the age of two, children learn to recite the first (usually up to ten) numerals orally, but do not yet grasp the meaning of the words in the count list (Sarnecka & Carey, 2008). Gradually, they learn how to count meaningfully by applying the rules for counting, namely one-to-one-correspondence of numerals and objects, the stable order principle - using the same order for numerals each time when counting - and the cardinality principle, which accounts for the last numeral used to count some objects indicates the quantity of the set (Gelman & Gallistel, 1978).

After having learned how to count, children find out that numerals are used in a stable order to count and gradually become more aware of ordinality (Fritz et al. 2013), which means that each number has a fixed position in a string of numerals and that one can determine the preceding and succeeding
numbers in the sequence. However, numbers do not only appear on a ‘number line,’ with larger numbers appearing further down this line, but each individual numeral also represents a specific quantity. Children slowly begin to develop an understanding of the cardinality principle of number. This principle gives number words meanings (Sarnecka & Wright, 2012). At this point children not only understand the numerical concept of succession, but also grasp the meaning of each individual number word (Sarnecka & Wright, 2012). They realize that each number can be decomposed into a fixed number of units and that, for instance, seven consist of seven individual objects and therefore the ‘sevenness’ of seven is unique to the number of seven (Fritz et al., 2013).

**DOMAIN SPECIFIC SKILLS**

Previous studies have indicated that the development of early number knowledge does not occur in isolation from other cognitive skills. Poor number concept development usually has multiple origins (Chinn, 2015; Desoete, 2015; Dowker, 2005; Purpera et al., 2017). Some researchers have identified domain specific skills that contribute to number concept development, such as maths vocabulary. Although the boundaries of an individual’s idiolect cannot be determined, based on structural and lexical features, the unique mix of each child’s mathematical vocabulary both mediates understanding in the classroom and allows children to connect concepts and words (García & Wei, 2014; Otheguy et al., 2015; Purpera et al., 2017).

**Maths vocabulary**

Maths vocabulary is likely to contribute to early number concept development and exposure to quality discussions in mathematics related language, such as number talk, contributes to the development of maths vocabulary. Levine and Baillargeon (2016) argue that variation of the amount and quality of number talk young children are exposed to may explain variations in individual children’s understanding of number concepts. Some children who hear plentiful talk about mathematics may have a larger repertoire of maths vocabulary that they can use to serve as linguistic placeholders (Carey, 2009) for true conceptual understanding of numbers (Levine & Baillargeon, 2016).

Gunderson and Levine (2011) and Levine et al. (2010) investigated the relationship between four-year-old (46 months) children’s cardinal number knowledge and their parents’ number talk when they were 14-30 month-old by video recording 90-minute natural interactions between parents and their children, once every four months. During the approximately 450 minutes of video, parents ranged from 4 – 257 mentions of number words. In other words, on average, the children were exposed to 1200 to 100 000 number word utterances per year, which is a fairly large range of exposure to numeracy-related language. The findings indicated that the amount of numeracy-related language which 14-30 month-old children were exposed to, had an influence on their understanding of cardinality at 46 months. These studies referred to monolingual talk and leaves open the question of what happens in multilingual homes.
In a similar experiment Klibanoff et al. (2006) found that the numeracy-related language which preschool teachers used, predicted the growth of young children’s mathematical concept development. Thus, children who have received substantial number talk input at a young age are more likely to understand the cardinal principle at three to four years of age, while children who do not experience this type of interaction are less likely to understand cardinality of small numbers at this age (Levine & Baillargeon, 2016, p.136). Different studies (Gunderson et al., 2015; Sarnecka & Lee, 2009) found that cardinal understanding emerges between the ages of three and four.

These findings highlight the importance of maths-related language during children’s early years of development. We argue that specific reference to noun numerals in talk is not the main object of functional number talk with young children; children also build adverbial-, adjectival-, and prepositional knowledge of words and of word order, all of which ultimately contribute to the framing of number concepts.

**DOMAIN GENERAL SKILLS**

Previous research indicates that domain general skills, such as logical reasoning (Handley et al., 2004; Morsanyi & Szüs, 2015) and executive functions (Fitzpatrick & Pagani, 2012; McLean & Hitch, 1999; Passolunghi & Segel, 2004) are also important skills for early number concept development.

**Logical reasoning**

Logical reasoning refers to the ability to identify patterns and relationships and developing these inductively and deductively. This amounts to fluid intelligence (Gf). Fluid intelligence (Gf) refers to the capacity to solve novel or abstract problems; it involves concept formation, classification, and includes inductive and deductive reasoning (Klauer & Willmes, 2002). Unlike crystallised intelligence, fluid intelligence is not a learned ability, but rather is determined by genetic and biological factors (Kvist & Gustafsson, 2008). Bergman et al. (2011, p.591) note that “Gf predicts performance on a wide range of cognitive activities, and low Gf in children is a predictor of academic difficulties.” According to Geary (2015), this human competence is underpinned by our ability to take advantage of our evolved brain and cognitive systems and to use these resources to create “evolutionarily novel abilities” (Geary, 2015, p.105).

Haverty et al. (2000, p.251) argue that “inductive reasoning skills are fundamental to the learning and performance of mathematics.” Maths tasks require the child to identify the rules of relationships between elements and then use these rules to complete structure (Weiβ & Osterland, 2013). Maths tasks also require information processing, visual-, abstract- and sequential reasoning (Wechsler, 2003), which are all elements of inductive reasoning. Klauer (1996) identified varied tasks (similar to skills used in maths) such as series completion, classification and analogy, which require inductive reasoning skills. He paired inductive processes with specific cognitive operations, such as identifying similarities and differences in relationships and attributes. But, inductive reasoning (together with verbal memory and pattern recognition) is also referred to as the cognitive aspects of language
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(Fillmore, 2000), as these aspects effect “the ease with which children recalled and made sense of the language they heard people using and detected the regularities that existed within such samples of speech” (Fillmore, 2000, p.49).

**Classroom engagement**

Research increasingly points to the importance of children’s ability to effectively self-regulate and engage in the learning environment for academic success in both maths and reading (Robinson & Mueller, 2014). Classroom engagement (i.e., being able to follow instructions, being able to complete work on time) falls into the broader category of learning-related behaviours and reflects student ability to follow instructions, complete tasks on time, and self-organize in the classroom (Fitzpatrick & Pagani, 2013; McClelland et al., 2006).

Engagement in learning is arguably an important outcome of executive functions, which represent a form of ‘top-down’ control that allows children to effectively manage interference from ‘bottom up’ sensory experiences, impulses, and emotional reactions (Blair & Diamond, 2008). Preschool-aged children who arrive at school better able to control and regulate their attentional and cognitive resources have an easier time sustaining engaged learning in the classroom (Pagani et al., 2010; Razza et al., 2010). In contrast, children who have difficulty inhibiting inappropriate behaviour and who are more distractible are at greater risk of disengaging from classroom activities. Consequently, as have others, we conceptualize classroom engagement as being driven by executive functions (Hughes et al., 2008; Li-Grining et al., 2010; Ponitz et al., 2009).

Among younger primary school children, teacher assessments of classroom engagement represent key components of school readiness. Indeed, they are predictive of academic achievement in maths - even once prior number knowledge and family socio-economic status are controlled for (Fitzpatrick & Pagani, 2013). Other research has found that classroom engagement is a mediator of the association between executive functioning and achievement (Sasser et al., 2015). As a result, classroom learning skills are likely to represent key proximal variables in explaining individual differences in mathematics achievement especially when language barriers present additional challenges for young learners.

**HYPOTHESIS**

We propose the hypothesis that maths vocabulary, logical reasoning and classroom engagement significantly contribute to young children’s early number concept development. Following Fritz et al. (2012, 2013) we suggest a five-level model for early number concept development, including the development of counting skills and an understanding of ordinality, cardinality, decomposability and relationality. Although children develop maths vocabulary in socially invented, named languages, mathematical terms do not always overlap with individual children’s linguistic systems, or idiolects (García & Kleyn, 2016). The notion of translanguaging goes *beyond* named languages and allows children to use internal versions of language. Children who can access and process information and
who can reason logically, with rich maths vocabulary, and who are highly engaged in classrooms, are more likely to form maths concepts in multilingual South African classrooms. Finally, children who can exercise self-control and who are more engaged in classrooms, are likely to develop an *elaborated* linguistic code, which allows them to make mathematical meaning.

We claim that, to improve underperforming South African grade R children’s maths understanding, both mathematics-specific skills (as proposed in the five-level model) and cognitive skills supporting number concept development, must be strengthened. Children’s linguistic code should be expanded, especially during the transition from pre-school to grade R, their classroom engagement must be enhanced throughout the year and teachers should deliberately plan lessons improve young children’s logical reasoning skills.

**FINAL REMARKS AND FUTURE DIRECTIONS**

In previous sections of this paper, we have made explicit the cognitive skills underlying our account of contributing factors for early number concept development. We hope that by providing a theoretical hypothesis of contributing skills for mathematical learning, we have provided some directions for putting the model to the test for future research. Although reliable instruments are available for early number concept development assessment of early grade learners (Henning et al., 2018), classroom engagement (Fitzpatrick & Pagani, 2013) and inductive reasoning (Weiβ & Osterland, 2013), the validity and reliability of an instrument, designed by one of the authors and which assesses maths vocabulary is yet to be determined.

Although many intervention programs (Mononen & Aunio, 2016; Clements & Sarama, 2011) have focused on improving children’s early maths skills, to our knowledge no intervention program has been designed to collectively improve children’s maths vocabulary, classroom engagement (executive functions) and inductive reasoning in order to improve their early number knowledge. Future research will have to include the development, implementation and evaluation of such an intervention program. Lastly, this study prompts exploration into the hypothesis that the isiZulu and Sesotho languages’ long number names overload children’s working memory, which in turn effect mathematics learning in the early grades.

**Author contributions**

All authors listed, have made substantial, direct and intellectual contribution to the work, and approved it for publication.

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INSTRUCTIONAL DESIGN IN PURSUING EQUITY: 
THE CASE OF THE ‘FRACTION AS MEASURE’ SEQUENCE

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ABSTRACT
The aim of this paper is to discuss an approach to instructional design in which we intertwine mathematics education research with development, draw insights from collaborations across international contexts, and place educational equity firmly at the centre of our work. Using an example of the instructional sequence on ‘Fraction as Measure,’ we illustrate how the two key aspects of the design process allow for developing instructional resources with equitable learning opportunities in mind. The two aspects entail specifying (a) the prospective endpoints of an instructional sequence (i.e., forms of students’ reasoning to be developed), and (b) how the learning process might be realized in the classroom, so that students would come to develop the specified forms of reasoning. We discuss how considerations of teacher learning, and processes of travel and scaling up of designed instructional innovations, need to be considered by designers aiming to advance educational equity.

Data from international comparisons suggest that both within and across countries, varying access to high quality educational opportunities accounts for much of the difference in resulting achievement. They also indicate that most of the world’s children receive mathematics education in classrooms that do not resemble those in which instructional innovations are typically developed. The instructional design work on which we report here explores the very question of supporting equitable mathematics learning in and beyond under-resourced classrooms.

The instructional design in which we engage typically involves conducting classroom design experiments, where a research team engages with a group of students for a period that can last between a few weeks and several months (Cobb, 2000). Once initially developed, the instructional resource is re-tested and modified in numerous classrooms, until it can be seen to reliably support the targeted forms of mathematical reasoning, and until the instructional conditions under which it does so are well understood. At first glance, our work can be regarded as unsuitable for the pursuit of equity in mathematics education, since the resulting instructional resources cannot be readily and effectively implemented by all teachers. This is because the instructional conditions under which the resources contribute to successful, equitable learning (including a kind of teaching required) are complex and take time and assistance to develop. Public education systems are rarely organized to proactively support long-term development of this kind of teaching, and conditions tend to be far less favourable in schools that serve the children of marginalized communities.

Despite the challenges our resources present for teachers’ learning, equity is a driving concern in our research. We use this paper as an opportunity to explain how we conceptualize and pursue equity in
our design work. We address some of the contributions that this approach to instructional design can make to increasing the opportunities of children from historically excluded communities to make sense of key mathematical ideas.

We first situate our work methodologically and discuss the history of developing and adapting an instructional sequence on fraction as measure. We then discuss how we use the two key aspects of the design process when developing instructional resources with equitable learning opportunities in mind. These aspects entail specifying (a) the prospective endpoints of an instructional sequence, and (b) how the learning process might be realized in the classroom. While our major focus in this paper is the design and adaptations of classroom resources for equitable teaching and learning, we touch upon broader issues that must be considered in instructional design for equity. These include teachers' learning, and travel and scaling up of designed instructional innovations. We illustrate how these broader issues shape our collaborations and design decisions.

CLASSROOM DESIGN EXPERIMENTS

Classroom design experiments are a research methodology used to study the process of students’ mathematical learning, as it occurs in the social context of the classroom, and the means by which that learning is organized and supported. The resource developed is often referred to as an instructional sequence, recognizing the sequential nature of increasingly sophisticated forms of reasoning in the classroom that require teacher's proactive support.

Central to the instructional sequence is a hypothetical learning trajectory (HLT) consisting of a series of conjectures about how the mathematical development of a classroom community is expected to unfold in response to instructional intervention. The HLT specifies the prospective learning endpoints, the learning starting points, the general path by which students’ mathematical reasoning will develop, and the means with which teachers would support this development (Cobb, 2000). The HLT provides the underlying rationale of an instructional sequence. It is explicitly formulated so as to allow (and, ideally, support) teachers to make reasoned adaptations of the resource, to address the specific circumstances of their classrooms.

The ‘Fraction as Measure’ instructional sequence includes a series of tasks, in which students are expected to use a variety of measuring tools, graphs, written symbols and oral expressions. However, the means of support specified by the HLT extend beyond these. They include guidance for the teacher on how to organize classroom activities in which students engage with the tasks and tools, so that this engagement cultivates students’ mathematical interests, provides cognitive challenge for individual students, and maintains opportunities for classroom discussions. Most importantly, it is intended that a particular kind of microculture will be constituted in the classrooms, so as to orchestrate rich whole-class discussions that can give rise to the expected forms of mathematical reasoning. Amongst other things, students are expected to listen to each other, explain and justify their solutions, attempt to make sense of the explanations of others, and indicate agreement and non-understanding.
'FRACTION AS MEASURE’ COLLABORATIONS

For over a decade, the first two authors have been developing and improving the ‘Fraction as Measure’ instructional sequence. The first of our formal classroom design experiments took place in 2007. Since then, we have engaged in a process of revising and improving the sequence. We have conducted other classroom design experiments in Mexico, including one that was implemented by a Mexican teacher, Guadalupe, with her regular fifth-grade classroom, where the first author served as a university mentor, never entering the school.

Most recently, the latter two authors incorporated the instructional sequence into their research and development work in the South African Numeracy Chair Project (SANCP) in the Eastern Cape. They first trialled the sequence in an after-school club and then conducted a four-lesson implementation study, where the sequence was taught by the researcher, in three grade 3 classrooms (108 students), where the language of instruction was not the home language of the overwhelming majority of the learners.

Across the studies, the ways in which students came to reason about the inverse order relation of unit fractions (grades 3 and 2) and about the relative size of any two fractions (grades 4 and above) are both consistent and impressive. For example, Vale and Graven (2018) documented the changes in grade 3 students’ participation and unit fraction understanding after the brief 4-lesson implementation of the sequence in three classrooms. In addition to increase in students’ contributions during classroom discussions, change was visible in the increase in the numbers of children who could correctly compare three pairs of unit fractions (1/2 and 1/4; 1/5 and 1/3; and 1/4 and 1/8). The comparison comes from 83 learners who took both tests and attended all the 4 lessons. While only 7 out of the 83 students could reliably compare three pairs of unit fractions on the pre-test, 59 did so on the post-test. While only four of these students also indicated correctly that 3/4 is less than 3/3 on the pre-test, 57 of the 59 students who successfully compared all unit fraction pairs also compared 3/4 and 3/3 correctly on the post test. However, since there were still some learners who were not able to consistently make fraction comparisons correctly in the post test begs the question: can the sequence be used to support all the children in a classroom to learn fractions?

Guadalupe’s fifth-grade classroom design experiment might be indicative here. She taught the sequence in her regular classroom during 18 dedicated weekly sessions, approximately 35 minutes each. Only 4 of the 20 students could reliably compare three pairs of unit fractions on the pre-test. In contrast, all could do so on the exit written test, comparing nine unit-fraction pairs including 1/4 > 1/456. In addition, 18 students correctly placed three fractions (16/11, 10/3, and 15/5) on a number line, while the remaining 2 students placed correctly two of those and made a numerical error in estimating the position of the third.

6 It is worth clarifying that we view implementation as a process of conjecture-driven adaptation and adaptations made to the sequence in this context were expected and were the focus of our learning from this study.
7 These were the same 3 pairs as used in SA on pre- and post- tests.
8 This task was not pre-tested.
Granted, the institutional conditions for the implementation of the sequence were quite different in these two cases. The first study aimed to assess the viability of the sequence adaptation in a new setting, across 3 different classrooms, in a way that would be convincing to the local teachers and school leaders. Fitting the implementation study into one week of lessons was important since the pace of teaching was dictated by a departmental push for curriculum coverage. The latter is a result of the work of one teacher who had experienced the sequence as worthwhile for her students’ learning during the initial lessons, had decided that all of her students’ learning with understanding was a reasonable goal with this tool, and dedicated more time in her classroom for such learning (Visnovska & Cortina, 2017).

These and many more of our classrooms design experiments were conducted in under-resourced schools that serve children living in poverty. However, as we explain next, the orientation towards equity in our research agenda goes beyond the selection of collaborating schools.

**SPECIFYING INSTRUCTIONAL ENDPOINTS**

Delineating the endpoints of an instructional sequence entails specifying how learning a mathematical idea could have enduring value for learners. This value must be judged in terms of what it represents for students’ future mathematics performance and for their learning in other fields. In addition to addressing the goals related to what Biesta (2010) refers to as qualification purpose of education, we find it important to judge the extent of the broader social significance of these goals, or how they address what Biesta refers to as the socialization and subjectification purposes of education. For instance, the contribution of the envisioned goals to both students’ access to and participation in the current social order, and their formation as informed, critical, and unique citizens, able of shaping their society, are taken into consideration.

We regard this aspect of the instructional design process to be of particular importance for the mathematics education of marginalized groups. The resources that are made available to these learners are often limited. Before entering school, children from these communities often have few opportunities to develop mathematical ways of engaging that are valued and expected at school reception, such as counting in the language of instruction. The schools that are available to them are often under-resourced. The teachers who work there are frequently less qualified. Student absenteeism due to illness, economic, and family circumstances is then more common.

There is certainly much that societies and governments can and need to do to improve the learning opportunities of children of historically marginalized communities. From an instructional design perspective, clarifying what is most critical or beneficial when supporting these students in developing specific mathematical ideas could allow for better use of the relatively limited instructional time and resources currently available to them.
Fractions are widely regarded as both mathematically and culturally indispensable concepts, the first extension of our numeration system beyond whole numbers. They occupy an important place in mathematics curricula of countries all over the world. The vast body of research literature concerned with teaching and learning fractions goes back many decades. Recognized as a complex, multifaceted idea involving a variety of meanings that relate to each other in an intricate manner, fractions provide a conceptual entry point to proportional (multiplicative) reasoning (Thompson & Saldanha, 2003), a type of reasoning that is indispensable for both individual wellbeing, and participatory democracy.

At the same time, fractions continue to be widely regarded as a difficult topic for teachers to teach and for students to learn. Alarmingly, the mathematics instruction typically made available to students from low income communities does not allow the vast majority of them to adequately make sense of this concept (Graven, Venkat, Westaway, & Tshesane, 2013). Given the substantial time that teaching and re-teaching fractions takes across the years of instruction, mostly to no avail, one has to ask whether this time could be better used. Can we steer away from the early introduction of formulaic procedures and symbol manipulation and focus on sense-making as the learning goal? Could the learning goal, and the learning pathway be expressed in terms of the specific meanings, images, and forms of reasoning that students should develop?

The endpoint of the ‘Fraction as Measure’ instructional sequence entails an image of fractions as numbers that account for the size of a measured length. In this image, it is expected that the denominator of a fraction will be construed by students as a number that accounts for the size of a subunit of measure, and the numerator as one that accounts for the iteration of that subunit, a certain number of times. For instance, a fraction $7/6$ would be interpreted as a length that corresponds to seven iterations of a subunit that is one sixth as long as a reference unit (see Figure 1).

It is worth clarifying that, in formulating this image of a fraction, we have been influenced by the insights and considerations of several authors, including Thompson and Saldanha’s (2003) ideas about understanding fractions as expressing reciprocal relations of relative size, Freudenthal’s (1983) concept of fraction as comparer, and Davydov’s (1969/1991) work on teaching fractions as length measures (Cortina, Visnovska, & Zúñiga, 2015). The endpoint of our instructional sequence is consistent with how Steffe and his colleagues (Steffe & Olive, 2010) expect students to reason when having developed relatively sophisticated understandings of fractions.

![Figure 1: Fraction 7/6 (black) as a length that corresponds to seven iterations of a subunit (striped) that is 1/6 as long as a reference unit (grey).](image)

We consider this image of fractions to have enduring value for students’ mathematical development in three ways. First, it has a strong quantitative component, which allows associating fractions to the measurement of continuous magnitudes. For instance, this image is consistent with construing a
measure such as 1375 mg as 1375 times a mass that is 1/1000 as much as a gram. Second, the image is multiplicative: it can serve as a basis for carrying out proportional comparisons, and for reasoning about relative size. As an example, the image is consistent with judging that if the value-added tax is 20%, then the price that a buyer always pays for a product is 120 times a one one-hundredth of its original value (or 6/5 of the original value). This type of reasoning is both difficult and unusual, especially in English or Spanish language environments, where relationships involving percentages are almost always expressed in an additive language, that is, “20% more than original value” or “25% off” (as opposed to multiplicative expressions such as “120% of the original value”, or “75% of the original price”, which are typical in some southeast Asian language environments). Third, since length is a unidimensional magnitude, this image is consistent with regarding fractions as numbers that occupy a specific place on the number line, an important sense-making tool.

Most importantly, this endpoint image of fractions is consistent with introducing students to mathematics as a human activity (Freudenthal, 1973), in which individual and collective sense-making are the primary tools for establishing the value of mathematical tools and ideas. We conjecture, and our experiences in classrooms to this point confirm this, that prioritizing the meaning-based goals for learning fractions, and the classroom microculture that can support such goals, would be beneficial for students’ mathematical development. This would be particularly so for those pupils whose opportunities to engage with and talk about mathematics are relatively limited.

A PATHWAY FOR LEARNING

As previously mentioned, central to the instructional design approach that we follow is the formulation of a HLT that specifies how students’ mathematical reasoning is expected to develop, and the means that would support this development. Underpinning this formulation is a view of mathematical learning as socially situated. Consequently, the role of instructional design is not limited to developing resources that can support what is regarded as rather stable and autonomous processes of conceptual development (Cobb, 2000). Instead, it is assumed that students’ participation in classroom cultural practices strongly influences their development of mathematical notions and ways of reasoning.

It is interesting to note that research literature on fractions is riddled with reports on the conceptual challenges experienced by learners, including misconceptions, hurdles, and interferences, and that these are positioned as an inevitable part of fraction learning. From a situated perspective on learning, however, these conceptual challenges are understood as a product of the social and cultural practices in which students engage with the idea. We argue elsewhere (Cortina, Visnovska, & Zúñiga, 2014) that these challenges are productively understood as didactical obstacles (ones resulting from teaching; Brousseau, 1997), rather than ontogenetic (ones resulting from learners’ cognitive development) or epistemological (ones resulting from the nature of mathematics).

From this theoretical perspective, the conceptual challenges in learning fractions are largely a function of the types of instructional activities, metaphors, representations, and tools that students
typically encounter during instruction. This opens the possibility that a thoughtful change in the instructional resources that perpetuate current classroom cultural practices will make it possible to overcome, or even bypass altogether, the currently identified and prevalent learning challenges. Discovering the alternative paths and the resources to support them, should be, from an equity perspective, an important instructional design task. It would certainly be of much relevance for the many children of marginalized communities, who are seldom provided with the necessary resources to overcome the challenges that emerge as a result of instruction.

The HLT that substantiates our instructional sequence on fraction as measure serves as an example of what different instructional practices and meanings, to those that are typically employed, might look like. We describe it in detail so as to clarify both what those differences are, and why they make a difference to students’ learning.

The HLT aims at guiding students in reinventing length measurement that requires the use of a reference unit, and subunits. It encompasses the consecutive emergence of three classroom mathematical practices. In the first one, the collective activity of the classroom community centers on measuring lengths with a standardized unit, and on reasoning about the advantages and insufficiencies of using a single reference unit to measure various objects. In the second practice, the activity shifts to producing additional measuring resources, namely, subunits of measurement the size of unit fractions; and reasoning about their relative size. Finally, in the third mathematical practice, the activity centers on reasoning about the relative size of lengths produced by iterating the subunits.

**The first classroom mathematical practice**

For this mathematical practice to emerge, it is expected that students will first become mindful of the limitation of using non-standard units—such as hands—when measuring. One of the means we developed to support the emergence of the first mathematical practice is a narrative that includes a series of stories about the trials and tribulations of an ancient community, who sought to find better ways of measuring. These stories are a resource to orient the students to view themselves as investigators of how ancient people developed the ability to measure with accuracy and innovation.

The first mathematical practice emerges once the students recognize the need for a standardized unit if people are to make consistent measures. Prior to arriving at such recognition, students explore measuring with parts of their bodies, such as their hands and feet. The teacher points to the inconsistencies of measures carried out by different students and makes these an issue for discussion in the classroom. For instance, the teacher might make it noticeable to the class that the number of handspans counted when different people measure the chalkboard is not always the same. Once the need for a standardized unit of measure is established, wooden sticks of the same length (about the width of this page) are introduced as a tool that fulfilled this need in the measurement narrative.
It is worth pointing here to one of the differences between the means of support involved in our instructional sequence and those that are commonly brought to bear in initial fraction instruction. In the ‘Fraction as Measure’ instructional sequence, the value of 1 is embodied by the stick\textsuperscript{9}. The stick is expected to be iterated, and each iteration is understood to be of the same length. The unrestricted availability of the equal-sized units introduced through this process makes it relatively easy for students to construe the stick’s length as a reference unit for measurement. They also construe the iteration of a measurement unit as a process by which different lengths can be created and compared.

In comparison, students are typically expected to first associate the value of 1 with a unit-whole, usually portrayed as a food item that can be easily divided (e.g., a cake). While this unit-whole is available as a source for the creation of sub-units, it often appears unique and not easily reproducible. In this process, comparison among different unit wholes is not established (Freudenthal, 1983), which can later challenge construing fraction quantities bigger than 1.

\textit{The second classroom mathematical practice}

The emergence of the second mathematical practice in the classroom is supported by activities, in which students produce subunits of the reference unit. For these activities to become meaningful, students first need to become mindful of the insufficiencies of measuring with this single unit (the stick). As students engage in measuring the length of different things, the teacher makes it noticeable that, frequently, there is a remainder that the measuring stick does not cover exactly. For instance, the teacher’s desk can be more than three sticks tall, but not as tall as four sticks (see Figure 3).

\begin{figure}[h]
    \centering
    \includegraphics[width=0.5\textwidth]{figure2.png}
    \caption{A desk that is taller than three iterations of the stick, but not as tall of four iterations.}
\end{figure}

The making of the subunits of the stick (reference unit) is introduced as a solution to the problem of accounting for the lengths of the remainders, in a systematic way. Building on the narrative of how ancient people measured, students are asked to make subunit rods by cutting straws, so that their lengths satisfy specific conditions. For instance, they can be asked to make a rod that would require five iterations of its length to cover the length of the stick, exactly (see Figure 3). If a straw is too long, given that five iterations of its length surpass the length of the stick, a student will have to make it

\textsuperscript{9} It is, in fact, embodied by any of the many sticks that, while owned by different people, are all understood to be of equal length.
shorter, using a pair of scissors. If a straw is cut too short, they will have to try again with a longer straw.

Figure 3: A rod of such length that five of its iterations cover the length of the reference unit.

Usually, students are asked to make at least five rods whose lengths are unit fractions of the length of the measuring stick (see Figure 4).

Figure 4: The measuring stick (reference unit) and measuring rods (subunits) of lengths 1/2, 1/3, 1/4, 1/5 and 1/6.

This second mathematical practice is considered to have been constituted once students can readily reason about the relative size of different rods, without having to physically produce them. For instance, they would be able to readily judge that a rod whose length is 1/11 of the length of the reference unit would be longer than one whose length is 1/15. Their reasoning would be based on the consideration that the length of the latter rod would have to be iterated more times to coincide with the length of the reference unit, so it would have to be shorter.

Here too, the differences between the means of support involved in our instructional sequence and those that are commonly brought to bear in initial fraction instruction are important. First, most commonly, unit fractions are construed as a quantity formed by one part, when a whole is partitioned into a certain number of equal parts. This process experientially only gives rise to the creation of a limited number of the entities that are expected to embody unit fractions (e.g., only 5 fifths are available), which are understood as being contained within a unit-whole. As a consequence, only some common fractions can be created (1/5, 2/5,..., 5/5). According to Steffe and Olive (2010) this is consequential for many novice fraction learners, for whom regarding the unit fraction quantities created in this way presents a major challenge to understanding fractions bigger than 1 later on.

The ‘Fraction as Measure’ instructional sequence addresses this challenge in that unit fractions are expected to be construed as the lengths of rods that, when iterated a certain number of times, fulfil a specific condition: producing a length equal to that of the measuring stick (see Figure 4). This condition does not limit the number of times that each resulting sub-unit of measure can be subsequently iterated (see Figure 1 for an example).
The second important difference rests on the observation that once unit-fraction pieces have been created in a part-whole model, students’ access to the object that represented the unit-whole is no longer experientially supported. In contrast, in the ‘Fraction as Measure’ sequence, the entities that students are expected to regard as embodiments of unit fractions—namely, the rods—are always apart from the reference unit (see Figure 4). This facilitates establishing unit fraction as a *relationship of relative size* between two quantities that are both accessible to students.

Finally, when the part-whole scenarios of cutting food items are used, students can only construct *some* of the unit fractions independently with reasonable accuracy (e.g., 1/2, 1/4, 1/8). This is problematic, as fraction learners invariably rely on the process by which unit fractions are produced when making the initial comparisons of their relative sizes. For instance, reasoning about the different sizes between the fractions 1/5 and 1/7, using a pizza or a chocolate bar as a reference, is only experientially accessible to some learners when pre-made manipulatives representing these quantities are readily available, which is less likely to be the case in under-resourced classrooms. In contrast, in the ‘Fraction as Measure’ sequence, all fractions are equally experientially accessible to students, and the process of their physical creation acts as a means of supporting students’ initial reasoning about their relative size.

*The third classroom mathematical practice*

The third mathematical practice entails using the subunits as units of measure, in their own right. In the instructional activities that are used to support the emergence of this practice, students are asked to use the rods to make paper strips of specific lengths. For instance, they might be asked to make a strip the length of which corresponds to three iterations of the 1/2 rod.

As these activities are implemented, the meaning of fraction inscriptions becomes established, where it is negotiated that the denominator will indicate the subunit that was used in making a measurement, and the numerator, the number of times that the subunit was iterated. This way of interpreting fraction inscriptions coincides with the endpoint of the instructional sequence, described in the previous section.

This mathematical practice becomes established once students develop the ability to readily gauge a fraction inscription as quantifying a length, so that it can be judged to be shorter than, longer than, or as long as the length of one or several iterations of the reference unit. Hence, students will be able to judge the fraction 5/6 as being shorter than one iteration of the reference unit, the fraction 4/3 as being longer, and the fraction 20/10 as being as long as two iterations of the reference unit.

The emergence of this practice is contingent on the specific meanings about length measurement that become established in the prior two practices, including the understandings that any subunits can be created from a reference unit, and that their resulting lengths can be iterated without restriction. Practices that emerge from scenarios that rely on construing fractions as being formed by
equal sized parts of a unit whole thus seem lacking. This might be why an additive interpretation of mixed fractions is used extensively in initial fraction instruction for handling quantities that are bigger than 1, thus contradicting the proclaimed aim of fractions becoming an entry into proportional reasoning.

**CAPITALIZING ON THE INSTRUCTIONAL DESIGN INNOVATIONS**

We conclude this paper addressing how the instructional innovations developed through the described instructional design approach can be recognized as an answer to a problem, by initiatives such as the SANCP, which are concerned with improving the quality of teaching and learning in school systems that predominantly serve low-income children. We use this as an opportunity to address how teachers’ learning, innovation travel, and scaling up also shape our design decisions.

In the SANCP the latter two authors work with so-called previously disadvantaged primary schools in the Eastern Cape. In terms of physical and pedagogical resources, these schools still face serious challenges, which shape learner access to mathematical sense making and reasoning. In this context, the third author as the incumbent Chair actively searches for research-informed resources that enable an equity focused agenda of increasing learner agency and participation in mathematics sense making. A range of such resources have been investigated, trialled, and implemented in various professional development projects and the after-school clubs.

In the case of fractions, a wide range of literature points to mathematics teachers and teacher educators grappling with the teaching for decades. The grade 3-6 teachers in SANCP faced such challenges as well. In particular, fraction teaching in SANCP tended to focus almost solely on part-whole models. This limited focus tended to restrict exploring generalized understanding and talk of principles for key concepts such as comparing the relative size of unit fractions and non-unit fractions. Furthermore, because teaching and learning occurs in a language that is not the home language of the majority of SANCP learners, teachers found the adoption of more exploratory discussions of key concepts challenging (see Graven & Robertson, in press, for an example).

The ‘Fraction as Measure’ instructional sequence was seen as an instructional design innovation that could potentially enable a way forward to the challenges experienced in teaching fractions in our schools. One of its favourable aspects was its focus on iteration and measure versus part-whole. The inclusion of a story with a driving problem needing solving (enabling experientially real engagement) particularly appealed to the South African context where increasingly mathematics educators are using stories to enable talk, discussion, and informal exploratory engagement including in SANCP professional development and parent projects (Graven & Coles, 2017; Graven & Jorgensen, 2018). While teachers often find it hard to shift from more traditional pedagogies where talk is teacher dominated and student talk is limited to providing brief answers to teacher questions, the introduction of a story and a series of activities that learners engage with experientially was seen to provide a promising way forward. It was equally important that the sequence supports teachers with
key prompts for the kinds of discussion to be promoted at key learning points (discussed in the three practices above).

Thus, the instructional sequence was seen to provide both key conceptual resources for the development of fraction sense making as well as resources for enabling increased student agency, participation, and discussion in the learning process. As many SANCP learners are learning in English (not their home language), the opportunity—built into the sequence—to talk through one’s thinking and reasoning in informal language was particularly important. Having trialled and adapted the sequence to local circumstances, we now look to supporting teachers in understanding and using the sequence in our PD programs (with departmental representation) and in our pre-service teacher courses at our university. This work is but the start of the process of addressing issues of scalability in making this instructional sequence available to others. The sharing of resources captured within the HLT, and the teaching experiences in different classroom settings were important in guiding the local adaptation and trials of ‘Fraction as Measure’ sequence. They were also essential in providing more equitable access to quality opportunities for addressing seemingly intractable didactical obstacles.

REFERENCES


ABSTRACT

This paper reports on the first two phases of a bigger PhD study that analysed the relationship between visualisation and reasoning processes when solving geometry word problems. For the first phase of the study, the participants consisted of 17 mixed-gender and mixed-ability Grade 11 learners from a private school in southern Namibia. For the second phase of the study, 8 of the original 17 were selected to participate. These participants answered geometry word problems individually and in small groups by making use of visual imagery as they reasoned their way through a problem. Analysis of the participants’ responses to the word problems was informed by elements of enactivism and consisted of a hybrid of observable visualisation and mathematical reasoning indicators. The key enactivist concept of co-emergence was one of the mediating ideas that enabled this analysis and the discussion of the links between visualisation and reasoning that emerged. The study argues that the visualisation processes enacted by the participants while solving such problems are inseparable from the reasoning processes. They are thus closely interlinked in the process of engaging in any mathematical activity – they co-emerge.

Keywords: co-emergence, enactivism, mathematical reasoning, visualisation, visual imagery

INTRODUCTION

One of the aims of the mathematics curriculum in Namibia is to enable learners to use mathematics as a means of communication with an emphasis on the use of clear expressions and to “develop the abilities to reason logically, to classify, to generalise and to prove” when presented with real life situations (Namibia. MoE, 2010, p. 2). Brodie (2010) views mathematical reasoning as a means to sense-making of and engaging in a mathematical activity. She assumes that “only through making sense of the mathematics can we truly move to sense-making as a worthwhile everyday life activity” (p. 59). Bjuland (2007, p. 2) perceives sense-making, conjecturing, convincing, reflecting and generalizing as interrelated processes of mathematical thinking and reasoning. Guzmán (2002) suggests that mathematical concepts, ideas and methods have a great richness of visual relationships that are intuitively representable in a variety of ways and can be clearly beneficial when solving problems (unpaged). Duval (2014) however states that it is not about knowing which kinds of representations learners use that matters but rather, “how to enable them to use different mathematical representations for the same object or the same relation” (p. 168). Along similar lines, Tripathi (2008) envisions that we may think of a visual representation as “a form of an idea that allows us to interpret, communicate, and discuss the idea with others” (p. 438). Furthermore, using
visualisation processes may offer new resources for the teacher that could help learners to become aware of their mental processes and of the importance of using appropriate visualisation methods in solving word problems “by saying farewell to the drilling practice in the world of word problems” (Csíkos, Szitányi, & Kelemen, 2012) and encouraging multiple representations. This was the motivation for this study, to find out the types of visualisation processes that learners used to solve word problems and how these related to their reasoning processes. The question that guided this study was:

How does enacted visualisation relate to mathematical reasoning when solving geometry word problems?

**VISUALISATION**

Arcavi (2003) asserts that mathematics, as a human and cultural creation dealing with objects and entities quite different from physical phenomena, relies heavily on visualisation in its different forms and at different levels, far beyond the obviously visual field of geometry, and spatial visualisation (pp. 216–217). The importance of visualising geometrical objects and the necessity of spatial intuition for successful mathematical teaching and learning is emphasized in the Namibian mathematics curriculum (Namibia. Ministry of Education [MoE]., 2010b). One of the aims of junior mathematics curriculum is to enable students to “develop an understanding of spatial concepts and relationships” (Namibia. Ministry of Education [MoE]., 2010a, p. 2). The use of multiple representations can be a powerful tool to facilitate learners’ understanding of geometry word problems. Tripathi (2008, p. 444) explores that the process of problem posing and solving that happens around the representations can foster mathematical learning. In addition, Arcavi (2003) emphasizes that “visualisation is no longer related to the illustrative purposes only, but is also being recognized as a key component of reasoning (deeply engaging with the conceptual and not merely the perceptual), problem solving, and even proving” (p. 235).

Gal and Linchevski (2010, p. 165) view visualisation as the ability to represent, transform, generalize, communicate, document, and reflect on visual information, which clearly plays a major role in the understanding of geometry. Hence, “when students are translating a mathematical text into a visual representation by drawing an auxiliary figure or making a modification of a figure, they employ the strategy of visualising” (Bjuland, 2007, p. 3). Our study adopted Arcavi’s (2003) definition of visualisation as he defined it as follows:

> the ability, the process and the product of creation, interpretation, use of and reflection upon pictures, images, diagrams, in our minds, on paper or with technological tools, with the purpose of depicting and communicating information, thinking about and developing previously unknown ideas and advancing understanding. (217)
The notion of Visual imagery (VI) was specifically employed to unpack this definition and to define visualisation for mathematical reasoning.

**Visual imagery**

Hegarty and Kozhevnikov (1999) define visual imagery as the ability to form mental representations of the appearance of objects and to manipulate these representations in the mind. Presmeg (1986) argues that “all mathematical problems involve reasoning or logic for their solution. Beyond this requirement, the presence or absence of visual imagery as an essential part of the working determines whether the method is visual or nonvisual” (p. 42). Therefore, visualising objects and graphically representing numerical information are important mathematical tools that help learners to solve problems and to understand complex mathematical concepts. Our study adopted Presmeg’s five categories of visual imagery (5VIs) to observe and analyse the visualisation processes that the participants used when they solved geometry word problems. Although Presmeg (1986) used the categories to identify and classify visualisers from nonvisualisers, these categories were instead used in our study to determine the extent to which the research participants opted to use visual imagery to solve selected word problems. These categories are:

**Concrete pictorial imagery (CPI)** – this refers to the concrete image(s) of an actual situation formulated in a person’s mind. This can include a picture in the mind, drawn on paper or described verbally.

**Pattern imagery (PI)** – this refers to the type of imagery in which concrete details are disregarded and pure relationships are depicted in a visual-spatial scheme. The essential feature of pattern imagery is that it is pattern-like and stripped of concrete detail (Presmeg, 1986).

**Memory imagery (MI)** – this refers to the ability to visualise an image that one has seen somewhere before. This too includes a history of recurrent occurrences.

**Kinaesthetic imagery (KI)** – this is the kind of imagery that involves muscular activity. A kinaesthetic visualiser wants to feel and touch.

**Dynamic imagery (DI)** – this imagery involves processes of transforming shapes i.e. redrawing given or initially own drawn figures with the aim of solving the problem.

**MATHEMATICAL REASONING**

Brodie (2010, p. v) defines mathematical reasoning as a process that involves forming and communicating a path between one idea or concept and the next. Huscroft-D’angelo, Higgins and Crawford (2014, p. 68) view reasoning as a fundamental skill in mathematics and stress that interventions focused on advancing student reasoning will be increasingly essential to mathematics education. Burns (1985, p. 16) advises that learners’ classroom experiences need to lead them to make predictions, formulate generalisations, justify their thinking and consider how ideas can be expanded, transformed or shifted. They should also be able to look for alternate approaches. Learners’ mathematical reasoning is a broad topic that may be viewed from many perspectives. Reid (2002, p. 25) affirms that reasons are expected in many domains of human experience, but in
mathematics the reasons are of a particular kind. Reid (2002, p. 27) further urges that we must pay attention to the different ways in which learners reason and the degree to which they formulate their reasoning. Mathematical reasoning in this study is defined by making use of four reasoning processes to tease out the patterns of reasoning in the participants’ responses to selected word problems. These reasoning processes are explanation, justification, argumentation and generalisation. These are defined as follows:

Reasoning processes (RP)

Explanation (RPE)
Mathematical explanation refers to the classification aspects of one’s mathematical thinking that he/she thinks might not be readily apparent to others. Webb (1991, p. 368) conjectures that content-related explanations consist of descriptions of how to solve a problem or part of a problem that includes some elaboration of the solution process.

Justification (RPJ)
Justification is defined by Staples, Bartlo and Thanheiser (2012) as “an argument that demonstrates (or refutes) the truth of a claim that uses accepted statements and mathematical forms of reasoning” (p. 448). As a learning practice, “justification is a means by which students enhance their understanding of mathematics and their proficiency at doing mathematics; it is a means to learn and do mathematics” (Staples et al., 2012, p. 447). The purpose of a justification in the context of geometry word problems is to provide a convincing argument, such as justifying why carrying out a series of representations is a valid method for determining the answer to a given word problem.

Argumentation (RPA)
Lithner (2000) defines argumentation as the “substantiation, the part of reasoning that aims at convincing oneself, or someone else, that the reasoning is appropriate” (p. 166). An argument according to Dove (2009) is a sequence of statements/sentences/propositions/formulas such that each is either a premise or the consequence of (some set of) previous lines, and the last of which is the conclusion” (p. 138).

Generalisation (RPG)
To generalise means to introduce new ideal objects, to overcome objective constraints (Otte, Mendonça, & de Barros, 2015, p. 144), to identify the operators and the sequence of operations that are common among specific cases and to extend them to the general case (Swafford & Langrall, 2000, p. 91). A generalisation of a problem situation may be presented verbally or symbolically. Narrative descriptions of the general case are verbal representations of the generalisation, whereas representations using variables are symbolic representations (Swafford & Langrall, 2000).
THEORETICAL FRAMEWORK – ENACTIVISM

In this section, certain enactivist terminologies are used whose meaning may not be apparent to all readers of this paper. These, as defined by Maturana and Varela (1998) are:

*Structure* describes the components and relations that actually constitute a particular unity and make its organisation real (p. 47).

*Unity* (entity, object) is brought forth by an act of distinction and implies the operation of distinction that defines it and makes it possible (p. 40).

Enactivism as defined by Begg (2013) is “a way of understanding how all organisms including human beings, organize themselves, and interact with their environments” (p. 81). It is a theory of cognition that has its roots in biological and evolutionary understandings and views human knowledge and meaning-making as processes that are understood and theorized from a biological and evolutionary standpoint (Towers & Martin, 2015, p. 249). Further, Kieren, Calvert, Reid and Simmt (1995, p. 2) relate enactivism to a given situation where we are called to position ourselves and view cognition not in terms of its products nor its mental structure, but in terms of action or even better, as living in the world of significance with others.

Enactivism argues for the inseparability of body, mind and the environment. In this paper the links between the environment (the geometry word problem) and the body/mind (of the problem solver) are the processes of visualisation and reasoning. Visualisation as a reasoning process is the heuristic by which the problem solving approach of the participants is analysed in our study. It is natural for humans to form a mental image when reading something as a result of visual imagery and reasoning which are at the heart of this. Li, Clark and Winchester (2010) assert that “a key idea of enactivism is that living systems adjust to their exceedingly complex surroundings in an autopoietic manner” (p. 411). This means that the world of meaning is not in us, nor in the physical world around us, it is in the interaction of both the learner (in this case the problem solver) and learning environment (in this case the problem) in a mutually affective relationship (Proulx, 2008). It is therefore with and within the structure that we make sense and give meaning to that physical world and bring forth a world of significance (ibid., p. 21). The point is that the problem and the problem solver constitute an intertwined system that has its own structures, and, from an enactivist perspective, these structures will determine the nature and the outcome of the problem solving process (Reid & Mgombelo, 2015, p. 173). As Maturana and Varela (1998) assert, “the being and doing of an autopoietic unity are inseparable” (p. 49), an idea which is summed up in Maturana and Varela’s (1998) aphorism: “All doing is knowing, and all knowing is doing” (p. 26).

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10 For the enactivist, structure has a far more literal meaning in the sense that it is the physical structure of the individual/organism that determines the distinctions that are able to be made, and the associated affordances that are able to be realised, during interaction with the surroundings (Proulx, 2008).
Enactivism + Visualisation = Enacted visualisation

Our study used enactivism, which acted as a linking mediator to bring visualisation and reasoning processes together. It is the lens through which the co-emergence of visualisation and reasoning processes were observed and analysed when the participants engaged with the tasks of the Geometry Word Problem (GWP) worksheet in small collaborative argumentative groups. Khan et al. (2015, p. 272) assert that enactivism is attentive to the coupling of organisms and their environments, action as cognition, and sensorimotor coordination. Since it is the potential for action in the world that focuses attention and drives learning, enactivism is concerned with the “learning in action” as opposed to embodied cognition’s “learning from action” (ibid, p. 272). Enacted visualisation is therefore visualisation in action whereby the methodological and analytical frameworks are underpinned by an enactivist perspective.

In enacted visualisation, the key enactivist concepts of co-emergence and structural coupling are two mediating ideas that enabled us to discuss the links between reasoning and visualisation that emerged during word problem solving. Co-emergence focuses on the idea that change in either a living system or its surrounding environment depends on the interaction between this system and the environment. When a system and an environment interact, they are structurally coupled, and they co-emerge (Li et al., 2010, p. 407). Thus, the co-emergence of visualisation and reasoning processes was observed when the participants attempted to make sense of the GWP and share their understanding of each problem with each other and as they justified their problem solving strategies when they interacted with each other. Structural coupling occurs as a result of the interaction between the organism with his/her living and active body and the environment. This interaction creates co-emergences and in return produces the “structural coupling” (Rossi, Prenna, Giannandrea, & Magnoler, 2013, p. 38). Enactivist researchers often talk about structural coupling “whenever there is a history of recurrent interactions leading to the structural congruence between two (or more) systems” (Brown, 2015, p. 189).

METHODOLOGY

With the aim of examining, analysing and interpreting how visualisation processes are integral to word problem solving, and studying their co-emergence with the reasoning processes during geometry word problem solving, this qualitative case study is located within the interpretive paradigm (Cohen, Manion, & Morrison, 2011). The interpretive paradigm fits an enactivist study as the interpretivists purpose to understand the meaning that informs human behaviour and to make “interpretations with the purpose of understanding human agency, behaviour, attitudes, beliefs and perceptions” (Bertram & Christiansen, 2014, p. 26). From an enactivist perspective, meaning-making is not to be found in “elements belonging to the environment or in the internal dynamics of the agent, but belongs to the relational domain established between the two” (Di Paolo, De Jaegher, & Rohde, 2010, p. 40).
Our study was conducted at a private school where the first author worked as a mathematics teacher. Data were collected in three phases from a sample of Grade 11 learners while solving selected GWP. The first phase had 17 participants responding to individual task-based interviews on a worksheet of 10 geometry tasks. The second phase had 8 of the 17 participants working in small groups responding to a worksheet of 5 geometry tasks during a focus-group interview. The third phase was a reflective interview with the 8 participants from the second phase.

A pilot study was conducted with a group of Grade 11 and 12 learners who were not part of the actual data collection process prior to actual data collection and analysis to ensure the validity and the legitimacy of the 15 tasks, and then to refine them. The pilot was also used to trial and refine the analytical frameworks.

DATA ANALYSIS

We used two analytical frameworks consisting of observable indicators. These were firstly the Visual Imagery (VI) framework (Table 1) and secondly the Reasoning Processes (RP) framework (Table 2) to analyse the responses of the selected learners. For the bigger PhD study, data was analysed in three phases corresponding to the three phases of data collection. This paper however only discusses components of the analysis of the first two phases.
**Table 1: Analytical Framework 1 - Visual Imagery**

<table>
<thead>
<tr>
<th>Category of visual imagery</th>
<th>Code</th>
<th>Definition</th>
<th>Observable Indicators/Researcher’s inferences</th>
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</table>
| Concrete pictorial imagery | CPI  | Concrete images of an actual situation formulated in a person’s mind; picture in the mind drawn on paper or described verbally. | CPI1: formulates a picture in the mind (PIM) (while reading/rereading a word problem); draws/sketches to represent a mental image or a concrete situation.  
CPI2: concentrates silently (after a question is posed) – the thinking process involves imagination and mind pictures.  
CPI3: clarifies the structure of the problem; gives explanations/suggestions based on imagination and the formulated PIM. |
| Pattern imagery            | PI   | This refers to the type of imagery in which concrete details are disregarded and pure relationships are depicted in a visual-spatial scheme. PI’s essential feature is that it is pattern-like and stripped of concrete detail. PI embodies the essence of structure without detail. | PI1: formulates/uses patterns with the purpose of depicting/communicating information. For example, patterns of the theorem of Pythagoras (i.e., $c^2 = a^2 + b^2$)  
PI2: engages patterns of data and arguments.  
PI3: uses visualisation to discover generalisations and to derive non-obvious concepts/formulas from such generalisations. |
| Memory imagery             | MI   | This refers to the ability to visualise an image of a formula that one has seen somewhere before or have previously learned. | MI1: formulates a mental image of a book/ board and depicts how a formula/concept was written (visualises something previously learned)  
MI2: sees a specific formula/method in mind that is needed to solve the problem (he/she may give description of the problem-solving strategy)  
MI3: recalls from memory; uses previous knowledge; an act of remembrance. |
| Kinaesthetic imagery       | KI   | This is imagery that involves muscular activity. A kinaesthetic visualiser wants to feel and touch. | KI1: patterns of movement and body engagement as part of problem solving.  
KI2: walks/traces a path with fingers/hand/pencil to illustrate an image of something.  
KI3: mimics/mimic/traces shapes without placing the pencil on paper. |
| Dynamic imagery            | DI   | This category involves the processes of transforming shapes i.e. redrawing given or initially own drawn figures with the aim of solving the problem. | DI1: redraws given or own drawn diagrams with a purpose of extracting simple figures; from complex figures, or to divide figures with lines to form other figures.  
DI2: visualises a series of several images connected in one smooth motion, in mind and/or paper.  
DI3: transforms/changes the orientation of picture/shapes/concrete objects. |
<table>
<thead>
<tr>
<th>Reasoning Processes (RP)</th>
<th>Code</th>
<th>Definition</th>
<th>Observable Indicators/researcher’s inferences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanation</td>
<td>RPE</td>
<td>Mathematical explanation refers to the classification aspects of one’s mathematical thinking that one thinks might not be readily apparent to others.</td>
<td>RPE1: makes sense of the problem and establishes a claim e.g. explains what the problem entails in simple terms and suggests known concepts/procedures. RPE2: explicates his/her own thinking processes (to produce meaning – includes reasoning without words) RPE3: suggests and defines problem solving strategies</td>
</tr>
<tr>
<td>Justification</td>
<td>RPJ</td>
<td>Mathematical justification refers to an argument that demonstrates (or refutes) the truth of a claim that uses accepted statements and mathematical forms of reasoning.</td>
<td>RPJ1: provides proofs to validate claims and arguments RPJ2: provides acceptable reason for action (asks for clarification from others) RPJ3: promotes understanding among those engaged in justification e.g. does something to answer another person’s concerns and lessen their worries</td>
</tr>
<tr>
<td>Argumentation</td>
<td>RPA</td>
<td>An argument is a verbal, social and rational activity aimed at convincing a reasonable critic of the acceptability of a conclusion by foregrounding a constellation of propositions justifying or refuting the proposition expressed in the conclusion</td>
<td>RPA1: provides support for explanations and justifications (this includes insisting on accuracy of their own and others’ claims) RPA2: convinces/persuades others via verbal/visual activity of the truth of their claims and appropriateness of their reasoning (or is convinced and persuaded by others – i.e. when they accept the truth of each other’s claims and explanations) RPA3: accepts/refutes truth of others’ claims that they may agree/disagree with</td>
</tr>
<tr>
<td>Generalisation</td>
<td>RPG</td>
<td>To generalise a problem situation is to identify the operators and the sequence of operations that are common among specific cases and to extend them to the general case.</td>
<td>RPG1: elaborates the problem further to try to learn more from the result by relating the problem to similar situations. RPG2: uses visualisation to demonstrate how the problem can be solved in a different way</td>
</tr>
</tbody>
</table>
FINDINGS AND DISCUSSIONS

Visual imagery

The purpose of this analysis was to tease out those participants whose preferred method of word problem solving was dominated by visual methods as opposed to those who preferred non-visual methods.

Figure 1 below illustrates the 17 participants’ preference use of VI.

![Figure 1: Overall percentage of the use of the 5VIs in the EVGRT W1 for all participants](image)

There were 11 participants whose preference of VI in word problem solving exceeded 30% as illustrated in Figure 1. Of this cohort, eight participants agreed to participate in the second phase of the case study which interrogated their use of visualisation processes in greater depth. The eight participants were Millie, Denz, Ethray, Ellena, Jordan, Meagan, Nate and Rauna as illustrated in Figure 2 below.
Figures 1 and 2 above revealed that each research participant in this study had a notable ability to employ visualisation processes to solve GWP. The results of this analysis also revealed that all learners can use visualisation processes to solve word problems, with a number of learners being able to draw upon a panoramic assortment of visual images, and a majority of the learners preferring the use of visual methods to solve word problems.

**Reasoning processes**

The eight participants’ RP were analysed versus their VI to tease out the co-emergence of VI and RP during the second phase of data analysis which comprised four components, each of which complemented the other. For the purpose of this paper, we only discuss the first three components of this analysis. In the first component, the analysis focused on the mathematical reasoning processes of each of the eight participants as they solved the word problems in their focus-groups. Figure 3 below illustrates the global overview of the eight participants’ analysis of the RP.

![Figure 3: Global overview of the participants’ reasoning processes](image)

On first glance at Figure 3 above, one might deduce that, on average, the three girls, Meagan, Millie and Rauna, reasoned more or better than the other participants. This is however not necessarily the case as all the participants solved the same tasks in their small focus groups and were all given sufficient time to work independently, and with each other to solve the tasks. The first focus group interviewed consisted of the three girls, Meagan, Millie and Rauna who took the longest, about two
and a half hours to complete the worksheet, and whose transcription amounted to 120 pages. The second focus group that was interviewed consisted of a girl and two boys, Ellena, Ethray and Nate, who took about an hour and a half to complete the same worksheet that the first group completed. The third interviewed focus group consisted of the two boys, Denz and Jordan, who took less than an hour to complete the same worksheet. The variable length of time that the three groups took to complete the tasks resulted in a skewed graph and a possible misinterpretation of the data. As we were more interested in the quality of the co-emergence of reasoning and visualisation processes, this skewed graph should not be a concern. What Figure 3 illustrates is thus a good quantitative description of the use of different reasoning processes for each participant and across participants.

Figure 3 also illustrates that of all the reasoning processes, generalisation was the least frequently used during the focus group task-based interviews. Generalisation is a much higher level of reasoning than the other three, hence its least application by the participants. In their study, Swafford and Langrall (2000) observe that students found it difficult to identify the operators and the sequences of operations that were common among specific cases of their solutions and to extend them to general cases. Similarly, the participants in this case study hardly elaborated the problems further to try to learn from them, and only did so when prompted. The participants were reluctant to generalise, preferring to find an answer and proceed to the next problem rather than trying to show how to solve the current problem in other ways.

In the second component of the second phase, the relationship between RP and VI is teased out for each participant. The results are presented quantitatively in Figure 4 below, showing the co-occurrence of various RP with different VI.

![Figure 4: Overview of the data analysis matrix for the relations of visualisation and reasoning processes](image-url)
The closest relationship between VI and RP was recorded between pattern imagery and the reasoning process of argumentation, as illustrated in Figure 4 above. This means that most of the research participants formulated patterns with the purpose of communicating information, engaged in patterns of data and argument, and used visualisation to venture generalisations (Table 1), providing proofs, explanations and justifications, while convincing/persuading others of the truth of their claims and accepting/refuting the truth of others’ claims at the same time (Table 2). There was also a strong connection between kinaesthetic imagery and the reasoning process of explanation, with a matrix coding of 397 references. Pattern imagery also recorded a close relationship with the reasoning process of justification, where participants provided proofs to validate their claims, provided/sought rationales for actions taken, as well as promoted understanding among those engaged in a justification. These recorded a matrix coding of 368 as illustrated in Figure 4. More specifically, the matrix coding between each of the 4PRs and their respective 5VIs, Figure 4 shows that RPE was strongly related to KI, PI and CPI. RPJ was strongly related to PI and KI. RPA was strongly related to PI and KI. RPG was strongly related to PI and KI. These relations are observed for all the eight research participants in the main study.

The third component of data analysis from the second phase is a qualitative analysis of eight vignettes, two per reasoning process. We especially selected these vignettes because of some striking features that we noted in the transcript or quantitative analysis of the second component of data analysis. The analysis presented in these vignettes were both systematic and insightful. Below is an analysis of one such vignette, Nate’s justification.

The problems that were posed were:

```
**Task 1**
Marina’s backyard is a square with a side length of twenty meters. In her backyard is a circular garden that extends to each side of her yard. In the centre of the garden is a square patch of spinach so big that each corner of the square touches a side of the garden. Marina really likes spinach! How much area of Marina’s garden is being used to grow spinach?

**Task 5**
In a cube with sides of length 10cm, denote one vertex by the letter V. Find the sum of the shortest possible total distances from V to each of the other vertices of the cube.
```

Unlike all the other focus groups participants, Nate was the most reserved. He did not speak much and participated minimally. However, when he participated, he sparked some interesting visualisation and reasoning processes. We particularly selected this vignette to discuss interesting ways in which Nate used the reasoning process of justification (RPJ) in the course of solving two problems: first in relation to how he justified his actions, claims and arguments during the first task and secondly, during the fifth task.
Once again, Nate remained silent when his peers started to deliberate over the fifth task. He quietly made gestures with his hand and observed the others as they attempted to find the dimensions of the cube. Ethray commented: “Okay, so now we have a cube [sketches another cube], each side is ten. So now we’re looking from there to there” [draws a diagonal in his sketched cube]. Ellena asked him a rhetorical question: “Isn’t it ten and then another ten?” [Looks at the diagonal as if though it is made of the adjoining 10m edges of the cube]. Ethray agreed with her, saying: “From there till there [walks a path on the surface of the cube with a pencil; formulating a right angled triangle]. Isn’t it also this fourteen point one? Here’s also fourteen point one [mimics drawing a diagonal on the surface of the cube]”. To the question why they believed that the length in question was 14.1 centimetres as they claimed, using Figure 5, Nate reasoned as follows:

Because this distance downwards is ten [walks a path from top to bottom edge of the cube with a finger]. That’s ten if you go the other way [moves his hand under the cube to show the 10m length]. So, [moves his hand as if he was drawing a diagonal on the face of the cube].

SOHCAHTOA is a useful mnemonic for remembering the definitions of the trigonometric ratios sine, cosine, and tangent i.e., Sine equals Opposite over Hypotenuse, Cosine equals Adjacent over Hypotenuse, and Tangent equals Opposite over Adjacent.
cube but did not say what he was doing] fourteen point one (...) so we basically look at the square from the side, cut it in half [sketches a triangle to represent half of a cube].

(a) “this distance downward is 10” (b) “that’s 10 if you go the other way” (c) “fourteen point one” (diagonal)

Figure 5: Visualisation and reasoning processes in action as Nate justifies his arguments

Nate was asked to show what he meant by “cut it in half”. Instead, and rather hurriedly, Ethray, who was convinced by Nate’s argumentation and justification, at that moment commented:

Cut this in half [he placed his hand on the surface of the cube as though it were a knife cutting through the cube] (...) if you cut this in half you’d have a triangle like that [places his hand like a knife again and moves his finger around the surface in question]. But then you’ll have like (...) it goes that way. Something like that [tried to sketch something like half of the cube but did not complete the sketch].

Ethray was convinced by Nate’s arguments yet unsure of the shape when a cube is cut in half. Nate sketched his mind picture of the half of the cube (Figure 6) in an attempt to help improve and promote understanding in his group.

Figure 6: Nate visualisation of a halved cube
This is an illustration that although the participants worked in small groups, they were able to reason as individuals who both influenced and were influenced by the reasoning of others. This is called structural coupling from an enactivist framework (Maturana & Varela, 1998) which then leads to the co-emergence of visualisation and reasoning processes.

CONCLUSION

The participants in our study incorporated both processes of visualisation and reasoning in their problem solving in no particular orderly pattern (Figure 7). This shows that the co-emergence of VI and RP happens in a circular pattern with no definite beginning. That is, the origin of the process is untraceable. It begins in the participants’ minds, and as observers we did not and cannot claim full access to the problem solvers’ minds. Maturana and Poerksen (2004) assert that “the observer is the source of everything, and without the observer, there is nothing” (p. 28). For the purposes of our study, however, we took a slightly more nuanced stance and suggested that the observer is the source of what he/she observes and the creator of what he/she sees. Although we were obviously unable directly to observe what the participants saw in their minds, we could rely upon what they uttered, both verbally and visually. Hence, what became of interest to us as observers was that which the research participants and their environments permitted and gave us access to.

Figure 7: The co-emergent relationship between visualisation processes and reasoning processes

The findings of our case study thus provide sufficient premise to conclude that visualisation processes and mathematical reasoning processes are closely interlinked in the process of any mathematical activity. Our study also argues that the visualisation processes enacted by the participants when solving a set of word problems were inseparable from the reasoning processes that the participants brought forth; that is, they co-emerged. This is our new contribution to knowledge of the mathematics education research. Reasoning, visualisation and problems solving are all common sites of research in mathematics education and constitutes some of the earliest work in the psychology of mathematics education. However, the use of enactivism to theorise the interaction of reasoning and visualisation in this study is a new contribution.

REFERENCES


LEARNING TO ELICIT AND RESPOND TO STUDENTS’ MATHEMATICAL IDEAS THROUGH TEACHER TIME-OUT

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ABSTRACT
This study explores the potential for mathematics teachers to learn ambitious teaching practices together with students and through the routine Teacher Time-Out (TTO). Since ambitious goals for students’ learning require ambitious teaching practices, studying potentials for learning such practices is important. The data material analysed, is taken from the project Mastering Ambitious Mathematics teaching (MAM). In this project, teachers work on given teaching activities in cycles of enactment and investigation. In this paper, the enactments are analysed and in particular the parts of the enactments where the participants pause instruction for by asking for a TTO. From 139 TTOs in total, 21 TTOs from one cycle are analysed in-depth, suggesting that the routine is a context for teachers’ opportunities to learn how to elicit students’ mathematical ideas and ways to respond to students’ mathematical ideas – in particular how to provide written responses to students’ mathematical ideas. Implications are discussed.

INTRODUCTION
Ambitious mathematics teaching lays the groundwork for all students’ development of mathematical understanding as well as procedural knowledge, for their engagement in mathematical problem solving and for them to experience mathematics in school as meaningful (Lampert et al., 2013; Lampert, Beasley, Ghousseini, Kazemi, & Franke, 2010). The work of teaching mathematics is complex and researchers have tried to identify the ambitious (also named core) teaching practices (e.g. Forzani, 2014; McDonald et al., 2013). Examples of such ambitious practices are working towards ambitious mathematical goals for the students’ learning of mathematics, to elicit and respond to students’ mathematical ideas in order to use students’ knowledge and experiences as affordances (e.g. Turner et al., 2012) and to build on their knowledge and experiences, to orient students towards each others’ mathematical ideas and to evaluate students’ mathematical understanding (Lampert et al., 2010). The mathematics teacher is challenged to carry out more than one of these ambitious practices at the same time and continuously to consider how and when to use them. Teachers’ professional development has ambitious teaching as an overall goal. As a reason, in professional development research teaching practices are central (Grossman, 2018; Grossman et al., 2009; Zeichner, 2012). This focus on teaching practices aims at better supporting teachers in developing their practices towards ambitious teaching practices (Gibbons, Kazemi, Hintz, & Hartmann, 2017; Lampert et al., 2010; McDonald, Kazemi, & Kavanagh, 2013). Studying potentials for learning such ambitious practices is important, in particular in contexts where students’ development of mathematical understanding is in need for development.
Even if the focus of attention in research has moved towards teaching practices (Grossman, 2018; Grossman et al., 2009; Zeichner, 2012), the literature on how teachers might engage in professional development together with students is scarce. The studies done by Gibbons et al. (2017) and Fauskanger (in press) are two exceptions. These researchers have studied the use of Teacher Time-Out (TTO) in professional development of teachers. In TTOs the participants can pause instruction in order to think aloud together, and they can have short discussions about aspects related to the ongoing instruction. After a TTO, the instruction continues according to a common developed plan. Instead of discussing what might have been done or what might have been asked, TTOs make it possible for participants in professional development to ask the students questions or to recommend questions to ask and to consider follow-up questions directly in instruction. In TTOs, the teachers are provided with an opportunity to make changes directly, shifting the focus in the interactions “from one of judgment and evaluation to one of collective consideration and opportunistic experimentation in the midst of teaching mathematics” (Gibbons et al., 2017, p. 29). As a reason, TTOs make it possible for teachers to take a collective responsibility for the ongoing instruction.

School-based professional development has many faces. One example is Lesson Study (e.g. Murata, 2011). When teachers are together in teaching in Lesson Study, one of the teachers teaches based on a common developed detailed plan for the research lesson. The other teachers observe and the discussion follows after the lesson. TTO was developed in school-based professional development (“Math Labs”, see Gibbons et al., 2017), where teachers as a part of their professional development together plan, conduct and discuss teaching. In addition, the teaching is rehearsed (cf. Kazemi, Ghosseini, Cunard, & Turrou, 2016) before it is enacted. TTOs are used in rehearsals as well as in teaching enactment. The instruction is planned with less details than in Lesson Study and known activities are used (cf. Lampert & Graziani, 2009), in order for the planning to take less time. As in Lesson Study, all teachers are responsible for the teaching, but in ‘Math Labs’ they are invited to contribute when the lesson is enacted – i.e. through asking for TTOs.

Gibbons et al. (2017) accentuate that TTOs potentially can support teachers’ professional development and at the same time develop professional learning communities where students are seen as important for teachers’ professional development. These researchers assert that TTOs support teachers when learning the complex, ambitious work of teaching mathematics (e.g. Lampert et al., 2010), by e.g. learning how to invite students into mathematical discussions (O’Connor & Snow, 2018). TTOs also support teachers in developing competence in enacting ambitious teaching practices where all students are seen as mathematical competent (Gibbons et al., 2017) and where teachers build their teaching on students’ ideas (Turner et al., 2012). Gibbons et al. (2017) highlight that future research e.g. should aim at developing deeper understanding of the potential TTOs have in teachers’ learning of ambitious teaching practices. In the study presented in this paper, aspects of this potential will be elaborated upon.

When studying the potential for mathematics teachers to learn ambitious teaching practices together with students and through TTOs, Fauskanger (in press) found that TTOs have a potential for mathematics teachers’ to learn 1) how to elicit students’ mathematical ideas, 2) how to orient
students towards each other’s ideas, 3) ways to respond to students’ mathematical ideas, 4) to evaluate the students’ mathematical understanding, and in addition 5) to develop their general teaching competence. In order to better understand the potential for teachers’ learning, this study digs deeper into TTOs in one cycle of enactment and investigation, parallel to examining the statements put forward by Gibbons et al. (2017) in a new context. This is done by exploring the following research question: What potential does the routine TTO have for mathematics teachers to learn how to elicit and respond to students’ mathematical ideas together with students? The data material analysed is taken from the project Mastering Ambitious Mathematics teaching (MAM).

METHODOLOGY

Design, data material and participants

The data material analysed is video recordings from the MAM project. In this project, teachers collaborate aiming at developing ambitious mathematics teaching practices. It is a school-based professional development project focusing on specific teaching activities. These activities are focusing on central mathematical ideas and they are developed to highlight specific ambitious teaching practices. The activities used in the MAM project include Choral counting, Quick images, Number strings, Problem solving and Games (cf. Lampert et al., 2010). The teachers work on these activities in cycles of enactment and investigation. Each cycle includes the following six steps:

1. The teachers prepare for the cycle by reading given articles and by watching a video showing enactment of the cycle’s activity. Some teachers try out the activity in their own classes.
2. One of the supervisors/teacher educators leads a discussion/an analysis of the literature as well as the video.
3. Supported by a supervisor, the groups of teachers plan the given activity for given groups of students.
4. One of the teachers teaches the activity in a rehearsal where the supervisor and the other teachers act as students.
5. The same teacher enact the activity together with a group of students. All participants can ask for TTOs.
6. Each group of teachers analyses the enactment together with their supervisor, followed by a similar analysis with all the participating teachers and preparation for the next cycle’s activity.

Thirty teachers from 10 different schools participate in the MAM project. 14 out of these teachers have chosen to be part of the research reported on in this paper. These teachers are divided into two groups (group 2 and group 3). They teach in grades five to seven (i.e. students aged 11 to 13 years). The teachers’ age varies from 23 to 59 years, their teaching experience from one to 30 years and their education from 15 to 120 (i.e. master degree) ECTS. One year full time study equals 60 ECTS. The focus of attention in the present study is not to analyse differences related to education, experience or age.
All steps in each of the nine cycles were videotaped and one researcher was present in each group taking notes. In this paper, the data material analysed is video recordings from the teaching enactment (step 5 above) from one cycle. However, this analysis was a second step. The first step was analyses of the teaching enactment in eight of the cycles where two groups of teachers were video recorded, leaving 16 recorded lessons (Fauskanger, in press). Based on the overview of the 139 TTOs in total presented in Fauskanger (in press), the present study digs deeper into the TTOs in one teaching enactment in one group in order to better understand the possible potential the routine TTO does have for mathematics teachers to learn how to elicit and respond to students' mathematical ideas together with students.

**Analytical approach**

In this study, practice is considered as what mathematics teachers do when they enact teaching in cycles of enactment and investigation. This study is informed by sociocultural views of teachers’ learning. Learning is understood as emerging in participation in activities (Lave, 1996) and shifts in participation make visible the learning that is occurring as the participants engage in practice (Lave & Wenger, 1991; Rogoff, 1997), i.e. in TTOs in enactments. Learning, in this view, is about developing the ability to engage in particular practices. This study is based on the assumption that learning together with colleagues, supervisors and students is important in order for teachers to develop ambitious teaching practices. Through this collaborative work, the participants are provided with an opportunity to develop teaching practices parallel to students’ learning (e.g. Horn & Little, 2010). In this context, practice is considered as the work mathematics teachers do when they teach students in cycles of enactment and investigation. The study seeks to understand the potential of TTOs in supporting mathematics teachers learning of the ambitious teaching practices eliciting and responding to students’ mathematical ideas. This is far from trivial (cf. Gibbons et al., 2017), but the six steps in the cycles in the MAM project have a potential to provide teachers with an opportunity to develop a common understanding of these ambitious teaching practices (Lampert et al., 2010, 2013).

The analyses started by identifying all TTOs in the data material based on the following definition of a TTO: The instances where the instruction is paused in order for the participants to better understand and/or act in relation to students’ thinking/students’ ideas, pedagogical choices and/or mathematical content (cf. Gibbons et al., 2017). As an example, in one out of the enactments a student strategy makes visible the commutative property of multiplication (see Figure 3). The participants have in their planning agreed not to focus on the commutative, but rather on the associative property. As a reason, the instructor asks for a TTO in order to ask the other participants the following question: “Should I focus on it [commutativity $(4 \times 3) + (4 \times 3) = (4 \times 3) \times 2$ as presented by a student or $(4 \times 3) + (4 \times 3) = 2 \times (4 \times 3)$]?” In the 10 seconds of TTO discussion that followed this question from the instructor, the participants agree not to focus on commutativity (e.g. $(4 \times 3) \times 2 = 2 \times (4 \times 3)$).
The identification of the TTOs was followed by content analyses (Hsieh & Shannon, 2005) of each of the TTO discussions. The example TTO presented above was coded as “Respond to student” (see Table 1). This analytical approach is seen as flexible and as a systematic approach for identifying patterns in rich data material as video recordings (Hsieh & Shannon, 2005). In Fauskanger’s (in press) study, all the TTOs were studied and coded in relation to ambitious teaching practices (e.g. Forzani, 2014; Lampert et al., 2010; McDonald et al., 2013) visible in each of the TTOs. An overview of all TTOs identified from the enactment sessions of nine cycles from the two groups of teachers is presented in Fauskanger (in press). This overview shows that the most TTOs in one session can be found from the enactment of the fourth cycle of group 3 (21 TTOs). In this paper, we have chosen to dig deeper into this session with most identified TTOs in order to investigate the potential for mathematics teachers to learn ambitious teaching practices like eliciting students’ mathematical ideas and to learn ways to respond to students’ mathematical ideas together with students. Our analysis started by identifying how many out of the 21 TTOs from teacher group 3 (fourth cycle) that initiate eliciting students’ thinking and respond to students’ ideas respectively.

RESULTS

In Table 1, the first comments/questions initiating all 21 TTOs are presented. This presentation illustrates who initiates the TTOs, the content of the TTOs and the duration of TTOs. We observe that the instructor (I) initiates 11 TTOs and the supervisor (S) and the observing teachers (OT) initiate 5 TTOs each. Due to space limits, this presentation in Table 1 does not include what immediately followed after each of the comments or questions had been uttered. More context (e.g. follow up comment or response to each TTO) is included related to each of the TTOs used as representative examples in the presentation of results below.

<table>
<thead>
<tr>
<th>TTO number (who initiates the TTO)</th>
<th>Sentence/question starting the TTOs</th>
<th>Elicit and respond in TTOs</th>
<th>TTO (Duration)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. (I) “Should I show the quick image or should I keep on [drawing]?”</td>
<td>03:57–04:00 (3 sec)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. (S) “Just stop there [discussion about communicativity, i.e. 8 × 3 or 3 × 8].”</td>
<td>05:43–05:44 (1 sec)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. (S) “Can you [to the student] tell, how did you see the eight?” (cf. Figure 2)</td>
<td>Elicit student thinking</td>
<td>05:48–05:50 (2 sec)</td>
<td></td>
</tr>
<tr>
<td>4. (I) “Should I focus on it [communicativity (4 × 3) + (4 × 3) = (4 × 3) × 2 as presented by a student]?” (Figure 3)</td>
<td>Respond to student</td>
<td>08:23–08:33 (10 sec)</td>
<td></td>
</tr>
<tr>
<td>5. (S) “You can ask [the student] where the six comes from [in 6 × 4].” (cf. Figure 4a)</td>
<td>Elicit student thinking</td>
<td>09:41–09:48 (7 sec)</td>
<td></td>
</tr>
<tr>
<td>6. (S) “Ask if the student saw the six groups with four [dots]?” (cf. Figure 4a)</td>
<td>Elicit student thinking</td>
<td>10:20–10:25 (5 sec)</td>
<td></td>
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</tr>
<tr>
<td>7. (I)</td>
<td>“Should I go further into the two solutions from the students, or? How?”</td>
<td>Respond to student</td>
<td>10:49–11:50 (61 sec)</td>
</tr>
<tr>
<td>8. (I)</td>
<td>“Should I draw the solution from the student in the same picture?”</td>
<td>Respond to student</td>
<td>12:12–12:18 (6 sec)</td>
</tr>
<tr>
<td>9. (OT)</td>
<td>“Say that in another class, there was a student who [saw 12 dots in a box].” (cf. Figure 4b)</td>
<td></td>
<td>12:24–12:30 (6 sec)</td>
</tr>
<tr>
<td>10. (I)</td>
<td>“Should I just say it [that 6 can be written as 2 × 3]?” (cf. Figure 4c)</td>
<td>Respond to student</td>
<td>12:53–12:54 (1 sec)</td>
</tr>
<tr>
<td>11. (I)</td>
<td>“Should I write ‘=’ or, how should I write the student solution?” (cf. Figure 4c)</td>
<td>Respond to student</td>
<td>13:00–13:36 (36 sec)</td>
</tr>
<tr>
<td>12. (OT)</td>
<td>“Draw the square like she said [the square of 12 dots].” (cf. Figure 4b)</td>
<td>Respond to student</td>
<td>13:59–14:00 (1 sec)</td>
</tr>
<tr>
<td>13. (I)</td>
<td>“But, that’s another solution [than the one that is drawn in red on the board].” (cf. Figure 4c)</td>
<td>Respond to student</td>
<td>14:29–15:09 (40 sec)</td>
</tr>
<tr>
<td>14. (OT)</td>
<td>“Mark those three [solutions] we want them to look at [seeing the connection].”</td>
<td></td>
<td>15:31–15:50 (19 sec)</td>
</tr>
<tr>
<td>15. (OT)</td>
<td>“Mark what the students say.”</td>
<td>Respond to student</td>
<td>16:40–16:41 (1 sec)</td>
</tr>
<tr>
<td>16. (OT)</td>
<td>“Then you have to push there [in order to get another colour on the smartboard pen].”</td>
<td></td>
<td>16:57–16:59 (2 sec)</td>
</tr>
<tr>
<td>18. (S)</td>
<td>“I wonder if [inaudible] if we should end this by coming up with three numbers and then [Instructor interrupts by saying ‘generalise in a way’]. Yes for instance if we take two times five, no two times eight times five [2 × 8 × 5, Instructor writes on the smartboard]. How to calculate this?”</td>
<td>Introduction to elicit student thinking</td>
<td>20:36–21:10 (34 sec)</td>
</tr>
<tr>
<td>19. (S)</td>
<td>“Which of these [examples] do you [the students] think is easiest when calculating two times eight times five?”</td>
<td>Elicit student thinking</td>
<td>24:08–24:10 (2 sec)</td>
</tr>
<tr>
<td>20. (I)</td>
<td>“Should I write it [the answer] below?”</td>
<td>Respond to student</td>
<td>24:28–24:30 (2 sec)</td>
</tr>
<tr>
<td>21. (I)</td>
<td>“Should we close the session?”</td>
<td></td>
<td>24:53–24:54 (1 sec)</td>
</tr>
</tbody>
</table>

As can be seen from Table 1, five out of the TTOs initiate eliciting students’ ideas whereas nine out of the 21 TTOs initiate responding to students’ ideas. Most of the TTOs focus on (challenges related to) eliciting and responding to students’ mathematical ideas, and it is these TTOs (i.e. TTO 3–8, 10–13, 15 and 18–20 in Table 1) which are elaborated upon in this paper. In the following, our in-depth analysis of the two focus areas in the TTOs will be presented separately.
The activity in the cycle analysed (the fourth cycle) is the quick image in Figure 1, introduced to the students by being shown for three seconds (not enough time to count the dots). This was followed by the students presenting their strategies for finding the total number of dots. In instruction, the main idea is to elicit and discuss the students’ strategies. The mathematical aim for the students’ learning for this session (lesson) is not explicit from the participants’ planning. However, from our analyses of the whole cycle of investigation and enactment (Fauskanger & Bjuland, in press) it becomes clear that it is related to the associative property of multiplication.

Figure 1: A quick image

Eliciting students’ mathematical ideas

From Fauskanger’s study (in press), we learn that most TTOs in all enactments were asked for in relation to eliciting students’ mathematical ideas and the TTOs were initiated by instructors, observing teachers as well as by supervisors. In the TTOs from the enactment of teacher group 3 (fourth cycle), five out of the 21 TTOs focus on eliciting students’ ideas. One example is taken from a sequence of the instruction where a student sees “three eights” (i.e. the three rows with eight dots) in the quick image (Figure 1) and the instructor has drawn three rows with eight dots in each row, as shown in Figure 2. The participants in group 3 had planned for this student strategy and the teacher asks if this student saw the eight dots as two fours (or as $2 \times 4$), when the supervisor asks for a TTO and asks the student: “Can you tell? How did you see eight [dots]?” (TTO3, Table 1). The teaching continues by the student telling how she saw the eight dots. By initiating this TTO, the supervisor elicits the student’s mathematical idea instead of the instructor guessing what the student might have had in his mind.

Figure 2: Three rows with eight dots

A second strategy is initiated by another student who sees “four times three plus four times three $[(4 \times 3) + (4 \times 3)]$” in the quick image. This idea is not further discussed (TTO4, Table 1), but it is represented by the instructor in the quick image (Figure 3) and written in a mathematical language as $(4 \times 3) + (4 \times 3) = (4 \times 3) \times 2$. There is also a potential when focusing on this strategy to elicit and respond to students’ mathematical ideas together with the students. However, the participants seem to agree to ask the students for other strategies instead.
As can be seen from this figure, the multiplication sign in the Norwegian context is “∙”. In the text, the more international “×” is used.

Figure 3: “Four times three plus four times three” in the quick image.

Later in the instruction, another strategy is brought into the discussion when a student sees “four times six”, represented as six groups of four dots in the quick image (Figure 4a). The supervisor asks for another TTO (TTO5, Table 1) saying: “You can ask [the student] where the six comes from” and later one more TTO (TTO6, Table 1): “Ask if the student saw the six groups with four [dots].”

Figure 4a: Six groups of four dots.

These two TTOs encourage a discussion where the student’s mathematical ideas are elicited. Several TTOs are identified in the discussion, elaborating on these initiatives from the supervisor. These TTOs are initiated by the instructor, the supervisor and by different observing teachers (TTO5–TTO13, see Table 1), illustrating how the teaching becomes a collective activity (cf. Gibbons et al., 2017).

Table 1 shows that five out of the 21 TTOs initiate eliciting students’ ideas. We have here exemplified by focusing on three of these TTOs (TTO3, TTO5, TTO6) initiated by the supervisor. Based on our analyses we suggest that TTOs make it possible for the participants in the professional development to pay attention to students’ thinking or their ideas (cf. Gibbons et al., 2017). Parallel to this, our exemplification illustrates that TTOs potentially are contexts in which teachers might learn how to elicit students’ ideas. From the TTOs asked for by the supervisor, the participants have opportunities to learn relevant questions to ask students in order for them to make their ideas visible.

Responding to students’ mathematical ideas

In the data material analysed, it is clear that TTOs are opportunities for teachers to learn more about responding to students’ mathematical ideas. Nine out of the 21 TTOs analysed focus on responding to students’ mathematical ideas in one way or another. The importance of writing students’ ideas on the (smart)board is highlighted in many TTOs. One illustrating example relates to a student who presents that she first found the dots in the first half of the quick image (n=12, Figure 4b). The instructor does not write this students’ strategy on the board, when one of the observing teachers asks for TTO and says: “Draw the square like she said” (TTO12, Table 1). This TTO was followed by the instructor drawing the rectangle in Figure 4b.
Related to the importance of the teaching practice responding to students’ ideas being ambitious (cf. Lampert et al., 2010), mostly challenges are put forward and discussed in TTOs in the data material analysed. Largely, these challenges focus on responding to students’ ideas in writing, or more specific to write students’ strategies presented orally on the board. One example relates to a student who has presented his strategy as “six times four.” This is written by the instructor as $6 \times 4$ on the board (Figure 4b). From analysing the teachers’ planning (Fauskanger & Bjuland, in press) we learn that participants consider the associative property of multiplication to be the focus of attention, and they would like to have three factors in order to illustrate this property. With this as a background, the instructor pauses the instruction and asks: “Should I just say it [that 6 can be written as $2 \times 3$]?” (TTO10, Table 1). The observers recommend the instructor to ask the students, and she elicits from the students that 6 can be written as $2 \times 3$. But when the students present how they see $2 \times 3$ in the quick image and the instructor writes this on the board, it becomes visible for her that this is another six than she thought of, i.e. two columns of three dots as the six on the dice (Figure 4c).

She asks for TTO and says: “But this is another solution [than the one drawn in red on the board]” (TTO13, Table 1). The instructor uses this TTO to discuss the challenge with the other participants. The discussion does not clarify that $6 \times 4$ based on this student’s strategy is six groups with four dots in each group. When $6 \times 4$ is equal to $(2 \times 3) \times 4$ in this context, $2 \times 3$ represents the two columns with three rows of four dots in each column. The instructor interprets $2 \times 3$ as two columns with three dots in each column (as the six on the dice, the rectangles in Figure 4c).

As can be seen from Table 1, nine out of the TTOs initiate responding to students’ ideas. Some of these examples (TTO10–TTO13) illustrate that the routine TTO has the potential to be a context for teachers’ learning of the ambitious practice of responding to students’ mathematical ideas. In particular, the participants have the opportunity to learn how to provide written responses to students’ mathematical ideas.
CONCLUDING DISCUSSION AND IMPLICATIONS

Analyses of 139 Teacher Time Out (TTO) in a professional development context (Fauskanger, in press), confirm the following suggestion put forward by Gibbons et al. (2017): the routine TTO has the potential to be a context where teachers have opportunities to learn components of ambitious teaching practices (cf. Lampert et al., 2010). In order to better understand these potentials, our in-depth analyses of 21 TTOs from the enactment in a cycle of enactment and investigation suggest that it is possible for the teachers to develop a better understanding of the teaching practice to elicit students’ mathematical ideas towards a more ambitious way of using the practice by e.g. practicing questions to ask students in order for them to make their ideas visible. Our analyses also suggest that the participants in TTOs have the opportunity to learn how to respond (in particular in writing) to students’ mathematical ideas. In the data material analysed, it is particularly prominent that TTOs potentially make it possible for the participants to develop their knowledge about how to represent students’ strategies or ideas in quick images.

By highlighting that TTOs might support teachers in their learning of ambitious teaching practices where variation in students’ knowledge and experiences are seen as affordances rather than as constraints (cf. Turner et al. 2012), this study supports the conclusions from Gibbons et al.’s (2017) study. As an example, TTOs support teachers in enacting ambitious teaching practices (e.g. Lampert et al., 2010) in which all students are regarded and treated as mathematically competent by eliciting and responding to their ideas. Potentially the participants might develop competence in building their instruction on students’ varied knowledge bases (cf. Turner et al., 2012), because TTOs are contexts in which the teachers might take collective responsibility for, engage in and learn here and now in authentic teaching contexts (cf. Gibbons et al., 2017). As in Gibbons et al.’s (2017) study, our analyses indicate that TTOs display the ambitious work of teaching mathematics, orient the teachers towards the complexity of this work and structure their participation in order to improve the work of teaching mathematics across TTO episodes.

Gibbons et al. (2017) challenge future research to elaborate upon how TTO as a routine in professional development can sustain and be further developed. The MAM project will continue, making it possible to study the development of TTOs in each group for one and a half year. This continuation will also make it possible to study if and how the supervisors develop their TTO expertise (cf. Gibbons et al., 2017). Lastly, the continuation of the MAM project will make it possible to study the potential the routine TTO has in this context through ten cycles of enactment and investigation. However, in order to study the potential of using TTOs in new contexts, similar projects in new contexts are welcome. In the Norwegian context where new guidelines for teacher education highlight ambitious teaching practices (cf. Mosvold, Fauskanger, & Wæge, 2018), the use of TTOs in field practice will be an important context for future TTO research. In contexts where students’ development of mathematical understanding is in need for development, exploring potentials for teachers’ learning of ambitious practices through e.g. using TTOs in professional development cycles of enactment and investigation will be important for future research.
REFERENCES


THE NEED FOR RELEVANT INITIAL TEACHER EDUCATION FOR PRIMARY MATHEMATICS: EVIDENCE FROM THE PRIMARY TEACHER EDUCATION PROJECT IN SOUTH AFRICA

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ABSTRACT
Recently, initial teacher education for primary mathematics teachers has drawn much attention worldwide due to its importance and contribution to childhood development. In South Africa, in response to a quest for relevant and quality primary mathematics teachers, the Primary Teacher Education (PrimTEd) project has been established as a collaboration between all higher education institutions (HEIs). Different workstreams in PrimTEd are mandated to develop sets of commonly agreed standards, materials and assessments of knowledge for teaching primary mathematics. A common assessment in mathematics was deemed necessary to allow each HEI to reflect on their student intake, and design of their Bachelor of Education programmes (B.Eds). The assessment workstream constructed an online test of 90 minutes, consisting of 50 items on different mathematics concepts pertaining to foundation and intermediate phase school mathematics for teaching. The authors, analysed the performance of the 2017 pilot testing with first year students (n = 317) from two universities, and the 2018 national assessment (n = 1117), where students from seven higher education institutions participated. The results from the 2017 pilot (\(\bar{x} = 45.89\%), SD = 14.8\)) and 2018 national assessment (\(\bar{x} = 48.46\%), SD = 16.8\)) reveal similar patterns of performance. As the test was set at the level of mathematics at which the students are expected to teach, it is concerning that the majority of students (71%) were not able to obtain more than 60%. This brings into question the assumptions made about the mathematics skills and competencies that entrants into the B.Ed programme bring with them into tertiary education. It is recommended that the lower than expected starting point, should be taking into account, when reflecting on the relevance of the preparation of primary mathematics teacher education for quality teachers of primary mathematics in South Africa.

Keywords: Primary mathematics education; PrimTEd project; assessment; initial teacher education; relevance; South Africa

INTRODUCTION

International and national benchmarking studies conducted in South Africa (such as Trends in International Mathematics and Science Study (TIMSS), Southern Africa Consortium for Monitoring Education Quality (SACMEQ), the Annual National Assessments (ANA) and the National Senior Certificate (NSC) exams) show that despite many years of mathematics development programmes aimed at redressing the devastating effects of the past, there is little evidence to prove we have made enough progress at the level of the learner (Pournara, Hodgen, Adler & Pillay, 2015).
The poor performance of South African learners in assessment of mathematics is primarily attributed to teacher quality which is a key determinant of learner achievement (Deacon, 2012). This is not a new observation. It is two decades since the President’s Education Initiative was undertaken and Taylor and Vinjevold (1999) reported the quality of teaching and learning (and hence the quality of learning outcomes) is significantly constrained by teachers’ poor conceptual knowledge of the subjects they teach. Taylor and Vinjevold (1999) referred to low levels of conceptual knowledge, and teachers’ poor grasp of their subjects. This is a serious and consistent concern as, while not a sufficient condition for excellent teaching, ‘disciplinary knowledge… is the foundation on which all other types of knowledge needed for effective pedagogy rest” (Taylor, 2018). Such concerns have been raised in relation to both the quality of teachers already teaching in the school system and the quality of initial teacher education.

Evidence of low levels of mathematics knowledge of practising teachers has been drawn from SAQMEC data of Grade 6 teachers. Venkat and Spaull (2015) found that 79% of South African Grade 6 mathematics teachers (n = 401, SAQMEC 2007) were classified as having content knowledge levels below Grade 6 (using 60% as a benchmark for mastery at a Grade level). Taylor and Taylor (2013) drew on the same SAQMEC data to show that the many Grade 6 teachers do not have a firm grasp of additive relations (addition & subtraction) and multiplicative reasoning (multiplication & division). For the latter, particular weaknesses with regard to rational numbers (encompassing fractions, ratio and proportion) were evident.

Evidence of low levels of mathematics knowledge at the initial teacher education level, has been at a more general and small-scale level. Taylor (2018) refers to a 2010 Council on Higher Education report which described the state of the initial teacher education (ITE) sector as far from healthy. In 2014, the Initial Teacher Education Research Project (ITERP) investigated the nature and quality of initial teacher education programmes offered by the Higher Education Institutions (HEIs) and the extent to which these programmes meeting the needs of the South African schooling system. ITERP considered intermediate phase (IP) courses in five HEIs on the content taught and the instruments for assessing the practice teaching in the mathematics education course. It reported that in four out of the five institutions, the mathematical work in their courses focus mainly on the mathematics content that South African learners deal with in the Intermediate Phase (Grades 4 to 6) and Senior Phase (Grades 7 to 9), but mostly at a much deeper level than expected at school and with a specific focus on the specialised content knowledge required by teachers (Bowie, 2014). Lecturers at the five universities reported very low mathematics knowledge by the students entering the B.Ed. programme referring to student teachers mostly only managing mathematics content at the Intermediate Phase level (4-6) (Bowie & Reed, 2016).

The key finding emerging from ITERP was that the quality of ITE in South Africa was questionable in relation to mathematics and language courses. But student teachers in ITE programmes researched through ITERP were not assessed on their mathematics knowledge. A mathematics subject and pedagogical knowledge test was administered to a very small sample (n= 30) of newly qualified.
teachers. Their mathematics was described as “downright poor” (where there was a mean of 56% on mathematics test set at Grade 4-7 level). Deacon (2012) called for the establishment of benchmarks – to diagnose what mathematics and English the students entering the Bachelor of Education programmes possess.

In this paper we contribute to addressing Deacon’s (2012) call to establish benchmarks in order to diagnose the mathematics that students entering B.Ed programmes possess. We report on a common assessment of the ‘mathematical knowledge for teaching’ amongst prospective teachers (students) entering undergraduate programmes in education at South Africa’s universities. These students enter four-year Bachelor of Education (B.Ed.) programmes with the view to become primary school teachers, at either Foundation phase (Grades R-3) or Intermediate Phase (Grades 4-7) levels. The common assessment was developed and administered as part of the Primary Teacher Education (PrimTEd) project. PrimTEd was launched in 2016 in South Africa to study the present state of mathematics education in primary teacher training and seek ways to encourage collaboration across institution for agreement on a set of common core standards for mathematics and language/literacy.

CONCEPTUAL FRAMEWORK

Since Shulman’s (1986) seminal work there has been much research on exactly what knowledge teachers require to be excellent teachers of mathematics, and how to prepare them for this role. It is now generally recognised that ‘more mathematics’ is not sufficient for good teaching of mathematics, and that what is required is specialised content knowledge (SCK) as well as pedagogical content knowledge (PCK).

In relation to mathematics the concept of ‘mathematical knowledge for teaching’ has arisen (see for example Thanheiser, Browning, Moss, Watanabe & Garza-Kling (2010) which built on the framework by Hill, Ball and Shilling (2008) which drew on Shulman’s (1986) framework). Thanheiser et al (2010) used ‘mathematical knowledge for teaching’ (MKfT) framework when discussing different types of knowledge, they want their preservice teachers to develop in order to teach mathematics in schools.

‘Mathematical knowledge for teaching’ has also been used in the South African context by Kazima, Pillay and Adler (2008) when they investigated case studies on teaching mathematics topics by reputedly successful, qualified and experienced secondary school mathematics teachers. The purpose was to learn from the selected sample of teachers, the mathematical demands of teaching the different topics and in the ways that they had chosen, and through this to further the understanding of the mathematical work of teaching.

In this paper we adopt the concept of ‘mathematical knowledge for teaching’ (MKfT) as the knowledge teachers require to teach primary mathematics well. In this regard, we adapt the description offered by Hart (2010) for what such knowledge entails to our South African context. Primary teachers must have deep knowledge of:
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1. The mathematical topics at the primary school level that includes a robust understanding of why particular concepts and procedures within each topic make sense mathematically;\(^\text{12}\)

2. The future use and further development of this content in previous and subsequent grade levels;

3. Appropriate representations, suitable classroom contexts, alternate approaches and methods (such as might be used by children in solving problems);

4. Interconnections and interdependence among the content and topics, as well as how a new concept can be built upon other existing ideas; and

5. When the mathematical ideas are developmentally appropriate for children to learn.

We concur with Kazima, Pillay and Adler (2008) that “mathematics for teaching needs to be understood as shaped by the particular topic being taught, as well as by how teachers select to introduce and approach the ideas and concepts they are teaching” (p. 283).

We draw from Ball, Thames and Phelps (2008) to illustrate that MKfT in primary school is not trivial. While a prospective teacher may have learnt how to follow a formal long division algorithm (and so obtain the correct solution), they may never have understood this and may therefore be unable to infuse this with meaning for a child. They are unlikely to know that there are two models for division: a quotative and partitive model (where \(18 ÷ 3\) can either be 18 shared into 3 equal groups or 18 partitioned into groups of 3).

Taylor (2018) offers another illustrative example which that MKfT in primary school is not trivial, when he cites this example from Hill, Shilling and Ball (2008):

1. Which of these three methods will work for multiplying ANY two whole numbers? Explain why.

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<thead>
<tr>
<th></th>
<th>A. 35</th>
<th>B. 35</th>
<th>C. 35</th>
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<td></td>
<td>125</td>
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<td></td>
<td>+600</td>
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</table>

We have explained the concept of MKfT in primary school, and illustrated that this is not trivial. The task of universities is to develop MKfT amongst prospective teachers, which is also not trivial. To develop their MKfT prospective teachers first require knowledge of the content (know how to do the mathematics themselves) and then they need to know why these make sense, how to represent them using multiple representations, how the particular aspect of content connects to other topics and grades, and at what stage children are ready to learn this content.

\(^{12}\) These topics include counting and cardinality, operations and algebraic thinking, number and operations in base ten, number and operations in fractions, measurement and data, and geometry (topics as described in the Curriculum and Assessment Policy Standards).
THE PRIMTED PROJECT

The Primary Teacher Education (PrimTEd) Project is a component of the Department of Higher Education and Training (DHET)'s (TLDCIP) program and as such is under the overall authority of the DHET’s Director-General. The PrimTEd Project is managed by the Chief Directorate for Teaching and Learning Development, located in the University Education branch of the DHET. PrimTEd is a collaborative initiative bringing together all the Higher Education Institutions in South Africa, to work together on key common standards, materials and assessment approaches for how to prepare teachers in initial teacher education to be better prepared for the teaching of mathematics and language/literacy in the primary school.

The PrimTEd Assessment workstream has been established as a coordinating body to bring together the assessment efforts of various workstreams constituted under the broad PrimTEd project. The workstreams include a focus on Mathematics (with ‘Number & algebra’, ‘Measurement & geometry’ and ‘Mathematical thinking’ workstreams), as well as a work stream on language & literacy, and work integrated learning (WIL). This is all further supported by a Knowledge Management workstream. The content workstreams are intended to design and share standards, materials, assessment tools and research relating to their focal areas. The assessments formulated by the assessment workstream are not intended for progression and certification purposes as ‘assessment of learning’ for progression and certification purposes remain the responsibility of each HEI. It is expected that standards and materials, templates and exemplar assessment tasks will be made available to the PrimTEd community by the content-specific workstreams, as well as in Work Integrated Learning (Venkat, Bowie & Alex, 2017).

The assessment workstream of the PrimTEd project began its work in 2016 with academic staff from four universities (of which two were historically disadvantaged, and one was rural) collaborating on the formulation of the items for the mathematics assessment. In 2017 the test was administered to first year Primary B.Ed. students in selected institutions and then it was modified and in 2018, students from seven HEIs wrote the test.

METHODOLOGY

This paper reports on part of the PrimTEd study by the assessment workstream on the mathematics assessment. The research question addressed is: What evidence can be drawn from the PrimTEd mathematics test data for 2018 to benchmark some of the mathematics students entering the B. Ed in South African know?

The overall design of mathematics assessment component of PrimTEd draws on design-based research which is systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation. Design-based research is based on collaboration among researchers and practitioners in real-world setting, and leading to
contextually-sensitive design principles and theories (drawn from Wang and Haffanin, 2005 as reported by Fonseca, Maseko and Roberts, 2018).

The purpose of the broader PrimTEd research is to improve B.Ed. programme impact through obtaining feedback on student teacher attainment at the first and fourth years of their degree programme. The results from these assessments are intended to allow programme designers and lecturers to reflect on and improve their B.Ed. programmes over time and have some sense of their own students’ performance compared to a national data set (Fonseca, Maseko & Roberts, 2018). In this paper we focus only on the first year students.

**Design of the PrimTEd mathematics test**

The test items were constructed by the team members of the PrimTEd assessment workstream after a rigorous consideration of what and how the test items to be constructed. Experts from four different Higher Education Institutions (HEIs), who had experience in mathematics education and particularly in primary mathematics education took part in the test design, and development of the assessment framework. The test was constructed as an online test of 90 minutes consisting of 50 items. The Cronbach Alpha for the pilot test in 2017 was 0.84 and for national test in 2018 was 0.86.

The content areas included were whole numbers and operations; rational numbers and operations; geometry; patterns, functions and algebra and measurement. The weighting of each content for the test was 24%, 38%, 8%, 16% and 14% respectively. These content areas were chosen from the Curriculum and Assessment Policy statement (CAPS) document for the mathematics curriculum of foundation and intermediate phases schooling in South Africa.

The test items were mainly from two cognitive categories, lower and higher cognitive demands. As reported by Fonseca, Maseko, & Roberts (2018) the items were classified as either lower or higher cognitive demand, applying the Stein, Grover and Henningsen (1996) framework on tasks. While ‘lower cognitive demand’ items were considered to be routine procedures; the ‘higher cognitive demand’ items involved moves between representations; required insight; connected across topic areas; and/or had no obvious procedure or starting point (Venkat, Bowie & Alex, 2017).

Fonseca, Maseko, and Roberts (2018) provide two illustrative examples of the kind of items included in the PrimTEd test:

Exemplar item 1: Rational number, low cognitive demand

*0.7 is a decimal fraction.*

*Write 0.7 as a common fraction.*

Exemplar item 2: Rational number, high cognitive demand

*A farmer’s cost for milk production is R3,12 for each litre. What are his production costs for 2.5 litres of milk?*

*The calculation you need, to get the correct answer is:*
Further exemplar items include the different ways to multiply (exemplar item 3) provided by Taylor (as reported above). This item would be classified as ‘whole number, high cognitive demand’ in the PrimTEd assessment.

Taylor (2018)’s example from SACMEQ of an ‘item requiring knowledge of arithmetic operations’, is also a good illustration of the kind of item included in PrimTEd:

Exemplar item 4: Whole number, low cognitive demand

* Solve: $10 \times 2 + (6 - 4) \div 2 = *

The test included some items which related to mathematical pedagogy. Such questions were specifically phrased to solicit analysis of a learner’s work or of a common error in mathematics.

Exemplar item 5: Mathematical pedagogy

*Linda says that $\frac{3}{4} = \frac{5}{6}$ and she uses the figure below to show why she says so.*

![Image of blocks representing fractions]

*Choose the BEST explanation of the key fault in Linda’s reasoning.*

- A) *She doesn’t know how to represent fractions*
- B) *She is using different units to represent the whole part and the proper fractions in $\frac{23}{4}$*
- C) *She doesn’t know what a mixed number is.*
- D) *She doesn’t know that $\frac{3}{4}$ is not $\frac{5}{6}$ but is actually $\frac{11}{4}$*

The pilot administration of the assessment in 2017, resulted in some changes to the assessment items for the test instrument used in 2018. These changes were proposed by members of the PrimTEd mathematics workstreams (number sense, mathematical thinking and geometry & measurement) in their review of the pilot instrument; as well as by members of the assessment workstream when reflecting on the facility and discrimination indices for each item using the pilot item response data. In particular, the following changes were made:

- The geometry and measurement items in the 2017 pilot were reviewed and more higher cognitive demand questions were included in this topic.
Several of the pedagogy questions were not answered correctly by any students in the 2017 pilot. These items were reviewed and in some cases replaced and in other cases reworded for clarity.

Some of the whole number and rational number questions were reworded for clarity.

As a result, the two assessments (pilot in 2017 and test in 2018) are similar (in that they have anchor items which are used in both tests), but are not identical (as the test instrument was refined based on the pilot data). Annual comparisons between the two assessments therefore cannot be interpreted to mean a decline or increase in attainment amongst the participating students. Nevertheless, percentage scores for each year; and the relative attainment by decile, topic and cognitive demand have been included in this paper. In reading these results, the pilot data from 2017 is simply suggestive of generally poor attainment. The more robust empirical data source is the larger-scale and more refined test attainment (which was refined after piloting) and administered in 2018.

ADMINISTRATION OF THE PRIMTED TEST

The 2017 test was piloted in the first semester with first year Bachelor of Education students in two universities with 317 students. The one university was an urban comprehensive university and the other an urban university of technology. The two institutions were selected conveniently, as their B.Ed. programme coordinators were willing and able to administer the assessments with the first year students.

The 2018 test was written in the first semester of 2018 with a student participation of 1,117 from seven higher education institutions. Once again the selection of participating universities was convenient – with the mathematics education colleagues across these institutions being willing to administer these assessments with their students. The seven institutions included 4 traditional universities, 2 universities of technology and 1 comprehensive university. These were located across four provinces (Gauteng, Free State, Eastern Cape and Western Cape) and included 3 historically disadvantaged institutions. The assessment drew on mathematics content at the Grade 4 - 7 level of the South African curriculum assessment policy statements.

In both years, the students were the first year registered students for Foundation or Intermediate Phase Bachelor of Education (B.Ed.) degree programmes. In both tests – the 2017 pilot test and the 2018 test – were administered as an online test monitored by the lecturers at the respective institutions and the data were captured and analysed at a national central level. The test was a total of 50 marks and then it was converted to a percentage.

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13 In total 9 universities participated in this assessment in 2018 with first year students. However, one of the institutions was unable to complete the assessment due to server capacity problems (due to errors on the PrimTEd administration side). Another institution opted to write the test in a pen and paper format. At the time of writing, this institution’s data had not been submitted for inclusion in the PrimTEd national data set.
Firstly, the test was analysed using descriptive statistics for overall attainment across all the items. Following Venkat and Spaull (2015) a benchmark for ‘mastery’ of the mathematics content in the test was set at 60%. This was considered a reasonable expectation for students (who had completed Grade 12 with a university exemption) and intended to teach primary school mathematics. It was expected that by fourth year level their attainment on such or similar assessment ought to be significantly higher that then first year benchmark.

Secondly the test results were analysed in relation to the assessment framework which was used to code each item. The assessment framework attended to the CAPS content area or topic, and the cognitive demand level. The assessment framework was collaboratively developed involving the participating members of the PrimTEd assessment workstream (spanning across 8 Higher Education Institutions).

ETHICS

The PrimTEd assessment workstream followed an ethical process requiring voluntary, informed consent for educational research with University of Johannesburg’s protocol number of 2017-072. For more detail in this process see Fonseca et al. (2018).

FINDINGS

The following table give an overall idea on the performance of the student teachers in the mathematics assessment in the years 2017 and 2018.

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<tr>
<th>HEIs</th>
<th>n</th>
<th>Mean (%)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot (2017)</td>
<td>2</td>
<td>317</td>
<td>45.89</td>
</tr>
<tr>
<td>National (2018)</td>
<td>7</td>
<td>1117</td>
<td>48.46</td>
</tr>
</tbody>
</table>

Table 1 shows that in 2017, two institutions participated in the pilot study with the student participation of 317 first year students. The mean percentage of the overall performance was 45.89% (SD = 14.84). When the adapted test was administered in 2018, the mean percentage of the overall performance was found to be 48.46 % (SD = 14.84). As both tests were set at the level of mathematics at which the students are expected to teach, it is concerning that the majority of students were not able to obtain more than 60%.

The following figures give an overall idea on the performance of the first year student teachers in the years 2017 and 2018.
Figure 1: Distribution of attainment per decile in 2017 pilot and 2018 test

Figures 1 indicates that most of the students entering the B.Ed. program in 2017 (8 in every 10) and also in 2018 (7 in every 10) were not meeting the 60% ‘mastery level’ of mathematical knowledge (assessed at Grade 4 - 7 level). The 2018 test showed a distribution which was slightly to the right of the 2017 pilot distribution, which as consistent with the higher mean; and understandable in relation to the improved test instrument design.

Focusing the more robust empirical data from 2018, the first year ITE students participating in PrimTED in 2018 show poor mathematical knowledge for teaching (MKfT). The majority of the first year students (71%) do not meet the minimum benchmark of 60% for knowledge of the mathematics content at primary school level. This has implications for the design and intensity of mathematics courses in the B.Ed. programme.

The following figure shows the relative performance by topic in the years 2017 and 2018.

Figure 2: Comparison of relative performance by topic in the years 2017 and 2018
The students were tested on the different topics in the Continuous and Assessment Policy Statement (CAPS) of the foundation phase and intermediate phase of the South African school curriculum. The content areas included were whole numbers and operations; rational numbers and operations; geometry; patterns, functions and algebra and measurement. The comparison is done to check the trends in performance of the intakes of 2017 and 2018 in the similar tests. The performance pattern shows that the worst performed topic in both the years was rational numbers (weighting in the 2018 test =38%). This finding coheres with the finding by Taylor and Taylor (2013) where particular weaknesses were identified with regard to rational numbers (encompassing fractions, ratio and proportion) when testing Grade 6 practicing teachers.

Both years’ students seemed to perform relatively well in geometry. It is assumed that the performance can be related to the comparatively lower cognitive demand items and the relatively low number of geometry items in the test. The lower attainment in 2018 is to be expected, as the geometry items were reviewed from the pilot and increased in their complexity.

It is evident from Figure 3 that the items on pedagogy was the worst performing items in both years.

![Figure 3: Relative performance by cognitive demand level for 2017 pilot and 2018 test](image)

It is assumed that since the students are in first year level, they might not have been exposed to the methods of teaching yet as the test was conducted in the first semester. The higher mean result of pedagogy items in the 2018 test is likely a result in the change in test design, and pedagogy items in the pilot which were replaced and re-worded for the 2018 test. It is also noted that – as would be expected – the lower cognitive level items were answered more successfully than the higher cognitive demand items.
DISCUSSION

The performance of the students in 2018 gives a clear indication that our student intake in Bachelor of Education programmes across 7 universities, shows poor mathematical knowledge for teaching (MKfT) in the primary school. Similar results were obtained in the 2017 pilot of a similar mathematics test, across 2 universities. This finding aligns with the similarly poor attainment in mathematics tests written by practicing teachers - from the previous small scale study conducted by ITERP (n = 30) for newly qualified Intermediate Phase (Grades 4-7) teachers, and the SAQMEC (n = 409) for Grade 6 practicing teachers.

The low percentages in higher cognitive demand levels also talks of the knowledge the students bring with them to the teacher education program. This can be attributed to the vicious cycle of their own learning when they were at schools. It has been noted by the International Mathematics Union (2014) that in South Africa at the school level, mathematics achievement is inadequate, with a low number of students going on to university with an adequate mathematical background, over the last 20 years. The low attainment in most of the content areas portrayed in the topic-wise analysis also gives a serious concern on the what mathematical knowledge do student teachers have when they enter the program. Particular attention is required for rational numbers (as a result of multiplicative reasoning, involving common or decimal fractions). Hence teacher trainers need to know to exploit time and resources wisely to render quality teaching and learning to happen in these programs.

CONCLUSION

So, what evidence can be drawn from the PrimTEd mathematics test data for 2018 to benchmark some of what mathematics students entering the education degree programmes in South African know?

The majority (7 in every ten) first year ITE students in 2018, across 7 South African universities, show poor mathematical knowledge for teaching (MKfT). The low benchmark of MKfT for prospective teachers entering the B.Ed. programmes has implications for the design of these programmes. Sufficient time is required for teachers to be able to develop deep understanding of the mathematics content. They need time and intensive instructional support to know how to do the primary school mathematics themselves, to know why these processes make sense, to know how to represent these solutions using multiple representations, to know how the particular aspect of content connects to other topics and grades, and to know at what stage children are ready to learn this content.

The PrimTEd mathematics test has provided a common assessment instrument which is at least showing some of the mathematics that student teachers bring with them into the B.Ed. programmes. A mean result of above 45%, at least shows that the instrument is not suffering from floor effects. However, considering that the items were pitched at the level of Grade 4-7 mathematics, with a
minority of items relating to mathematics pedagogy; that the majority of prospective teachers are not able to reach a minimum benchmark of 60% is concerning.

This finding is perhaps not surprising, given that small scale evidence suggested similar results for newly qualified teachers, and practicing teachers at Grade 6 level. What is new is that this dire situation is now evident amongst first year entrants into Bachelor of Education programmes. What is not known from this evidence, is the extent to which the Bachelor for Education programmes are able to work with students with this low level of MKfT, so that by the time they exit the 4-year programme they have made substantial improvements in their MKfT. The data from Fonseca et al., (2018), drawn from only one institution, shows that there were very small gains, when comparing fourth year students to first years. It is not yet known the extent to which this finding is more prevalent across other institutions.

This suggests several possible responses by HEIs. First, HEIs could reflect on their entrance criteria, and the extent to which their intake is sufficiently proficient in primary level mathematics to be able to benefit from a degree designed to support MKfT at primary school. Secondly, the extent to which – with the evidence of poor MKfT at the first year – the B.Eds. programmes are appropriately pitched to work with students, at the mathematics level which they have been diagnosed to have. Do the B.Eds. programmes take these low attainment results into account, and provide enough mathematics (both quantity and quality) of mathematics engagement to have shifted the prospective teachers enough? By the end of B.Eds. programmes do newly qualified teachers know:

- how to do the primary school mathematics themselves,
- why processes make sense,
- how to represent these solutions using multiple representations,
- how the particular aspect of content connects to other topics and grades, and
- at what stage children are ready to learn this content?

In Bowie’s report (2014), on the ITERP Project, it was noted that although the sampled institutions had some strong aspects in their courses, to improve the quality of “IP/SP mathematics tasks for teachers” institutions need to pursue on working cooperatively. Our findings from this initial data about the MKfT primary mathematics amongst first year B.Ed. students, make it clear that the low student performance calls for HEIs need to collaborate to redesign the curriculum of the ITE programs for its relevance. The work of the broader PrimTEd project is a step in the right direction. Much remains to be done to research and improve mathematics learning in Initial Teacher Education programmes for primary school teachers.

ACKNOWLEDGEMENTS

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REFERENCES


AN EXPLORATION OF PEDAGOGICAL CONTENT KNOWLEDGE FOR TEACHING OF SECONDARY SCHOOL GEOMETRIC PROOF DEVELOPMENT IN MALAWI

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ABSTRACT
This paper presents findings from a qualitative case study of exploring aspects of knowledge involved in the pedagogical content knowledge category of explaining and representing geometric proofs. Data were generated by interviewing four Malawian secondary mathematics teachers about their views on knowledge for teaching geometric proof development and observing their lessons. The findings suggest that knowledge of explaining and representing geometric proof development involve several aspects. These include; knowledge of aspects to be emphasised during teaching of geometric proving; knowledge of proving activities; knowledge of explaining geometric proof concepts as connected entities; knowledge of inductive and deductive forms of representing geometric proofs; knowledge of relevance of geometric proofs; and knowledge of teaching materials.

Key Words: Geometric proof development, Pedagogical content knowledge

INTRODUCTION
The Malawi National Examinations Board (MANEB) mathematics chief examiners’ reports indicate that secondary school students consistently experience challenges in developing geometric proofs during national examinations (MANEB, 2016). The reports by MANEB and the ministry of education in Malawi show that this problem is due to lack of teacher knowledge which leads to poor teaching of mathematics including geometric proof development (Government of Malawi, 2008). This support many studies which argue that the quality of teachers’ mathematical practices is directly related to their content knowledge (Ball, Thames & Phelps, 2008; Hill, Rowan, & Ball, 2005; Shulman, 1986). Although Malawi government acknowledges the problem of lack of teacher knowledge in mathematics, no study has been done to understand the nature of teacher knowledge required for teaching geometric proof development. The problem of students’ challenges in developing geometric proofs is also experienced in several parts of the world for example USA, UK and Australia (Battista, 2007; Chinnappan, Ekanayake, & Brown, 2012; Jones, 2002). Several reasons have been advanced for this problem; interwoven nature of geometry and geometric proving (Battista, 2007), poor teaching strategies which emphasises on memorising the proof steps but not on understanding why the proofs work (Jones, 2002), and lack of research which emphasise on the concept of proof development in the study of geometry (Battista, 2007).

Research which aimed at addressing this problem has focused on several issues. Herbst and Brach (2006) focused on developing frameworks for understanding how labour is divided between teacher and students during teaching and learning of geometric proof development. Jones et al. (2009) focused on exploring good models of pedagogy that help students not only to understand the
deductive process of geometric proof development but also to understand how and why the proof works. Other studies focused on understanding content knowledge used by students when developing geometric proofs (Chinnappan et al., 2012). This shows that previous studies on geometric proof development were mainly concerned with teaching strategies and subject matter knowledge (SMK) for teaching geometric proofs but not on pedagogical content knowledge (PCK). In their review of how PCK was conceptualised and empirically studied in mathematics Education, Depaepe, Vershaffel and Kelchtermans (2013) found that mathematics topics which were popularly studied included fractions at elementary level, and algebra and functions at secondary school level. This agrees with Battista’s (2007) argument that although geometric proving is regarded as a difficult mathematical domain, it has not received much attention by scholars who studied mathematical knowledge for teaching.

Therefore, the purpose of this study was to explore PCK for teaching secondary school geometric proof development with an aim of filling the gap in global literature and improving the teaching of geometric proof development in Malawi.

LITERATURE REVIEW AND THEORETICAL FRAMEWORK

Shulman (1986) introduced the notion of teacher knowledge as a combination of SMK and PCK and suggested that research on teacher knowledge should focus on understanding both SMK and PCK for teaching a particular subject. In response to this suggestion Ball and her colleagues studied mathematical knowledge for teaching (MKT) (Ball et al., 2008). Their argument was that teaching of mathematics involves some work. As such their aim was understand knowledge that teachers require to conduct that work effectively. The categories of knowledge required by the teachers were summarised in an MKT framework which divides SMK and PCK into three domains for each. SMK is divided into common content knowledge, specialised content knowledge, and horizon knowledge of Mathematics. PCK is divided into knowledge of content and students, knowledge of content and teaching, and knowledge of content and curriculum. Baumert and Kunter (2013) developed a Cognitively Activating Instruction (COACTIV) model in a study aimed at conceptualising SMK and PCP needed for teaching secondary mathematics. Baumert and Kunter (2013) argued that although SMK includes content of the secondary school mathematics, it is not enough to equip teachers with skills that are necessary for coping with the mathematical challenges facing them during the preparation and implementation of instruction. As such, teachers need PCK as well in order to be able to conduct their work of teaching mathematics. COACTIV distinguishes three dimensions of PCK:

- Knowledge of the didactic and diagnostic potential of tasks, their cognitive demands and the prior knowledge they implicitly require, their effective orchestration in the classroom, and the long-term sequencing of learning content in the curriculum;
- Knowledge of student cognitions (misconceptions, typical errors, strategies) and ways of assessing student knowledge and comprehension processes;
- Knowledge of explanations and multiple representations (Baumert & Kunter, 2013, p. 33).

COACTIV model suited this study because it was developed based on observation of secondary mathematics classroom practices. As such COACTIV model was used to guide this study during data
One of the criticisms of the COACTIV model is that it assumes that it is possible to generalise a framework for all domains of secondary school mathematical (Scheiner, 2015). But the demands of teaching specific domains of mathematics are different (Battista, 2007; Scheiner, 2015). As such it is necessary that recent literature elaborates mathematical knowledge for teaching specific mathematical topics and domains across educational levels (Hoover, Mosvold, Ball, & Lai, 2016; Scheiner, 2015). The other drawback is that the COACTIV model has clarified aspects of knowledge involved in the first two PCK categories but not the third category of knowledge of explanations and multiple representations. Knowledge of cognitively activating tasks involve knowledge of the level of cognitive demands of tasks, prior knowledge required by the tasks, their effective implementation in the classroom, and appropriate sequence in the curriculum and during instruction (Baumert et al., 2010). Knowledge of student’s cognitions and ways of assessing students’ knowledge and comprehension processes involves knowledge of working with students’ existing conceptions, misconceptions, prior knowledge and difficulties, and ways of overcoming those (Baumert et al., 2010). This implies that these 2 PCK categories can be clearly conceptualised by teachers as well as teacher educators. However, it might be difficult to teachers and teacher educators to clearly conceptualise PCK category of knowledge of explanations and multiple representations because its aspects are not clarified. In this paper, I have mainly concentrated on elaborating on what is involved in the PCK category of knowledge of explanations and multiple representations with a specific focus on geometric proof development.

**METHODOLOGY**

The study was conducted using qualitative multi-case study design. The sample comprised four male secondary mathematics teachers. The teachers were from three different secondary schools and a minimum of six years of teaching secondary mathematics. These teachers were purposefully selected on assumption that teachers with long teaching experience have rich information about knowledge for teaching geometric proof development which they have accumulated over the years. This assumption is based on a study conducted by Herbst and Kosko (2012) who found that teachers with different experiences held different levels of knowledge for teaching geometry and suggested that mathematical knowledge for teaching geometry may be learnt from the experience of teaching geometry.

The primary defining features of a case study are that it is rooted in a specific context and it draws from multiple perspectives through either single or multiple data collection methods (Ritchie, Spencer, & O’Connor, 2003). As such, data generation involved interviewing the teachers about their conceptualisations of knowledge required for teaching geometric proof development and observing their lessons. The duration of the lessons varied from 40 minutes (single period) to 80 minutes (double period), interview with each teacher took approximately 1 hour. During the time of lesson observations, John and Kim (pseudonyms) were teaching circle geometry, while Pike (pseudonym) was teaching quadrilaterals. The lessons were video-recorded and the interviews were audio-recorded. About 40 lessons were observed but due to the focus of this paper, only 2 lessons are discussed.
The data were analysed separately using thematic analysis with an aim of capturing and interpreting sense and substantive meanings (Ritchie, Spencer & O’Connor, 2003). Thematic analysis began by transcribing the video-recorded and audio-recorded data into verbatim. This was followed by reading of the transcribed data several times and coding it using PCK categories of COACTIV as predetermined themes. The aim was to identify chunks which belonged to the category of explaining and multiple representation. The chunks which belonged to the category in focus were analysed further to identify themes for presenting aspects of knowledge involved in explaining and representing geometric proof development.

RESULTS AND DISCUSSION

As already explained, the COACTIV model does not clarify the subcategories of knowledge that teachers require in order to provide appropriate explanations and multiple representations. This study has found that this PCK category involves knowledge of areas to be emphasised during teaching of geometric proving, knowledge of proving activities, knowledge of explaining geometric proof concepts as connected entities, knowledge inductive and deductive forms of representing geometric proofs, and knowledge of teaching materials. These subcategories are discussed in the following sections.

Findings from the interview data analysis

The following are the aspects of teacher knowledge which were identified upon analysing and coding the interview chunks which belonged the PCK category of knowledge of explanation and multiple representations.

Knowledge of areas to be emphasised during teaching of geometric proving

The teachers explained that teaching of geometric proof development involves guiding students in a stepwise process. As such when teaching geometric proof development, the teachers emphasise that students understand each of the steps. These steps are elaborated by Paul in the following extract:

*When I am teaching I usually move with the students in steps so that they know how to construct the proof for the theorem that we aim to prove at that particular day. Because most of the theorems are in words or statements then first step is that I make a sketch or a diagram. Then I ask the students to analyse the diagram to identify given information and the information that we are required to prove. Then I do some constructions if it is necessary. Lastly, I ask the students questions that would help us to come up with arguments for our proof. So, for example, I would say which angle is equal to angle y? When the students identify the angle, I ask them to give the reason.*
There are several geometric proving steps that Paul has highlighted in the extract. These are, representing the theorem or word problem into a diagram, identifying given information and the statement to be proved, adding necessary features to the diagram, developing proving statements that are supported with reasons. All teachers explained that these are the steps that they guide their students to follow when teaching them how to develop a geometric proof. This agrees with Cheng and Lin (2009) who defines geometric proving as a multi-step process of constructing a sequence of argumentation from X to Y with supportive reasons. This implies that a teacher is required to know the areas that must be emphasised when explaining and representing geometric proof development.

Knowledge of proving activities

The teachers also explained that teaching of geometric proving involves engaging the students in empirical activities to help them understand how the proof works. Kim explains as follows:

> What actually happen is that students get confused with simple things. So, if you just start proving without engaging them in an activity like measuring or discussions on how to prove, they just memorise the theorem and the proof. So, to avoid memorisation, it is necessary that the students be involved in activities. It is those activities like measuring and discussion that can instil the knowledge or make the knowledge be established in their brain. This helps the students to know that these theorems did not just come or were not just created from nowhere but that they are there and they are true. So asking students to do measurements before proof construction helps them to have tangible evidence that the theorem is true.

Kim’s extract suggests that students should take an active role during geometric proof development lessons. This might include either doing empirical activities or group discussions aimed at enhancing understanding of how the proof works. The ideas suggested by Kim support Ding and Jones (2009) who suggested that teachers need to view proof development as a means of mathematical explanation and discovery, hence they are supposed to engage their students in exploration activities. Kim’s view that he was responsible for providing students with proving activities also concurs with Jones et al.’s (2009) proposal that teaching of geometric proof should also include involving students in exploration activities where proving is perceived as an activity associated with the search for a proof. This suggests that teachers need to know proving activities that would enhance students’ understanding of geometric proof development and promote mathematical explorations.

Knowledge of explaining geometric proof concepts as connected entities

The teachers also explained that teaching of geometric proof development required teachers to help students to make connections. This is because when students are developing geometric proofs, they are required to show a network of relationships among several geometric concepts concerning lines and angles. Pike said that teaching of geometric proof concepts as connected entities could help students be able to apply theorems correctly during proving or solving of problems. He said that
teachers must teach geometric proofs while bearing in mind that learning of geometric theorems is dependent on ability to make connections among different geometric concepts. Pike’s views about connections are presented in the following extract:

A teacher must teach geometry while bearing in mind that what students learn this year will be used next year and also that what the students are learning this year will be affected by what they learnt last year. So, for example, when you are teaching about congruency in Form 2, you need to know what the students learnt in Form 1 that can affect their understanding of the theorem, and you also need to know what the congruency theorem will be used for in Form 3 and Form 4. In that case, a teacher should know what the students will need in order to connect this year’s geometry to next year’s geometry.

The extract by Pike suggests that teaching of geometric proofs requires knowledge of whole secondary school Euclidean Geometry. Pike explained that a teacher must teach geometry while bearing in mind about the topic’s prior knowledge and what they will learn in the future. Meaning that students should be helped to see and make connections within the whole web of secondary geometry. This agrees with Battista’s (2007) argument that learning of geometric proof development is complex due to the interwoven nature of geometry. Meaning that if students are unable to make connections among different geometric concepts, they might not succeed in developing geometric proofs. This implies that effective teaching of geometric proof development requires knowledge of explaining and representing geometric concepts in a connected manner.

Knowledge of teaching materials

The teachers also explained that to teach geometric proof development effectively, a teacher must know the type of materials to be used for teaching a particular theorem, and how to use the materials. The materials that they mentioned included textbooks, models, mathematical tools like ruler and pair of compasses, paper and any other teaching aids. They said that the teacher must choose a textbook that explained the proofs in detail and that can be easily understood. The teacher must also know how to use every tool in the mathematical instrument box in order to guide the students to use them properly. Apart from mathematical instrument tools, the teachers also explained that it was also necessary to use materials which would help the students to see how the proof worked and to remove misconceptions about proofs. John explained this point as follows:

The other thing is that in other topics we do use teaching and learning aids to remove misconceptions of students using hands on activities but you find out that in geometry we neglect the use of teaching and learning aids because we are not sure of the type of teaching and learning aids that we can use to construct a geometric proof. So, we teachers are sometimes not resourceful to say what type of material should I find and use in class so that students should understand this proof. If we want our students to understand how to develop proofs in geometry definitely we must first let them prove using materials and then move on to the formal proof.
There are several points emphasised by John. The first point is that he thought that students’ misconceptions in geometric proofs can be removed by using teaching and learning materials. However, John notes that most of the times, teachers do not use teaching materials when teaching geometric proofs because they do not know the type of materials that they can use. Heinze, Cheng, Ufer, Lin and Reiss (2008) recommended use of materials for improving students’ abilities to develop geometric proofs. They report of high abilities in development of geometric proofs among students when materials were used to show the process of proving on a diagram. The extract by John also implies that teaching of geometric proof development must start from development of inductive proof through the use of tangible material and proceed to development of deductive formal proof. This implies that teachers need to know how to represent geometric proofs in both informal inductive ways and formal deductive ways.

Knowledge of relevance of teaching geometric proofs

Knowledge of relevance of geometric proving included understanding the importance of proof in both mathematics as a field and in everyday life. The teachers explained that it was also necessary to help students appreciate the rationale for learning geometric proof development. They said that students become motivated to learn something when they understand its usefulness. Kim complained that sometimes students do not pay attention when learning how to prove geometry theorems because they do not see a link between the proofs and their daily lives. Kim emphasised as follows:

Of course, for students to be motivated to learn something, they must be convinced on how that particular thing is useful in their real world. It is necessary to provide students with opportunities of relating geometric proof development to the real world. The other reason why students do not perform well on geometry proof development is lack of motivation. If the students were taught in such a way that they realise the importance of geometric proofs in their daily life then they would begin to like it for its usefulness and not for exam purposes only.

Kim thought that in order for students to be motivated to learn geometric proofs, they must be convinced about why proofs are useful to their life. This agrees with Jones et al. (2009) who argue that apart from helping students to develop geometric proofs in a good way, teachers also need to know how to help the students to understand the functions of deductive arguments. Kim and Ju (2012) argue that proof is core to development of mathematics, therefore it should be designed to help students understand its significance and cultivate their competence. Jones et al. (2009) claim that being able to help students to be able to proceed with deductive proof in geometry is not enough, it is also important to help students understand why such deductive arguments are necessary. This means that students might be motivated to learn geometric proof development if they understand the value of deductive formal proof. As such, it is necessary for teachers to
understand the relevance of geometric proof development both to students’ daily lives and to the field of mathematics.

Findings from lesson observation data analysis

The results of lesson observation data from John, Paul and Pike show that geometric proof development was mainly represented to students in a deductive form. These three teachers guided the students in formulating logically sequenced statements to verify a given claim. But Kim used both inductive and deductive forms of proof development representation by involving students in exploratory activities where they proved geometric claims empirically, then discussed how to develop the formal proof of a theorem. The following extract is an example of how Pike helped the students to develop a deductive proof to show that opposite angles of a parallelogram are equal.

Firstly, Pike drew a parallelogram and labelled it ABCD on the chalkboard and engaged the students in the following dialogue. Some of the features like diagonal AC and the letters on angles were done by the students during the dialogue.

**Figure 1: Diagram used by Pike when developing a proof of opposite angles of a parallelogram**

13. Pike: Our aim is to prove that opposite angles of a parallelogram are equal. So firstly, we need to know these angles because you cannot start proving before identifying these opposite angles. So who can mention these angles that we are asked to prove?

14. Student: Angles ABC and ADC, or angles BAC and BCD.

15. Pike: Yes, we need to prove that angle ABC is equal to angle ADC, and angle BAC is equal to angle BCD. So we will not only prove one opposite set but both sets. How can we prove these two statements? (silence for 6 seconds). Okay we need to come up with two triangles and prove that they are congruent. So what can we do to have two triangles in that parallelogram?

16. Student: We can join two vertices for example A and C or B and D.

17. Pike: Yes correct, so who can come and join one of the pairs of vertices?

18. Student: (He joined AC).

19. Pike: Okay after drawing diagonal AC, we have come up with triangle ABC and triangle ADC. So let us see, who can come and label angles that are equal using the small letters as usual.

20. Student: (Labels angle BCA as \(x_1\) and angle CAD \(x_1\) )
21. Pike: What is the reason?
22. Student: Alternate angles
23. Pike: Yes alternate angles, how do you know that $x_1$ and $x_2$ are alternate angles?
24. Student: Because the angles lie on parallel lines AD and BC?
25. Pike: Yes, ... so who can show another set of equal angles on the diagram?
26. Student: (Labels angle BAC as $y_1$ and angle ACD as $y_2$)
27. Pike: What is the reason?
28. Student: Alternate angles, AB is parallel to DC
29. Pike: Yes, ... What is the other argument that we can use? (Silence for 5 seconds). Try to remember theorem we proved yesterday and apply it.
30. Student: Line AD = line BC and the reason is opposite angles of a parallelogram.

The extract shows that Pike guided the students in developing the proof by following the areas of emphasis explained during interviews. Firstly he drew a diagram that he used for developing the proof. Secondly he emphasized on understanding what to prove (Utterances 13-15). Thirdly he asked students to think of a construction to be added to the diagram (Utterances 15-18) guiding the students in adding features on the diagram and developing proving statements (Utterances 19-30) and developing proving statements. The extract also shows that Pike is reminding students to relate the given information to their prior knowledge to label equal angles and identify equal lines. The equal angles are labelled using prior knowledge that alternate angles are equal (Utterances 18-21). Equal lines have been identified using knowledge that opposite sides of a parallelogram are equal (Utterances 23-28). The extract also shows that Pike taught geometric concepts as connected entities by encouraging the students to apply the theorem learnt in the previous lesson (Utterance 29).

However, it can be argued that despite involving students in answering questions and adding features into the diagram, Pike provided too much guidance for the students. This is evidenced in utterance (15) where he explained how the proof would be developed. According to Chen and Lin (2009), deciding on the theorem to be used as an intermediary condition for developing a geometric proof is the most challenging part in geometric proof development. This implies that there was need for Pike to engage the students in strategies that could help them to decide on their own how to develop the proof. This could be done either by engaging the students in empirical activities and group discussions as suggested during the interviews, or using prompts that would help the students to figure out on their own how the proof could be developed. As Sylianides and Stylianides (2006) noted, treatment of proof development in high school geometry is problematic when only treated as a formal process and isolated from other mathematical activities. They argue that this type of approach does not offer students opportunities to make sense of and establish mathematical truth.

The following lesson extract is an example of an exploratory activity that Kim used when proving that angles in the same segment are equal. Kim started by drawing a diagram containing three angles at the circumference. Figure 2 presents the diagram drawn by Kim.
After drawing the diagram, Kim asked the students to draw a similar diagram in their respective groups, then to measure the angles, and discuss the results to come up with a theorem. Table 1 presents values found by students after measuring the angles. This is followed by a lesson extract presenting the dialogue between Kim and the students in relation to the values they presented.

Table 1: Values of angles reported by the students

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
<th>Group 5</th>
<th>Group 6</th>
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<tr>
<td>E = 52°</td>
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<td>C = 35°</td>
<td>C = 30°</td>
<td>C = 40°</td>
<td>C = 29°</td>
</tr>
</tbody>
</table>

3. Kim: Okay, so that’s what you came up with. So can you study the sizes of angles for each group individually? What do you notice from the result?

4. Student 1: I noticed that the angles at the circumference are equal.

5. Kim: Yes, but we need to be specific here, which angles at the circumference? Any angle as long as it is at the circumference? Who can improve the statement?

6. Student 2: The angles subtended by the same arc at the circumference are equal.

7. Kim: Very good … We can also say angles in the same segment are equal. This is the theorem that we are going to prove today. So, we will use the same diagram on the board. We are given a circle with centre O, chord AB subtending angles AEB, ADB and angle ACD at the circumference. We want to prove that angles in the same segment are equal. So in our case we want to prove that which angles are equal?

8. Student: Angle ACB, angle ADC and angle AEB.

9. Kim: Yes, that is our task: we need to prove that these angles (pointing at the three angles at the circumference) are equal. So in your same groups, you should discuss how to come up with the proof. You should think of the theorem to use, also discuss if there is need for adding a construction, and then come up with the proving statements which will show that these angles are equal.
The dialogue in the extract shows that students were guided from informal inductive understanding of the theorem to formal deductive understanding of the proof. The extract also shows that the students were not only helped to understand the theorem and the problem to prove but also to discover a theorem from their empirical work (Utterances 3-6). This indicates that Kim’s aim was to help the students to derive a theorem on their own through an empirical activity. In so doing the students might have appreciated the discovery function of proofs in mathematics (Jones et al., 2009). The extract also shows that Kim followed the steps of areas of emphasis during geometric proving. He began by drawing the diagram, after the measuring activity he asked the students to identify equal angles subtended by the same arc (Utterances 7-8). Then he asked the students to begin the discussion by identifying the theorem to be used for developing the proof, the construction to be made, and then develop the proving statements. When the students were presenting their proofs at the end of the discussion, it was found that all groups decided to join AO and BO, and to use the same theorem which states that an angle subtended by an arc at the centre is equal to an angle subtended by the same arc at the circumference. The proving statements which were developed by the students were valid and justified with correct reasons, hence Kim acknowledged that the proofs that were presented by the students were correct. This implies that the empirical activity enhanced students’ ability to develop the formal proof. As Stylianides and Stylianides (2006) argue, inductive forms of proof representations provide students with opportunities to be involved in formation of patterns and conjectures, hence it is a good way of helping students to understand deductive proof and why proof works. Providing students opportunities to discuss how to develop the proofs on their own might also have helped the students to understand how and why the proof works. Involvement of students in deductive reasoning provides students opportunities to develop arguments, hence to enhance understanding of proof development (Stylianides & Stylianides, 2006). The findings from the two lesson dialogues support those of the interviews that that teaching of geometric proof development requires several aspects of knowledge of explanations and representations. These include knowledge of areas of emphasis, knowledge of teaching geometric proof concepts as connected and knowledge of proving activities.

CONCLUSION

This study aimed at exploring aspects of knowledge that are involved in the work of teaching secondary geometric proof development. Specific focus was on exploring the PCK category of explanations and representations under COACTIV model. The study suggests that explaining and representing of secondary geometric proof development involves several aspects. Firstly, it involves knowledge of areas to be emphasised during teaching of geometric proving. Secondly, it involves knowledge of proving activities. Thirdly it involves knowledge of explaining geometric proof concepts as connected entities. Fourthly it involves knowledge inductive and deductive forms of representing geometric proofs, and knowledge of teaching materials. This implies that if teachers have these aspects of knowledge, they might be able to make clear explanations and use appropriate representations during teaching of secondary geometric proof development. The study suggest that although the other two PCK categories of COACTIV model are clarified, there is need to study them further in relation to geometric proof development.
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ABSTRACT

We report on the impact of a mathematics professional development course on secondary teachers’ mathematical knowledge and on their learners’ attainment. The teachers’ scores on a mathematics test improved significantly as a result of their participation in the course. In turn, using a quasi-experimental study we examined the learning gains of approximately 1000 Grade 9 learners from nine secondary schools taught by teachers who had attended the course. We compared these results with those of a comparison group of approximately 1000 learners in the same schools taught by teachers who had not participated in the course. While the intervention group made larger gains, these gains were not statistically significant in comparison with the control group. A closer investigation of the teaching experience of the teachers who had participated in the course compared with their colleagues in the comparison group showed that those in the comparison group had considerably more experience in teaching Mathematics at Grade 10 to 12 level. This suggests that the intervention cannot make up for the experience of teaching mathematics at senior secondary level in the first year after completing the course. It also points to the importance of identifying a matched comparison group of teachers when conducting quasi-experimental impact studies of professional development.

Keywords: Learning gains, mathematics teacher knowledge, impact of professional development

INTRODUCTION

There are attempts across the world to improve teachers’ mathematical knowledge in order to raise learner attainment. In South Africa, despite a wide variety of programmes costing many millions of Rand, there is little evidence that these interventions have had much impact on learners’ performance in Mathematics. The impact problem is frequently attributed to teachers’ poor mathematical knowledge (Carnoy et al., 2011; Taylor & Taylor, 2013).

In 2010 the Wits Maths Connect Secondary project (WMCS) set out to develop models of professional development for secondary mathematics teachers that would improve learner attainment in Mathematics. In 2012 the Transition Maths 1 (TM1) course was offered for the first time to a small group of teachers in one district in the broader Johannesburg area. In 2013 the Learning Gains I impact study showed that learners taught by teachers who had attended the course out-performed learners in the same schools taught by teachers who had not attended the course. The results were
treated as “evidence of promise” since the sample was small, the gains were small and the variation within the intervention and comparison groups was large (Pournara, Hodgen, Adler & Pillay, 2015).

The notion of learning gains is a useful measure of learner attainment in the context of impact studies because it enables us, to some extent, to attribute learning gains to the teaching received from a particular teacher in a given year. Put simply, the gain is the change in test-score from pre- to post-test over one academic year. That said, we are well aware of a range of interventions that are taking place in secondary schools and so we make all claims with caution, knowing that no individual intervention at the level of the teacher can account entirely for improvements in learner attainment.

The TM1 course has been revised and improved annually since 2014, and by the end of 2018 had been offered to four more cohorts of teachers across 80 secondary school in the Gauteng province of South Africa. A follow-on impact study, Learning Gains II, commenced in 2016 to extend the Learning Gains I study with a more robust instrument and a larger sample of teachers, learners and schools. The key question the study seeks to answer is “what is the effect of teachers’ participation in the TM1 course on their learners’ attainment in Mathematics?”

In this paper we report on the initial findings of the Learning Gains II study, and identify key issues that need attention as the study continues and which have a broader impact for similar intervention studies. We begin with a brief review of the literature on teacher knowledge, mathematics professional development on the impact of these on learner attainment. Thereafter we provide a description of the TM1 course, giving the reader some insight into the mathematics and teaching components of the course by means of specific examples of tasks. We then report the results of teacher and learner testing and discuss the implications for this research study and impact studies more broadly.

TEACHER KNOWLEDGE AND LEARNER ATTAINMENT

Shulman’s (1986, 1987) distinctions between subject matter knowledge (SMK) and pedagogical content knowledge (PCK) have provided much impetus for a great deal of research on teacher knowledge. While it is widely agreed that the knowledge teachers need for teaching mathematics is more than sound content knowledge of mathematics itself, the elaboration of the detail takes different forms. Some refer to the additional knowledge as PCK (e.g. Krauss, Baumert, & Blum, 2008) while others (e.g. Ball, Thames, & Phelps, 2008) distinguish sub-categories of SMK as common, specialised and horizon content knowledge, and further sub-categories of PCK such as knowledge of content and students, curriculum and teaching. While we find the SMK-PCK distinction useful, the boundaries between them are too blurred to be useful as analytical constructs. We therefore choose to speak of “mathematics-for-teaching” (MfT) (Adler, 2005; Adler & Davis, 2006) as an amalgam of mathematical and teaching knowledge. MfT includes both subject content knowledge and mathematics-specific pedagogical knowledge.
Elsewhere (Pournara et al., 2015) we have argued that in contexts where teachers’ mathematical knowledge bases are poor, proxy measures such as state certification, number of post-school maths/math education courses taken and years of teaching experience may be relevant predictors of learner attainment in secondary mathematics. However, these proxy measures alone are insufficient as measures of teachers’ mathematical knowledge.

Attempts to measure teachers’ mathematical knowledge have taken various forms across the world. In some instances, teachers have been given the same/similar test items to the learners they teach. Harbison and Hanushek (1992) and Mullens, Murnane, and Willett (1996) found that primary teachers’ scores on such tests were good predictors of learner performance. In South Africa, Taylor and Taylor (2013) reported the poor performance of Grade 6 teachers and learners on items in the Southern and Eastern Africa Consortium for Monitoring Educational Quality (SACMEQ) III study, thus implying a link between (poor) teacher knowledge and (poor) learner performance. More sophisticated measures have been developed in Germany and the United States (Baumert et al., 2010; Hill, Ball, & Schilling, 2008; Krauss et al., 2008). These studies have both found associations between teacher knowledge and learner attainment.

While teacher knowledge is key in all contexts, it is particularly crucial in contexts of poverty and low achievement. Many of the teachers who attend the TM1 course are teaching in such contexts. Nye, Konstantopoulos, and Hedges (2004) and Krauss et al. (2008) have shown that variances in learning gains attributable to teaching are higher in low socio-economic status (SES) schooling contexts.

PROFESSIONAL DEVELOPMENT AND LEARNER ATTAINMENT

The impact of mathematics professional development is a concern across the world. Based on a literature survey of English mathematics education research publications, Adler, Ball, Krainer, Lin, & Novotna (2005) reported a predominance of small-scale qualitative studies. The review by Gersten, Taylor, Keys, Rolfhus, and Newman-Gonchar (2014) of studies of professional development relating to school mathematics showed that very few of the initiatives which met acceptable standards of rigour also led to positive effects on learner attainment. Sample-McMeeking, Orsi, and Cobb (2012) reported the effects of a middle school intervention in the US where teachers took university summer courses in mathematics lasting two to three weeks. They reported an effect size of 0.20 (Hedge’s $g$) on learner attainment for teachers who had attended two courses but there was no discernible effect size for those who had attended only one course. Therefore, further work is required to carry out rigorous studies on the impact of teacher professional development on learner attainment in mathematics, and this study makes a contribution in this regard.

THE TRANSITION MATHS 1 COURSE

The TM1 course is underpinned by the assumption that focusing on teachers’ MfT will lead to better teaching which will in turn translate into improved learner attainment. The course is targeted at teachers currently teaching in Grades 8 and 9, and aims to address the transition from mathematics
in the Senior Phase (Grades 7 to 9) to mathematics in the Further Education and Training (FET) band (Grades 10 to 12). The course consists of eight two-day contact sessions over a ten-month period and focuses on mathematics content (75%) and aspects of mathematics teaching (25%) – a similar ratio to the course described in Sample-McMeeking et al. (2012) mentioned above. Of the 16 days, six days focus on algebra and number, four days focus on functions, with three days each on Euclidean geometry and trigonometry. Teachers submit seven assignments and write two tests. The tests and assignments include mathematics content and tasks related to teaching.

We approach the learning of MfT through revisiting known mathematics (Pournara, 2013) and learning new mathematics. When working with familiar mathematics, a revisiting approach frequently draws on extreme cases and problematizes taken-for-granted aspects to deepen teachers’ knowledge rather than merely redoing known mathematics to improve their procedural fluency (Kilpatrick, Swafford, & Findell, 2001). An example of a revisiting task is given in figure 1.

![Figure 1: Multiple representations of one linear function](image)

**Figure 1: Multiple representations of one linear function**

Here we provide teachers with five representations of the same linear function, $y = 2x - 1$. We then invite them to consider questions about each representation, some of which are familiar such as “where is the $x$-intercept in the table?” We also pose questions that are likely new and unusual, for example: “where is double in the graph?”, “where is double in the table?” and “where is the $y$-intercept in the function machine?” While these questions are not necessarily difficult to answer, they provide an opportunity for teachers to think in new ways about a familiar representation and to extend their network of connections between representations.

We extend teachers’ knowledge beyond the mathematics they are currently teaching so that they can teach Grade 10 and beyond in the future. For this reason the content we deal with extends into the Grade 11 curriculum in algebra, functions and trigonometry, and to Grade 10 level in Euclidean geometry. As part of the course, we pay attention to common procedures in the FET band such as completing the square, dealing with this algebraically and geometrically. Figure 2 shows a task with both typical and extreme examples where teachers are challenged to use three different methods to
solve a quadratic equation. While one it is clearly not strategic to solve $r^2 = 100$ by completing the square, the act of doing so shows how the formula works in all cases, even for special cases.

![Solving quadratic equations 3 ways](image)

**Figure 2: Solving quadratic equations with extreme examples**

The focus on mathematics teaching is built around the notion of teachers’ *mathematical discourse in instruction* (Adler & Ronda, 2014; Adler & Venkat, 2014) which is operationalised through what is known as the Mathematics Teaching Framework (MTF). Here we focus on key elements common to all teaching practices: identifying and articulating a lesson goal, designing and selecting examples sets, selecting representations, selecting and designing tasks, producing explanations and justifications, and building opportunities for meaningful learner participation in lessons. Each of these aspects is sufficiently close to teachers’ current practice and hence possible to implement and then to work on so as to become more skilful at each one. We illustrate the teaching focus though an example from a session on explanations where we deal with the pervasive error of conjoining in algebraic simplification. Teachers are asked to produce an explanation that will convince learners that $4p + 5 \neq 9p$. This typically leads to a range of responses from teachers such as the four illustrated in figure 3.

**Numerical approach using a single case**: The letter stands for an unknown number. So let’s try $p = 2$. If $p = 2$, then what is $5p + 4$? Is it the same as $9p$?

**Appealing to everyday life using letter as object**: We can think of $5p$ as 5 pencils, but 4 is just a number. When we add, we won’t get 9 pencils.

**Appealing to everyday life using letter as specific unknown**: We can think of $p$ as a box with a number of sweets, but we don’t know how many sweets are in the box. Is $5 \boxplus + 4$ the same as $9 \boxplus$? i.e. Is 5 boxes of sweets plus 4 more sweets the same as 9 boxes of sweets?

**Comparing different algebraic expressions using principles of variation**: Let’s compare different algebraic expressions. What is the same/different about the following expressions:

- a) $5p + 4p$
- b) $5p + 4m$
- c) $5p + 4$

*Figure 3: Four possible responses to explain $4p + 5 \neq 9*
We then move on to evaluate each explanation in the light of its mathematical correctness, its generalizability and the extent to which it is appropriate for Grade 8 learners. We highlight the limitations of the *letter-as-object* explanation (Küchemann, 1981) and draw attention to the important yet subtle distinctions between the *pencil explanation* and the *sweets explanation*, showing why the latter is more productive for making sense of algebraic symbols later in algebra because it does not treat the letter as representing the object but rather as representing the *number of objects*. The fourth example shown above illustrates principles of variation, which is given much attention in work on exemplification.

**RESEARCH DESIGN AND METHODS**

We adopted a quasi-experimental design to assess the effect of the TM1 intervention on the participating teachers and on the attainment of their learners. In this section we describe first the sample of teachers taking part in the TM1 course in 2016 and the methods used to analyse their gains in MfT during the course. We then examine a sample of Grade 9 learners during the 2017 school year to assess the impact of the TM1 course.

There were 39 teachers who completed the TM1 course in 2016. To assess their gains on the course in terms of their MfT, tests were administered at the start and the end of the course. The test at the end of the course was more cognitively demanding than the test at the start and covered more topics. Both tests were developed by the project team and were in their third iteration of minor revisions during the 2016 course.

Ideally we wanted all 39 teachers to participate in the Learning Gains II study. However, this was not possible because we intended to test Grade 9 learners and so could only select teachers who taught at least one Grade 9 class in 2017. This reduced the sample to a possible 25 teachers. Thereafter we invited schools to participate, requiring that each school have a least one teacher who had completed TM1 in 2016 and one other teacher, also teaching Grade 9 mathematics, who had not done the course in a previous year. Some teachers dropped out of the study either because they moved schools or because they did not continue to teach a Grade 9 class for the entire year. In the end, the sample consisted of ten TM1 teachers, in 9 schools, with 10 teachers from the same schools in the comparison group. In terms of analysis, a repeated measures t-test analysis was used to compare the mean test scores at the start and the end of the course. This was carried out only for the 10 TM1 teachers in the study.

At the same time, we tested 991 Grade 9 learners taught by TM1 teachers over the 2017 school year. We refer to these as the *TM1 learners*. We also tested 988 Grade 9 learners from the same schools but taught by the comparison teachers. These learners are referred to as the *comparison group*. The test was administered to both groups in February and September 2017.
The test, designed by the project team, tested key aspects of number, algebra, and function. Most items were typical curriculum items at Grade 8 and 9 levels. The test was designed to contain a spread of items across difficulty levels, and included several algebra items from the Concepts in Secondary Maths and Science Project (Hart, Brown, Kerslake, Küchemann, & Ruddock, 1985). Items were revised through an iterative process, to reduce the complexity of several items, so that for example, fewer concepts/procedures were tested in a single item. The test was designed to be administered in a typical maths lesson (approximately 1 hour) in order to reduce interference in the teaching schedule. The total mark for the test was 45. The test was piloted in 2016 with Grade 9 and 10 learners in schools similar to those participating in the study. A Rasch analysis showed that the test was fit for the purpose of testing learning gains at Grade 9 level although there were a few too many items that were difficult for many learners.

For the purposes of the Learning Gains II study, each test item was coded as correct, wrong or missing with only 1 mark being allocated for a correct response. Therefore a learner’s test mark simply indicated how many items s/he had answered correctly. There was no provision for partial marks and no consideration of partially correct responses. This coding scheme provides a clean and simple measure of gains. It is both cheaper and more reliable to code responses in this way than dealing with further codes for partially correct responses. However, it is likely that this strategy will under-report actual gains because learners may make fewer errors in individual items yet still not provide the correct answer.

In terms of analysis, a repeated measures ANOVA analysis was carried out to see whether the interaction between pre to post gains in the learner assessment and the learners’ group (comparison and those taught by TM1 teachers) was statistically significant. In other words, we examined whether learners taught by TM1 teachers made greater gains in the assessment than the comparison group learners.

RESULTS

We first present the quantitative results and analysis from the TM1 tests for teachers, and then the results of the learner tests.

For the TM1 teachers, we compared the mean test scores before and after the TM1 course. The mean pre-course test mark was 57.3% and the post-course mark was 72.1%. A repeated sample t-test analysis showed that this increase was statistically significant at the 5% level ($t = 3.67$, $df = 10$, $p < 0.05$). We therefore concluded that the course had a significant impact on the teachers’ MfT. Given that the post-course test was substantially harder and covered more topics, we would argue that the statistics under-report the impact of the course on teachers’ mathematical knowledge for teaching.

Secondly, we examined in the results of the Grade 9 Learning Gains test scores for the pre- and post-tests, comparing the mean scores for the comparison group and the TM1 learners (Figure 4). As can be seen in the figure, the TM1 learners made greater gains than those in the comparison group.
However, carrying out a repeated measures ANOVA analysis, the interaction between pre/post-test and learner group was not found to be significant (Wilks’ Lambda = 1, \( F(1, 1975) = 0.91, p = 0.34 \)). We therefore concluded that there was no statistically significant difference in the gains in the learner test scores pre to post between the comparison group and the TM1 group.

![Graph showing mean test scores for learners’ pre and post for TM1 learners and comparison group](image)

**Figure 4: Mean test scores for learners’ pre and post for TM1 learners and comparison group**

While in the Learning Gains I study, the learners’ taught by TM teachers out-performed those learners taught by the comparison group of teachers, it was not the case in this study in 2017. A closer look at the teachers’ levels of teaching experience is a possible explanation for the apparent lack of impact of the intervention. We compared the TM1 teachers and the comparison group teachers on their number of years of teaching Mathematics (in general) and on their number of years teaching Mathematics in each of Grades 8 to 12 (Table 1).

<table>
<thead>
<tr>
<th>Years of teaching Mathematics</th>
<th>N</th>
<th>Years of Teaching</th>
<th>Grade 8</th>
<th>Grade 9</th>
<th>Grade 10</th>
<th>Grade 11</th>
<th>Grade 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave TM1 2016</td>
<td>10</td>
<td>13.0</td>
<td>6.3</td>
<td>8.9</td>
<td>3.2</td>
<td>1.7</td>
<td>0.9</td>
</tr>
<tr>
<td>Ave Comparison</td>
<td>10</td>
<td>14.6</td>
<td>4.0</td>
<td>5.5</td>
<td>4.1</td>
<td>5.2</td>
<td>4.9</td>
</tr>
</tbody>
</table>

*Table 1: Teachers’ years of experience of Mathematics teaching*

The data shows that the two groups of teachers had, on average, been teaching for roughly a similar number of years although, within each group there was a wide range of years of experience. While on average the TM1 group had more experience teaching at Grade 8 and 9 levels, the comparison group had considerably more experience teaching at FET level, particularly in Grades 11 and 12. This suggests possibly that participation in the TM1 course does not make up for years of teaching experience at FET level, particularly beyond Grade 10. This is not surprising. The TM1 course is
designed for teachers who teach Mathematics mainly in Grades 8 and 9 (or who are teaching Mathematical Literacy) and wish to strengthen their MfT thus increasing their opportunities to teacher higher grades in the future. The course is not intended for teachers already teaching confidently in Grades 11 and 12. Put crudely, the comparison group consists of the “more senior teachers” with respect to Mathematics. It is therefore not surprising that the TM1 learners did not significantly outperform the comparison learners. If it can be assumed that teachers teaching higher grades have stronger mathematical knowledge for teaching, then the overall findings of this study fit with the underlying assumptions behind TM1 – that paying attention to teachers’ mathematical knowledge for teaching is a necessary condition for improving teaching.

**DISCUSSION**

Impact studies, irrespective of whether or not they report statistically significant results, do not provide insights into the mechanisms which enable or constrain the desired change. In the case of this study, little can be said about why the gains were small for both the TM1 learners and the comparison group. Further research is necessary to unearth possible reasons for the continued low performance of learners in Grade 9 Mathematics. A related qualitative study is underway to investigate the nature of learners’ errors and the extent to which these errors may change between pre- and post-test. Such changes in the nature of learners’ errors cannot be picked up by a coding system that does not make allowance for partially correct responses. This points to the need for mixed methods impact studies where quantitative impact analyses are complemented by qualitative studies such as those that attend to learner error.

Within the broader WMCS project, related qualitative research studies are underway to investigate teacher take-up from the TM1 course through carefully designed case-studies of practice.

It may be that more time is needed for the impact of teachers’ participation in TM1 to impact their practice in ways that also impact learner attainment. For example, Clarke (1994) has argued that the impact of professional development programmes on teachers’ practice is delayed. A “delayed impact study” is underway to investigate the impact of teachers’ participation in TM1 two years after completing the course. This study will include learners in Grades 9 and 10 in order to expand the sample of TM1 teachers who can potentially participate in the study. This of course raises some concerns about the test instrument which was designed specifically for Grade 9 level. However, given the low performance of Grade 9 learners on the test in 2017, there may be less of a flooring effect in the scores of Grade 10 learners. Of course it must be noted that the test does not contain any Grade 10 content and so performance on the test cannot be taken as a measure of competence in Grade 10 Mathematics.

The impact of professional development initiatives cannot be divorced from the specific contexts in which teachers work. A more careful look at the mechanisms linking teacher context and learner impact is required to evaluate and develop teacher professional development initiatives. While the
TM1 course has continually strived to remain close to teachers’ practice, more needs to be learned about how individual school contexts enable and constrain teachers’ work.

In terms of research design, particularly in the context of South African secondary mathematics, the above finding on teacher background and learner attainment shows the possible importance of matched sampling in the teacher group. The implication of this possible finding means that in terms of research design, this may expand the size, cost and complexity of the study since it is seldom possible to find comparison teachers, within the same schools, who have similar years of experience in Grades 8 and 9 but have not participated in TM1. Inevitably this means the inclusion of new comparison schools which potentially strengthens the findings of the study. However, experience has shown that many schools like those participating in this study are not in a position to confirm which teachers are teaching in each grade until early-to-mid February by which stage data collection for a study such as this has already commenced. Consequently the matching of teachers is likely only possible after the pre-test learner data has been collected. This leaves some of the matching of teachers up to chance as the researchers have little control over these matters.

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THE QUALITY OF ARGUMENTATION IN A EUCLIDEAN GEOMETRY CONTEXT IN SELECTED SOUTH AFRICAN HIGH SCHOOLS: VALIDATION OF A RESEARCH INSTRUMENT

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ABSTRACT
The research reported in this study examines the nature of Grade 11 learners’ argumentation features and characterises the quality of argumentation in selected Dinaledi high schools in an effort to adapt and validate a research instrument. Mathematics education reform efforts have highlighted the importance of argumentation in the acquisition of mathematical knowledge. This is attested to by the Curriculum and Assessment Policy Statement’s (CAPS) prescription of investigations as one of the central elements of the mathematical activity. However, very little is known about the quality of mathematical argumentation in high school mathematics classrooms. To add to the literature on argumentation in mathematics from a South African perspective, a survey questionnaire was used to adapt and validate an analytical tool on the quality of argumentation. The data were examined through the lenses of Toulmin’s argumentation scheme and an analytical tool adapted from Osborne, Erduran, and Simon’s framework. The findings suggest that learners hardly construct rebuttals and that the level of their argumentation is low. These results suggest that this tool can be used as a reliable assessment and diagnostic tool in both instructional practices and mathematics education research. The study recommends the consistent use mathematical investigations as a platform to develop argumentation skills in learners. The implication for this recommendation is that mathematics teacher education programmes need to enhance preservice teachers’ engagement in investigations so that learners can argue with purpose. The discussion highlights the implications of this recommendation. Future research on argumentation is explored.

Keywords: Validation; argumentation quality; triangle sum conjecture; investigation; mathematical knowledge construction

INTRODUCTION
Recent mathematics curriculum reform statements have framed investigations as a key feature in the learning of mathematics in high schools (e.g., National Council of Teachers of Mathematics [NCTM], 2002; Department of Basic Education [DBE], 2011). These efforts are supported by research suggesting that formulating arguments supports learning of mathematics (Jahnke, 2008; Rumsey & Langrall, 2016). In addition, current research in learning, teaching, and assessment has repeatedly pointed to the importance of eliciting learners’ preconceptions in instruction (National Research Council [NRC], 1993). I argue that these approaches, which differ from the more dominant knowledge transmission method, are appropriate as they seek to create classroom environments that resemble the practice of mathematicians. Knowledge transmission method relates to the notion that the
“expert” (teacher) is required to fill learners’ minds with information to be memorised and regurgitated when required (Thomas & Pedersen, 2003). In contrast, the methods advocated by curriculum reform efforts underscore investigations as a mathematical activity to reflect mathematics as a human activity. However, conducting mathematical investigations involves high levels of mathematical reasoning (Desforges & Cockbum, 1987).

I follow Blair (2012, p. 72) here in distinguishing between an “argument” and “argumentation” by pointing out that the former is a ‘set of one or more reasons for doing something’ and the latter the ‘activity of making or giving arguments’. Perhaps it is important to note from this distinction that an argument is the product of the process of argumentation. Further, argumentation is not used to refer to a debate, although debate is one form of argumentation, but rather, to a process of thinking and dialogue in which learners construct and critique each other’s arguments (Nussbaum, 2011). According to DeJarnette and González’s (2017), making and justifying a claim, defined in this study as a statement which an interlocutor makes to convince their audience – is a fundamental aspect of doing mathematics. However, the fact that argumentation is not explicitly stated in the CAPS document as a teaching and learning tool is an indictment of the discipline that portrays itself as the epitome of reasoning. Ricks (2010) bemoans the character of school mathematics by pointing out that it deprives learners of the natural socialising appeal of mathematical activity.

Several studies on argumentation have focused on studying opportunities in mathematics classrooms focusing on identifying, creating, and evaluating arguments argument structures (e.g., Aberdein, 2012; Mariotti, 2006; Pedemonte, 2007). The underlying theme of the findings of these studies is that the argumentation process enables the shifting of mathematical authority and ownership from the textbook or teacher to the community of learners who become producers of mathematical understanding and knowledge (Bay-Williams, McGatha, Kobett, & Wray, 2013; Rumsey & Langrall, 2016). In addition, the power of argumentation is that it bears resemblance to how mathematical knowledge is constructed.

Although argumentation is seen by mathematics education documents and researchers in mathematics alike as vital in the learning of mathematics, little research has focused on the issue of measuring the quality of argumentation in learners across the school grades. Given this background, the purpose of this study is to take a step towards addressing this scarcity by examining learners’ quality of their arguments along with the mathematics inherent in the task.

THE SOUTH AFRICAN GEOMETRY CONTEXT

The South African high school Euclidean geometry curriculum is briefly discussed to provide the context in which this study was conducted. In this study geometry has been taken to be the mathematics of shape and space, which traditionally incorporates but is not limited to Euclidean geometry. The importance of Euclidean geometry education as an integral component of mathematics curriculum was confirmed when it was made compulsory once again in South African high schools in 2011 (Bleeker, Stols, & Van Putten, 2013; Department of Basic Education, 2011).
According to Adler (2010), this reintroduction is a response to an outcry at universities about the widening gap between school mathematics and tertiary education with a mathematical content. In addition, this reintroduction of proof into the curriculum reflects the notion that there is an appreciation of proof as the basis of mathematical knowledge construction.

In South Africa, as in most countries of the world, the geometry curriculum includes Euclidean proof and analytical geometry. Whereas Euclidean geometry focuses on space and shape using a system of logical deductions, analytical geometry focuses on space and shape using algebra and a Cartesian coordinate system (Uploaders, 2013). However, the focus of this study is exclusively on Euclidean geometry on the basis that learner performance is consistently poor in Euclidean proofs. Euclidean proof (formal deduction) starts in Grade 10. At this grade level, learners are expected to investigate, make conjectures, and prove the properties of the sides, angles, diagonals and areas of quadrilaterals; namely, kite, parallelogram, rectangle, rhombus, square, and trapezium (Department of Basic Education, 2011). In addition, they are required to know that a single counter-example can disprove a conjecture, but numerous specific examples supporting a conjecture do not constitute a general proof. These requirements are fulfilled through argumentation.

The curriculum at Further Education and Training (FET) Phase (i.e., Grades 10–12), advocates for teaching that involves not only the “how” of mathematics, but also the “why.” This aim notwithstanding, drawing on my own personal experience, there is a lack of direction as to how the “why” part of the aim can be incorporated and made a permanent feature in common the mathematics classroom. Thus, very few will contest the argument that the weakness in CAPS is that there appears to be a lack of explicit focus on argumentation as a heuristic.

**REVIEW OF LITERATURE**

Research studies have shown that learners have difficulty with Euclidean geometry. Various sources of this difficulty have been identified. Easdown (2012) suggests that this difficulty manifests itself in three ways: appreciating why proofs are important; the tension between verification and understanding; and, proof construction. In support of Easdown (2012), de Villiers (1990) concludes that on the basis of extensive interviews with learners, most learners’ difficulty with proof seem ‘not lie so much with poor instrumental proficiency nor inadequate relational or logical understanding as in poor understanding of the usefulness or function thereof’ (p. 11). Ball, Hoyles, Jahnke, and Movshovitz-Hadar (2002) concur. They point out that learners’ failure in Euclidean geometry stems at least partly from the standard practice of simply presenting formal deductive proof without regard to its function. In a word, many learners do not seem to appreciate the function or purpose for learning proof in mathematics.

DeJarnette and González (2017) conducted interviews with 23 high school geometry learners drawn from a public school that served a racially and socioeconomically diverse community. The participants were organised into seven groups of 3-4 each to work on a 1-point perspective drawing problem which required them to justify the decisions they made about similar figures. Although they found
that most often learners drew upon information from the diagram to warrant their claims about similarity, they did not report on the analysis of justifications which their groups of learners used. The commitment to reporting on the basic elements of argumentation – claims, warrants, and rebuttals – only might have threatened the validity of their results.

In another study conducted by Conner (2008) in which she observed a high school preservice teacher and her learners on the east coast of the US. The teacher and her learners were exploring the relationship between two angles in a quadrilateral during her student teaching experience period in the final semester of her university experience. In addition, she also engaged her learners in argumentation on problems involving polynomials. This preservice teacher was allowed to function independently in her classes; she set her own learning goals within the confines of the curriculum. Conner (2008) found that although much of the discourse in the preservice teacher’s classes conformed to an IRE model of instruction, complex models of argumentation were constructed and analysed through incorporating only the basic components of Toulmin argument pattern (TAP). The IRE or the triadic dialogue is the conversation that takes place where the teacher initiates (I) the question, the learner responds (R) and finally the teacher evaluates (E) the response in terms of school mathematics perspective.

According to the van Hiele\textsuperscript{14} (1986) model of geometric thinking, teaching needed to match learners’ thinking and language that progress from one level to the next was more dependent on and could be accelerated by instruction and experiences than age. By “language” here is meant:

The entire linguistic infrastructure (i.e., symbols, terms, notation, definitions, and representations – and rules of logic and syntax for their meaningful use in formulating claims and the networks of relationships used to justify them) that supports mathematical communication with its requirements for precision, clarity, and economy of expression. (Ball, Hoyles, Jahnke, & Movshovitz-Hadar, 2002, p. 908)

Ball et al. (2002) further point out that language is essential for mathematical argumentation and for communicating about mathematical ideas, claims, explanations, and proofs. Therefore, learners working at different levels could not understand each other’s explanations even though they might be describing the same shape or idea. So, if learner and teacher were at different levels of thinking, progress through the levels was stunted and as a consequence learning of deductive proof would be undermined.

Fukawa-Connely and Silverman (2015) conducted an online research with nearly 100 participants organised into 34 teams. These teams were working on tasks that progressed from learning how to use the GeoGebra tools to creating and making explicit claims about angle relationships and figures such as triangles and perpendicular bisectors, and other complex polygons. They explored how argumentation developed in an online environment that allowed small groups to synchronously create, manipulate, conjecture, and discuss dynamic geometry sketches. Demonstrating the efficacy

\textsuperscript{14} The description of this model is beyond the scope of this study. Usiskin (1982) provides a critical outline of this model.
of TAP, they provided a detailed analysis showing that learners make detailed and mathematical
descriptions of their data and develop abstract warrants. However, inconsistent with other studies,
the major finding was that warranting claims was normative in the discussions.

Considered as a whole, these studies make a case for argumentation in mathematics classrooms.
However, what has emerged is the need to focus on the quality of argumentation as learners engage
in mathematical activities that fostered argumentation. It would seem, however, that none of the
studies explored or described the quantification of arguments in classrooms. The purpose of the
present study is to bridge this gap in the literature on mathematical argumentation by first
understanding the nature of learners’ argumentation features, and quantifying and describing
learners’ written geometrical argumentation.

THEORETICAL ORIENTATIONS

The research reported in this study is guided by Stephen Toulmin’s (2003) argumentation theory and
the literature on the quality of argumentation. Toulmin (2003) presents a model, generally referred
to as Toulmin’s argument pattern (TAP), to describe the structure of an argument and how its
elements were related. The TAP model consists of six interdependent components: claim, data,
warrant, backings, qualifiers, and rebuttals. TAP is a framework that has been extensively used in
instructional practices as a tool to construct mathematically sound arguments (Osborne, Erduran, &
Simon, 2004; Venville & Dawson, 2010). In the context of mathematics lessons, the use of TAP has
mainly concentrated on the description of small group discussions among learners (see, for example,
purpose, the assessment of learners’ written argumentation was performed through a modified TAP
structure (Figure 1).

In brief, the basic idea of this model is that a statement, claim or conclusion is justified by providing
a ground (as shared by the mathematical community). For this study, “ground” refers to datum,
warrant or backing provided by the interlocutor in justifying their claim. A warrant is a proposition
that connects datum and claim. Rebuttals are taken to mean statements that sought to show the
weakness in a conclusion. However, not every one of these components is used in every argument.
For instance, given the tentative nature of mathematical knowledge and the fact that for learners the
knowledge being constructed is new, qualifying phrases such as “most probably” or “presumably”
are omitted and therefore implied in a claim.
To successfully engage in this instrument, the learner requires a variety of strategies for selecting, recalling, and connecting facts drawn from a rich knowledge base related to this specific geometric figure (Magajna, 2011). The simplified version of Toulmin’s (2003) argumentation pattern (TAP) model, like Webb and Webb’s (2008), makes provision for participants to also think about possible rebuttals to their claims. Thus, the analysis of written argumentation enabled the making of judgments of the quality of the arguments themselves; that is, determining what makes one argument better than the other. Accordingly, the research question posed in this quantitative study is: What is the Grade 11 learners’ argumentation ability? To further elucidate this question, two specific sub-questions guided this study.

1. What is the nature of argumentation in the frames?
2. How is the quality of learners’ argumentation as they engage in this task?

**METHODOLOGY**

The present study employed a descriptive design not only to understand the nature of the argumentation features in Grade 11 learners \((n = 135)\) but also to adapt and validate an instrument designed to characterise the quality of argumentation in a task embedded in Euclidean geometry. To this end, a written argumentation frame for Euclidean geometry (AFEG) was employed to collect data. To analyse the data, Toulmin’s scheme and a modified Osborne, Erduran, and Simon’s (2004) were used.

**Participants**

The study took place at three randomly selected Dinaledi schools located in the South African province of KwaZulu-Natal. The participants were a cluster sample of 135 Grade 11 learners. Then, two extreme cases were purposively selected to capture the distinction between a low level argumentation and a high level argumentation. In the pursuit of increasing the participation and performance in mathematics and physical sciences by historically disadvantaged learners, the
Department of Basic Education established the Dinaledi School Project, in 2001 (Department of Basic Education [DBE], 2009). The efforts in increasing the number of learners taking mathematics result from the fact that, according to the South African Institute of Race Relations (2012) only an average of 40 per cent of South African learners who complete school at the National Senior Certificate level sit for mathematics examination in South Africa. Disturbingly, the proportion of learners enrolled for mathematical literacy rather than mathematics is skewed in favour of the former (Grussendorff, Booyse, & Burroughs, 2014).

Seventy eight (78) of these participants were female and fifty seven (57) male with an average age of 17.4 years and 17.8 years (age range 15 to 18 years). In each of the schools, all the learners were studying Mathematics, Physical Sciences, Life Orientation and at least four other subjects, including two compulsory official South African languages at first- and second- language level. By the time of the research, September 2017, the sampled learners had covered the Euclidean geometry section of the curriculum.

**Instrumentation**

The mathematical statement that *The interior angles of a triangle sum up to $180^\circ$* was part of the Euclidean geometry content covered in Grade 10 mathematics. The model can be used for both developing a theoretical perspective on argument and analysis of argumentation process in classrooms (Simon, 2008). The answer to the second research question arose from the administration of the AFEG instrument. The duration of the questionnaire was 20 minutes. It consisted of prompts as shown in Figure 2.

![Figure 9: A sample prompt](image)

**Data collection and coding**

Informed consent forms were distributed to the population of Grade 11 learners in each one of the three schools. As already mentioned, 135 learners’ argumentation ability was assessed. A pretest was conducted to determine the level of the difficulty of the argumentation framework. The questionnaire was administered in the beginning of the third term in 2017.
Adaptation of the argumentation framework

A group of ten conveniently sampled Grade 11 learners that did not participate in the present study was asked to respond to the draft argumentation frame (AFEG) to gather evidence for the instrument’s suitability in South African. Pretesting was necessary given the fact that for most of Grade 11 South African learners, English is a second language if not third or fourth language. Grade 11 learners who were not part of the sample to determine minor language modifications were made. Overall, the instrument was found to be at the right level for the target population.

Subsequently, the final AFEG survey questionnaire was administered to the participants. It included demographic choices relating to the learners’ gender and home language. The argumentation data was coded as shown in Table 1. A learner’s argument was labelled as “low” if it was devoid of a rebuttal and “high” if it contained a rebuttal. Learners who provided arguments which were mere hedged were coded as “uncodifiable” and thus classified as being of low quality.

Adaptation and validation of the analytical framework

Given that TAP merely focuses on the structure of an argument, the quality of an argument was judged through a modified Osborne, Erduran, and Simon’s (2004) scheme. This scheme was modified on the basis that it was developed for science education where competing ideas can remain both unresolved and valid. The source of this difficulty lies in the fact that science, whose basis is empiricism, relies on inductive reasoning. However, that situation does not obtain in mathematics. The basis of mathematical knowledge is abstraction; that is, the foundation of mathematical knowledge is proof; very few proofs are accepted only to be retracted later. Given this background, the position taken was that “grounds” replace concepts such as “qualifiers”, “backings”, and “data” for the modified analytical scheme. This stance finds support in Osborne, Erduran, and Simon (2004) assertion that claims, rebuttals, and justifications are the salient features of argumentation which are critical for developing and evaluating practice with argumentation in the classroom.

The psychometric properties of this analytical tool were assessed to ensure that it was valid and reliable. To achieve content validity, a discussion on the constituent elements of the scheme, coding, and scoring system of learners’ data took place to develop an analytical tool. Two university experts in the field of argumentation who were from outside the university where the author was based, were consulted. The internal consistency coefficient of the instrument was calculated as $\alpha = .81$. Overall, the analytical framework was found to be sufficient for the purpose of the study. Further, these psychometric results suggest that this instrument can used as a reliable assessment and diagnostic tool in instructional practices and mathematics education research.
Table 1: Definition and coding of argument components

<table>
<thead>
<tr>
<th>Argument</th>
<th>Definition</th>
<th>Code description</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>My statement is that ...</td>
<td>A claim (C) is a conclusion put forward publicly for general acceptance (Toulmin, 2003).</td>
<td>No reply; uncodifiable.</td>
<td>Low</td>
</tr>
<tr>
<td>My statement is that ...</td>
<td>C (Claim; conclusion)</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>My reason is that ...</td>
<td>A warrant is ground (G) provided in justifying the claim.</td>
<td>C+G (Providing reason for claim)</td>
<td>Low</td>
</tr>
<tr>
<td>Arguments against my idea might be that ...</td>
<td>A rebuttal (R) meant statement that sought to diminish the strength of a conclusion (Pollock, 2001).</td>
<td>C+G+R (Refutation of claim/ground)</td>
<td>High</td>
</tr>
</tbody>
</table>

FINDINGS

First, all the participants’ argumentation frameworks were analysed to determine the nature of argumentation and thus answer the first research question. To this end, Toulmin’s (2003) modified model of argument was used as an analytical framework to identify the salient features of argument constructed by the learners’ as found in their individual argumentation frameworks. The salient elements of argumentation were counted and the results are shown in Figure 3, according to the schools. The notable feature of these data is that rebuttals were few across all the schools, thus suggesting that arguments with rebuttals are difficult to construct for the learners.

As already mentioned, I modified Osborne, Erduran, and Simon’s (2004) analytical tool to code participants’ responses in the AFEG instrument. In Figure 4, a summary of all the coded data as constructed by participants is provided. The various instances in which elements of TAP were used are indicated as C, C+G, and C+CG+R respectively indicating that there was a claim, claim with ground, and claim which not only included a ground but a rebuttal as well.
I present two sample learners’ written argumentation frames: Learner A and Learner B. The sample frames provide an example of application of the coding system adopted in this study. For instance, Learner A’s (Figure 4) argumentation was judged to be of low quality given that the statement provided rebuttal did not constitute a rebuttal. Thus, Learner A provided a statement that could not be categorised as a condition under which his claim or ground cannot hold. He suggested that an argument against his claim that “angle c and e are equal” may be that “they might be a third and fourth angle that is equals to the mentioned ones”. This statement seems to point to the learners’ inability to understand the question; perhaps another example of language interference with learning, a phenomenon common among many in the sample for whom English is not their home language.

![Figure 11: Learner A’s argument](image1)

In contrast, Learner B’s (Figure 5) frame represented a high quality argumentation. In her rebuttal, she indicated that the claim would not hold if “DE is not a solid line like BC”. Indeed this naïve observation might arise particularly from learners who demonstrated lack of understanding that the auxiliary line represents a construction for the purpose of proving the theorem.

![Figure 12: Learner B’s argument](image2)

The analysis of the learners’ writing frames, as shown in Figure 6, revealed several noteworthy findings. First, the majority of arguments emerging from the data was at a low level (70%). Second, though only a small minority, 18% of these arguments (claims, claims + grounds) included claims that were substantiated. Third, particularly discouraging was that only 2% of arguments developed by learners were characterised as being of high quality because they consisted of rebuttals. What was important about these findings was that it provided deeper insights into learners’ difficulties with constructing and sustaining a mathematical argument. The other notable feature of these results was that learners in School A provided the least number of arguments developed by its learners that could not be classified.
Although the data were analyzed by two researchers, we used Cohen’s (1968) kappa coefficient (κ) to determine the reliability. In addition, this coefficient was appropriate to use on the basis that we adopted a multicategory rubric comprising an ordinal scale in which responses were classified into 1 of 5 types of categories. Cohen’s interrater agreements (κ) were calculated for each of the five responses using STATA, a statistical software that enables analysis, management and graphical visualization of data. The very few unanticipated responses received were fitted into the rubric such that the following kappa (κ) coefficients were obtained: content = .95 and argumentation = .97. As Altman (1991) suggests, these values indicated very good agreement between raters.

CONCLUSIONS

The purpose of the present study was to understand the nature of learners’ argumentation features, modify and validate of an existing model to quantify these learners’ written argumentation in a geometry context. The findings were that Grade 11 learners who participated in this study make very few rebuttals. Also, it was found that they argue poorly. The challenge for teachers lay in designing learning experiences and assessment tasks that take an investigative approach to “working mathematically”. By extension, teachers need to understand how to conduct instruction on mathematical argumentation in the classroom faced two challenges.

The recommendation emanating from these findings is that attempts need to be made to consistently use mathematical investigations as a platform for explicitly teaching with a view to developing argumentation skills in learners. A study by Venville and Dawson (2010) found that it may take only short intervention to realise an improvement in the structure and complexity of learners’
argumentation skills. However, flowing from this recommendation are implications for teacher education. Very few will contest the argument that preservice teachers are themselves products of the classrooms where argumentation was rarely seen as a means to learn mathematics in their school years. Thus, high school mathematics methods courses need to be geared towards helping these teachers to understand the value of argumentation in fostering the learning of mathematics. The focus on investigations should help preservice teachers to appreciate how their future learners can argue with purpose.

Future research on argumentation writing frames should also explore the use of open-ended interviews to probe learners’ responses and thus provide deeper insights. Because the sample was selected from Dinaledi schools, the findings cannot be generalised to the larger population of high schools, and second was that we believe that an intervention programme should have been integrated into the study, funding permitting. Throughout the study, however, we attempted to devise a methodology that future research can use to quantify arguments in mathematics and thus report not only on statistically significant findings but also on their practical significance. It is hoped that such reporting can serve as a stimulus for placing argumentation at the heart of mathematics education.

REFERENCES


Department of Basic Education. (2011). *Curriculum and Assessment Policy Statement Natural Sciences - Senior Phase Grades 7-9*. Pretoria: Department of Basic Education.


This questionnaire consists of two Sections. The first one is intended to make analysis simple. The second section asks you to use your previous knowledge of Euclidean geometry axioms. I am interested in the claim that you can make from the data in the diagram, below. This questionnaire is not part of your regular geometry activity and so it will NOT affect your marks. Your name will not be linked to your responses. Please, use the dotted lines to respond to each prompt.

SECTION A: Demographic information

Please, circle/tick one answer for each of the following.

<table>
<thead>
<tr>
<th>Personal particulars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender:</td>
</tr>
<tr>
<td>Female</td>
</tr>
<tr>
<td>IsiZulu</td>
</tr>
</tbody>
</table>

SECTION B: Geometry Task

Instructions

• This questionnaire will NOT affect your marks. Please, do not spend a long time on any one statement – your first thoughts are usually your best.

• Write your responses on the spaces provided after the statement. Please respond to every statement – it’s important that you respond to each statement honestly.

• All the information will be used for research purposes only. Your responses will be treated confidentially. Your responses will not reveal any information that could identify you.

• This survey should take you about 0 minutes to complete.
In the Figure 2, line DE is parallel to line BC on triangle ABC. Please, make ANY statement or claim from the diagram and justify it. Please, think carefully as you argue your points using the guide provided below.

(1) My statement is that .................................................................................................................................................................................. (Claim)

(2) My reason for making this statement is that .................................................................................................................................................................................. (Ground)

(3) Arguments against my idea might be that .................................................................................................................................................................................. (Rebuttal)

End. Thank you.
A PRESERVICE TEACHER’S PRACTICE OF ORCHESTRATING CLASSROOM DISCUSSION WHEN TEACHING LINEAR EQUATIONS

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ABSTRACT
This study investigated a preservice secondary school teacher’s practice of orchestrating classroom discussion when teaching linear equations. Data were generated using video lesson recordings of nine lessons and were analysed using thematic analysis. Themes were developed a-priori from the theoretical framework and a-posteriori from the data. Findings show that the preservice teacher’s capacity to orchestrate classroom discussion was influenced by his mathematical knowledge for teaching. In particular, the preservice teacher anticipated what students would do by focusing on the correct solution processes but did not plan for expected students’ errors and misconceptions. In addition, the preservice teacher monitored students’ work by listening, observing students’ work, and asking the students to explain their solution processes but did not keep track of students’ approaches because of lack of analysis skills and questions that could elicit students’ reasoning and arguments. The preservice teacher also selected certain students to solve problems on the chalkboard in order to find out if the students knew the “correct” solution process of a particular problem. Furthermore, the preservice teacher attempted to draw connections between algorithms but did not draw connections between students’ mathematical ideas and other students’ ideas because he did not give students opportunities to present their work. Implications of these findings for mathematics teacher preparation are discussed.

Keywords: Orchestrating classroom discussion, mathematical knowledge for teaching, preservice teacher, secondary school, linear equations

INTRODUCTION

The rationale for Mathematics Education is to develop students’ problem solving abilities, innovative, logical thinking and analytical skills, to develop ability to recognise problems and to solve them relating to mathematics knowledge and to stimulate and encourage creativity, originality and curiosity in the students (Ministry of Education, Science and Technology, 2013; Sa’ad, Adamu & Sadiq, 2014). Algebra provides opportunities to achieve these goals because it is a language of Mathematics (Li, 2008). However, several studies report that secondary school students experience poor performance in Algebra (Egodawatte, 2011; Mamba, 2011; Sa’ad et al, 2014). Thus, in order to improve students’ performance in Mathematics in general, the teacher should enhance profound understanding and acquisition of Algebraic concepts and thinking skills. It is, therefore, important to study preservice teachers so that we improve teacher education to prepare good teachers.
Leading discussion is one of the tasks and activities that are important for beginning teachers to understand, take responsibility for, and be prepared to carry out in order to perform their instructional responsibilities (Ball & Forzani, 2009). These tasks and activities are called “high-leverage practices” (p. 504). High-leverage practices are tasks and activities that powerfully promote learning and are central to skillful teaching (Ball, 2016). In a group or class discussion, the teacher and students work on specific content together, using one another’s ideas as resources. The purposes of a discussion are to build collective knowledge and capability in relation to specific instructional goals and to allow students to practise listening, speaking, and interpreting. The teacher and students contribute orally, listen actively, and respond to and learn from others’ contributions.

Recently, research studies have begun to show that teaching practices are influenced by Mathematical Knowledge for teaching (Sherman, 2016; Snider, 2016; Mosvold & Hoover, 2017). Mathematical Knowledge for Teaching (MKT) is “the mathematical knowledge needed to perform the recurrent tasks of teaching mathematics to students” (Ball, Thames, & Phelps, 2008, p. 399). MKT consists of six categories: Common Content Knowledge (CCK), Specialised Content Knowledge (SCK), Horizon Content Knowledge (HCK), Knowledge of Content and Teaching (KCT), Knowledge of Content and Students (KCS), and Knowledge of Content and the Curriculum (Ball, et al., 2008). Literature also shows that a lot of research has been carried out on teachers’ MKT (Ball et al., 2008; Hill & Ball, 2009; Huang, 2012). However, research reports about the contribution of preservice secondary school teachers’ MKT on teaching practice are very scanty. For instance, review of research on MKT by Mosvold and Hoover (2017) found only one study on preservice primary teacher that focused on the influence of MKT on teaching practice. In addition, Sherman (2016) studied preservice elementary teachers’ early practice of eliciting and responding to students’ mathematical thinking. To this effect, the study reported in this paper was aimed at investigating how a preservice secondary school teacher enacted the practice of orchestrating classroom discussion.

**STUDY CONTEXT**

Malawi is one of the countries which are experiencing challenges in the education system. Secondary school students’ performance in national examinations continues to be poor with only around 50 percent of students passing end-of-cycle examinations (Ministry of Education, 2008). Analyses of national examinations chief examiners’ reports for years 2008 to 2013 also indicate students’ poor performance in algebra in general and equations in particular. While explanations are available concerning system failure, (Ministry of Education, 2008), teacher knowledge and enactment of teaching practice are also vital in the development of students’ conceptual understanding.

In Malawi, learner centred approaches are advocated by both preservice and inservice teacher training programmes. The approaches mostly used in Mathematics classrooms include whole-class and group discussion, pair work, question and answer and explanation. Literature shows that Malawian teachers, both preservice and inservice, display challenges in the ways they use whole-
class and group discussion when teaching Mathematics (Mamba, 2011). It is for this reason that the current study was conducted.

This study examined the following research questions: 1. How does a Malawian preservice secondary school teacher orchestrate classroom discussion when teaching linear equations?; 2. How does the preservice teacher’s MKT influence his ability to conduct classroom discussion when teaching linear equations? Linear equations were chosen because many students in Malawi find this a difficult topic to grasp. (Malawi National Examinations Board, 2013). The results from this study could inform preservice teacher educators about the content of Mathematics teacher preparation.

THEORETICAL FRAMEWORK

Stein, Engle, Smith, and Hughes (2008) developed a framework that consists of five practices for orchestrating classroom discussion including anticipating, monitoring, selecting, sequencing and connecting. These practices give teachers a roadmap they can follow before and during mathematics lessons to orchestrate discussions responsive to both students and the mathematics.

**Anticipating:** Stein et al. (2008) assert that a teacher should begin with anticipating what and how students will solve the problems in the classroom. Anticipating requires that teachers solve the problem in as many ways as they can. Smith and Stein (2011) explain that “anticipating students’ responses involves developing considered expectations about how students might mathematically interpret a problem, the array of strategies – both correct and incorrect – that they might use to tackle it, and how those strategies and interpretations might relate to the mathematical concepts, representations, procedures, and practices that the teacher would like his or her students to learn” (p. 8).

**Monitoring:** Monitoring students’ responses involves listening, observing and identifying key strategies that students use to solve the problems while students work on the tasks. (Stein et al., 2008). Teachers generally do this by circulating around the classroom while students work either individually or in small groups. Carefully attending to what students do as they work makes it possible for teachers to use their observations to decide what and whom to focus on during the discussion that follows (Lampert 2001; Smith & Stein, 2011). During this time, the teacher should also ask questions that will make students' thinking visible, help students clarify their thinking, ensure members of the group are all engaged in the activity, and press students to consider aspects of the task to which they need to attend (Smith & Stein, 2011).

**Selecting:** Having monitored the available students’ strategies during the lesson, the teacher can then select particular students to share their work with the rest of the class to get specific Mathematics into the open for examination, thus giving the teacher more control over the discussion (Lampert 2001). The selection of particular students and their solutions is guided by the mathematical goal for the lesson and the teacher’s assessment of how each discussion will contribute to that goal.
According to Stain et al. (2008), teachers are supposed to purposefully select those that will advance mathematical ideas. These need to be highlighted to make problem solving strategies transparent for the students.

**Sequencing:** Having selected particular students to present, the teacher can then make decisions regarding how to sequence the students’ presentations. By making purposeful choices about the order in which students’ work is shared, teachers can maximise the chances of achieving their mathematical goals for the discussion (Stein et al., 2008). They need to think about the order they want to present the students’ work samples. The teacher might want to have misconceptions addressed first so that the class can clear up that misunderstanding to be able to work on developing more successful ways of tackling the problem (Smith & Stein, 2011). They also need to decide how students will share their work.

**Connecting:** Connection binds together certain choices and decisions made for more or less discrete parts of mathematical content (Rowland & Ruthven, 2011). Stein et al. (2008) assert that the teacher helps students to draw connections among their solutions, other students’ solutions and the key mathematical ideas of the lesson. The teacher can help students to make judgments about the consequences of different approaches for the range of problems that can be solved, one’s likely accuracy and efficiency in solving them, and the kinds of mathematical patterns that can be most easily discerned. Rather than having mathematical discussions consist of separate presentations of different ways to solve a particular problem, the goal is to have students’ presentations build on one another to develop powerful mathematical ideas. They need to craft questions to make the Mathematics visible to students. They need to compare and contrast 2 or 3 students’ work to find out the mathematical relationships in the solution processes and find the connections between the students’ work and the original problem (Smith & Stein, 2011). Connection also includes the links made between different lessons, between different mathematical ideas and between the different parts of a lesson. It also includes the sequencing of activities for instruction and an awareness of possible difficulties and obstacles that students may have with different mathematical topics and tasks (Rowland & Ruthven, 2011).

**RESEARCH METHOD**

This was a qualitative descriptive case study involving one preservice secondary school mathematics teacher named Yani (pseudonym). Yani was in his final year of study at the time the data was being generated. He had taught in primary schools for seventeen years before joining the secondary school teacher education programme. I thought the participant who served as a primary school teacher for that long was the best participant to choose because he was an “information-rich” case for in-depth study (Yin, 2014). He must have had experience regarding orchestrating classroom discussion. I generated data using video lesson recordings of nine lessons and nine lesson plans. Using video allowed me to record the events thoroughly and to look at the episodes multiple times for further analysis (Girden & Kabacoff, 2011). Before beginning the data generation, I asked for permission from
the principal of the concerned college, the school head teacher and the mathematics teacher of the concerned class.

I analysed the data using thematic analysis (Ritche & Lewis, 2003). Firstly, I transcribed the video recordings in whole. Then, I analysed transcripts of selected episodes. I chose the particular episodes because they contained events that best showcased Yani’s ways of orchestrating classroom discussion. (Goldman, et al., 2007). I developed themes both *a-priori* from the theoretical framework and *a-posteriors* from the data (Powell, Francisco, & Maher, 2003). To achieve credibility of the results, another researcher analysed the data. In all cases we got at least 90% agreement, with no discussion between the researchers. Furthermore, the findings were read and critiqued by other researchers (Yin, 2014).

**FINDINGS**

The presentation of the findings begins with summaries of the extracts from lesson plans and the video lesson transcripts for lessons 1, 2 and 4 and discussion follows.

**Lesson summary**

**Lesson 1:**

Objectives: By the end of the lesson, students should be able to a) define equation; b) distinguish between equation and expression; c) solve linear equations in simple form.

Examples: a) identifying variables, coefficients and constants in the expression \(4p + 4q + 3r + 6\); b) comparing the expression \(4x + 4\) and the equation \(4x + 4 = 20\); c) formulating the equation \(4 + x = 10\) from a word problem; d) solving the formulated equation; and e) solving the equations \(16 + x = 25\), \(x + 9 = 23\), \(19 = 10 + 3x\), \(47 = 10h - 33\) and \(14 - x = 8\).

Exercise: Solve \(3 + 8p = 51\), and \(32 = 6 + 3k\).

**Episode 1**

Yani wrote \(4x + 4\) on the chalkboard and asked students to name it. Some students explained that it is an expression. Then Yani wrote \(4x + 4 = 20\) and asked the students to name it. Some students said that it is an equation. Finally, Yani explained that an expression is a mathematical statement while an equation is a mathematical statement with an equal sign. Yani gave students an exercise presented in Figure 1. He asked the students to name an expression or equation.
Lesson 2:

Objectives: By the end of the lesson, students should be able to a) find the solutions to equations involving algebraic fractions; b) solve equations involving brackets and 3) solve equations using balance method.

Examples: a) Solve equations $19 = 10 + 3x$, $14 - x = 8$ in pairs, $3 = \frac{24}{x}$ and $\frac{9}{x} = 4$ involving fractions in pairs; b) solving equations involving parentheses like $4d + (5 - d) = 17$, $\frac{5 - 6}{3} = \frac{c - 4}{2} + 6$, $5(3c + 4) - 3(4c + 7) = 0$ and $\frac{3(2x + 3)}{5} = 2(3x - 2) + 4$.

Episode 2

During the second lesson, Yani wrote the equation $\frac{24}{x}$ on the chalkboard and asked the students to differentiate between the equation $3 + 8p = 51$ and $3 = \frac{24}{x}$. Maria answered by explaining that the equation $3 = \frac{24}{x}$ is fractional while $3 + 8p = 51$ is non-fractional. Then Yani asked the students how they would solve the equation involving a fraction. He gave an example of $\frac{1}{2} + \frac{3}{4}$ and asked questions.

Yani: Is this equation (meaning $3 = \frac{24}{x}$) similar to this one (meaning $3 + 8p = 51$)?

Students: No

Yani: What is the difference?

Student: Arrangement of numbers, $3 = \frac{24}{x}$ has a fraction while $3 + 8p = 51$ does not have a fraction.

Yani: That’s right, here we don’t have any fraction it is a simple straight line equation now do we know the value of $x$?

Students: Noooo!...,
Yani: How can we come up with the value of $x$? In the first place, let’s look at the $x$, and 3. Remember we are dealing with fractions, what do we do to find the value of something, let’s say we have $\frac{1}{2} + \frac{3}{4}$, how do we solve this one?

Pemphero volunteered to simplify the expression and his solution process is presented in Figure 2.

\[ \frac{1}{2} + \frac{3}{4} = \frac{5}{4} \]

After Pemphero had simplified the expression, Yani asked her to explain how he arrived at the answer.

Yani: How did you arrive at the answer?

Pemphero: I found the common denominator 4, then, I divided 2 into 4 to get 2. I multiplied 2 by 1 and got 2. Then I divided 4 into 4 to get 1. I multiplied 1 by 3 to obtain 3. Then, I added the 2 that I got previously and the 3. So we have $\frac{2+3}{4} = \frac{5}{4}$. Four divided into 5 gives 1 and remainder $\frac{1}{4}$.

Yani: Yes, she had at first to find the common denominator. Now, let’s try to apply the same thinking in this problem over here (meaning $\frac{3}{x} = \frac{24}{x}$). Can someone solve this?

Madalitso volunteered and she solved it as presented in Figure 3.

\[ x = \frac{24}{3} \]

Since Madalitso solved the equation without explaining the procedure, Yani asked her to explain how she solved it.
Yani: Can you now explain to us?

Madalitso: I multiplied \( x \) on both sides, then I cancelled it with the \( x \) below. Then I multiplied \( x \) and 3 on the left so I got \( 3x = 24 \), I divided both sides by 3 to get \( x = 8 \).

Yani: Why did you multiply by \( x \) on both sides?

Madalitso: Because it’s a variable.

Yani: No. It is because we want to find the value of \( x \).

**Episode 3**

In lesson 2, Yani gave the students the equation \( 4d + (5 - d) = 17 \) to solve in groups. After the group work, some students presented their work. In solution process A (Figure 4) the student conjoined \( 2d \) and \( 5 \) on the left side and introduced \( d \) on the right side of the equation. After that, he ignored the \( d \) that he introduced to the right side. Thus he later had \( 9d = 17 \). He divided by 9 on both sides and arrived at \( d = 1 \frac{8}{9} \). After this step, the student seemed to be doing something unrelated to the equation.

![Figure 4: Students’ solution processes to the equation 4d + 5 - d = 17](image)

In Figure 4, the student in solution process B seemed to follow the student in A. So he erased the last part of his colleague’s work and from \( 9d = 17 \), the second student came up with \( d = 1.888889 \) which he rounded to \( d = 1.9 \). Both the first and the second student exhibited the conjoining error. Despite these errors, Yani paid attention to solution process C probably because the student produced a correct answer. He repeated the solution process and emphasised on coefficient.

Yani: This is correct (meaning solution C). Remember here, we have brackets. Outside the brackets we have a coefficient that requires multiplying by what is inside. What coefficient do we have here?

Students: One.

Yani: Yes one. So we remove the brackets and come to the second step. Thereafter, you group like terms and you have \( 3d \) equal to 12 after adding and subtracting. Dividing by 3 on both sides gives \( d = 4 \).
Lesson 4:

Objectives: By the end of the lesson, students should be able to a) formulate equations from verbal representations and b) solve the equations so formed.

Examples: a) Changing subject of formula; b) translating \( x + 10 = 24 \) and \( 2(x + 12) = 42 \) to verbal representations by selected students and then others translating the verbal representations back to the equations; c) translating word problems to equations.

Exercise: a) Solve the equations \( 2x + 17 = 59 \) and \( g + g - 7 = 29 \); b) Formulate an equation from the word problem If Geoffrey has \( g \) marbles and Olivia has 7 less than those of Geoffrey, how many does Olivia have?

Episode 4

In this episode from Lesson 4, Yani had students verbalise algebraic relationships and then other students came up with equations from the verbal representations. He asked students to verbalise the problem where \( S1 \) means student 1, \( S2 \) means students 2 and so forth.

\[
\begin{align*}
S1: & \quad \text{I am } x. \\
S2: & \quad \text{I am 12 added to } x. \\
S3: & \quad \text{I am twice the sum of } x \text{ and 12.} \\
S4: & \quad \text{I am 42, the result.}
\end{align*}
\]

Yani helped the students to formulate an equation using the information. However, when a student (S5) came up with the equation \( 2(x + 12) = 42 \), Yani disagreed and came up with \( x + 12 + 2(x + 12) = 42 \) which was incorrect. The equations so formed are presented in Figure 2.

<table>
<thead>
<tr>
<th>Equation by S5</th>
<th>Equation by Yani</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 2(x + 12) = 42 )</td>
<td>( x + 12 + 2(x + 12) = 42 )</td>
</tr>
</tbody>
</table>

*Figure 5: Yani’s symbolic representation of a verbal problem*

After he formulated the “equation” in Figure 5, Yani asked the students to solve for \( x \). Then he went from one student to another to mark the written work. Two of the students’ solutions are presented in Figure 6.
DISCUSSION

Setting Goals

Specifying the lesson goal is a critical starting point for planning and teaching a lesson (Smith & Stein, 2011). It is an a priori practice and must occur before enacting the five practices. For this reason, data analysis also involved setting goals. The summaries for the lesson plans of three lessons, show that the lesson goals were specific meaning that they specified exactly what the students would be able to do, measurable, that is, they could be observed by the end of the lesson and were attainable for the participants within scheduled time and specified conditions. The lesson goals were also realistic meaning they were relevant to the needs of the students and the goals were time bound such that they were achievable by the end of the training session. A lesson goal should also make clear how well a student must perform to be judged adequate, indicating a degree of accuracy, a quantity or proportion of correct responses. The results, however, indicate that the lesson goals lacked the degree of accuracy; for example, Yani wrote, “by the end of the lesson, students should be able to formulate and solve linear equations in simple form”. While “formulating and solving linear equations in simple form” is a reasonable expectation for the preservice teachers, it provides no detail on how well students were expected to perform to be judged adequate. Without specifying the degree of learning, it is difficult to know what counts as evidence of students’ learning. The lesson goal might be stated as “students should be able to solve at least three linear equations in simple form”.

Selecting Examples

Examples are a particular case of a larger class, from which students can reason and generalise (Watson & Mason’s, 2002). The findings show that the selected examples were appropriate and in order of complexity. However, the examples were mostly arithmetical such that \( \frac{3(2x+3)}{5} = 2(3x-2) + 4 \) was the only algebraic equation in Lesson 2. Filloy and Rojano (in Kieran, 1992, page 402) refer to an “arithmetical” equation as an equation of the form \( ax+b = c \) and an
“algebraic” equation as an equation of the form $ax + b = cx + d$. Although the example sequence suggests more a focus on making distinctions between the operational relationships that the unknown is placed in – additive relationships at first, and then multiplicative relationships, Yani’s choice of examples was haphazard in a way. For example, in Lesson 2, he gave the students $4d + (5 - d) = 17$ and $\frac{5 - 6}{3} = \frac{c - 4}{2} + 6$ to solve one after another. Although these examples are in order of complexity, the skills and prior knowledge to be used to solve these two equations are different. This would confuse the students keeping in mind that they are aged between 12 and 15 whose cognition may not be as flexible as the problems would require. In Lesson 1, Yani selected examples that could help students translate word problems into equations but he had no objective for these examples. These challenges signify Yani’s limitations in knowledge of types of linear equations, lack of clarity of lesson goals and that he was not familiar with challenges students might face when solving the equations.

**Anticipating**

Three themes regarding anticipating were developed from the theoretical framework: anticipating what students will do, planning how to respond to student approaches and identifying responses that address mathematical goals. Findings reveal that Yani solved the problems before taking them to class. However, did not anticipate students’ difficulties which would most likely be the most useful in addressing the mathematics he was teaching. On his lesson plans, Yani produced correct solution processes that he expected his students to produce during class discussion and individual exercises. This could be a result of three problems. Firstly, it could be that Yani did not have knowledge of the students’ errors and misconceptions in the topic. Secondly, it could be that Yani valued correct responses and solution processes more than the incorrect ones. Thirdly, it could be that Yani did not understand the value of anticipating students’ thinking. The results suggest that MKT leads to effective lesson planning. Morris, Hiebert and Spitzer (2009) also provide clear research evidence that demonstrates the importance of teacher knowledge in planning and teaching of classroom Mathematics.

**Monitoring**

The findings show that Yani monitored by listening, observing individual, group and pair work, and asking the students to explain their solution processes. Episode 2 illustrates Yani’s questioning to give students opportunities to explain. The questions Yani asked include probing, leading and questions requiring “yes” or “no” answers. Probing questions seek explanations from students. They check whether correct answers are supported by correct reasoning. Leading questions give hints or guide the students in problem solving. An example of a probing question is found in Episode 2 after Pemphero and Madalitso had presented their solution processes. Yani asked them to explain their solutions. However, in the final sentence of Episode 2, Yani’s explanation of the reason for multiplying
by \( x \) on both sides of the equation \( 3 = \frac{24}{x} \) shows that he lacked the knowledge of the “why” himself.

The low order questions and lack of knowledge of the “why” of equation solving prevented Yani from eliciting students’ ideas and higher order thinking.

Secondly, although Yani monitored students’ progress by listening, observing and questioning, the results reveal his inability to keep track of students’ approaches. For instance, in Episode 4, Yani asked students to solve the incorrect equation \( x + 12 + 2(x + 12) = 42 \). In Figure 6, the question mark indicates that Yani was not sure of the exact difficulty for the student. He did not consider the students’ samples worth discussing. He did not realise that student 6 made a computational mistake when subtracting 36 from 42 while student 7 committed a conjoining error. Student 7 added \( 12 \) and \( 2x \) to come up with \( 14x \). Infact, when solving the equation, student 7 combined \( 12 \) and \( 2x \) in \( 12 + 2x \) to come up with \( 14x \) because of inability to accept the lack of closure. Inability to accept the lack of closure is students’ difficulty in holding unevaluated operations in suspension (Chalouh & Herscovics, 1988). Students perceive expressions as incomplete statements and they are unable to hold unevaluated operations as solutions to algebraic problems. This leads to the conjoining error whereby students use the notation for algebraic product for the algebraic sum (Stacey & MacGregor, 1994). Yani might not have called for discussion of these samples probably because he lacked knowledge of students’ errors and misconceptions, inability to analyse students’ solution processes and that he lacked “why” questions. The limitations in designing and framing questions that provoke students’ talk might have resulted from Yani’s inability to plan questions during the planning stage. This highlights the fact that, in order to listen to, analyse and understand students’ thinking, teachers need CCK, SCK, KCS and KCT.

Selecting

The findings show that Yani selected particular students to present their mathematical work during the whole-class discussion. He selected specific students at the beginning of the discussion to present their work as the discussion proceeded. His typical way to accomplish “selection” was to write the problem on the chalkboard and then selected volunteers to solve the problem one after another. If the first student failed, he called other volunteers until one of the students produced a correct solution process. If the first student solved the problem correctly, he continued with another problem. This is illustrated in Episode 3 in which Yani did not ask the students to explain the three solution processes. Asking the students to explain the solution processes would help reveal their thinking. Alternatively, Yani would let students solve the problem individually or in groups and then select those individuals or groups with particularly useful ideas to share with the class.

Sequencing

The findings show that since Yani selected the students to solve the problems anyhow, there was no students’ work that he could sequence for presentation. The students were trying to solve the problems right on the chalkboard. The findings suggest that the students would benefit more if Yani
gave them the problems to solve either individually or in groups and then having those students or
groups with particular ideas present their work on the chalkboard. By making purposeful choices
about the order in which to share students’ work Yani could have maximised the chances of achieving
his mathematical goals for the discussions. During planning Yani needed to consider possible ways of
sequencing anticipated responses to highlight the mathematical ideas key to the lesson.
Unanticipated responses could then be fitted into the sequence as he made final decisions about
what was going to be presented.

Connecting

The findings also reveal that Yani helped the students draw connections between concepts such as
“expression” and “equation”. In Episode 1, he focused on differentiating between expression and
equation because he said “students confuse between the two”. Thus he helped the students draw
connections between key mathematical ideas in the lesson. Episode 2 illustrates Yani’s ability to help
students connect fractional and non-fractional linear equations in which a student explained that

\[ \frac{24}{x} = 3 \]

is a fractional linear equation while \( 3 - 8p = 51 \) is non-fractional. On the contrary, Yani
encouraged students to apply ideas used to simplify the expression \( \frac{1}{2} + \frac{3}{4} \) when solving the equation

\[ \frac{24}{x} \]

yet their algebraic structures are different and thus operations in the solution process for

\[ \frac{1}{2} + \frac{3}{4} \]

are different from the operations in the solution process for \( \frac{24}{x} \). In this regard, the
connection was not appropriate because he regarded an expression as an equation. This reveals that
Yani had limitations in his example space for illustrating fractional equations. An example space is a
collection of examples to which an individual has access at any moment, and the richness of
interconnections between those examples (Watson & Mason, 2005). It might also be inferred that
Yani lacked structure sense of linear expressions and equations indicating limitations to choose an
example for a particular purpose which is part of KCT. Structure sense (\textit{surface structure, systemic
structure and structure of an equation}) is the knowledge of the arrangement of terms and operations
in an expression or an equation (see Mamba, 2011). Structure sense cannot be ignored and has to be
recognised and used if algebraic problems are to be solved successfully (Herscovics & Linchevski,
1994). Yani’s confusion between equation and expression is contrary to the idea of connection by
Stein et al. (2011) and Rowland and Ruthven (2011) who argue for promoting connections between
mathematical ideas of the lesson. The inability to understand students’ errors and misconceptions
also signify Yani’s limitations in making connections between students’ work and the original problem
(Smith & Stein, 2011). The findings also display a broken link between lesson 4 objectives and the
selected example whereby Yani planned to involve students in changing subject of formula but there
was no objective for this task.
Conclusion

In this study, Yani’s ability to orchestrate classroom Mathematics discussion was investigated. The findings show that the case of Yani illustrates the need for guidance in shaping classroom discussions and maximising preservice teachers’ potential to extend students’ thinking and connect it to important mathematical concepts. For instance, Yani was able to anticipate what students would do mainly by focusing on the correct solution processes but did not plan for expected students’ errors and misconceptions. The findings also reveal that Yani selected particular students to share their work with the rest of the class. However, the selection of particular students was not based on their solutions because he selected the students before they solved the problems in their notebooks. The findings also show that Yani attempted to draw connections between algorithms but did not draw connections between students’ mathematical ideas and other students’ ideas because students’ solution processes were not presented during the discussion. These findings confirm the finding that a key challenge mathematics teachers face in enacting current reforms is to orchestrate whole-class discussions that use students’ responses to instructional tasks in ways that advance the mathematical learning of the whole class (Lampert, 2001).

These findings inform teacher educators about the content of Mathematics teacher preparation. The findings suggest that detailed anticipations though challenging are important to foster argumentation in the Mathematics classroom. In addition the findings suggest that teacher educators should help preservice teachers to analyse students’ solution processes and ask questions during monitoring in order to sample students’ work for presentations. Furthermore, the finding suggest that selecting and sequencing students’ solutions are aimed at making connections between algorithms as well as between different solution processes and students’ ideas. As such, teacher education programmes in Malawi would benefit more from guiding preservice teachers in anticipating, monitoring, selecting and sequencing students’ solution processes for presentation and discussion. The findings also suggest that it is imperative to improve preservice teachers’ MKT in order to improve their ability to orchestrate classroom discussion.

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SCIENCE EDUCATION
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USING CONCEPT MAP CONSTRUCTION AS A PROFESSIONAL DEVELOPMENT ACTIVITY AIMED AT DEVELOPING A TEACHER’S CONTENT KNOWLEDGE FOR TEACHING A BIOLOGY TOPIC: A SELF-STUDY

David Kaseke¹ & Eunice Nyamupangedengu²

ABSTRACT
Many professional development activities for teachers take the form of workshops, conferences or degree programs in which opportunities for improvement are provided as a one-size-fits-all. While these activities can improve teachers’ content knowledge or pedagogical knowledge, they do not cater for individual teachers’ needs. As a response to this ‘one-size fits all’ situation, this study investigated the effectiveness of concept map construction as a professional development activity aimed at developing an individual teacher’s content knowledge of a biology topic using the methodology of self-study. The methodology of self-study was chosen as it offers opportunities for an individual to study own practice for purposes of improving specific aspects of one’s practice in this context-content knowledge of meiosis. The data that were collected consisted of concept maps and journal entries. Three concept maps were constructed and analysed with input from a critical friend and content expert. Journal entries consisted of my reflections on the feedback I got from and the discussions I had with the critical friend. Findings from this study showed that the use of concept map construction by an individual teacher in the context of a self-study can reveal the teacher’s content knowledge gaps and misconceptions about the topic under study. The study therefore concluded that constructing concept maps as a professional development activity to represent one’s content knowledge has the potential to expose the builder’s level of understanding of a biology topic and to provide opportunities for correction and improvement of one’s content knowledge. Through the use of the methodology of self-study and working with a content expert as a critical friend, individual teachers can successfully engage in professional development for purposes of improving their content knowledge of biology one topic at a time.

INTRODUCTION AND BACKGROUND

This paper is based on the research that I did for my Master’s degree. My supervisor Eunice who is the second author in this paper played the roles of a content expert and a critical friend by providing feedback on the concept maps that I was constructing and asking me questions to challenge me to seek more knowledge of meiosis the topic that I was studying. In the paper I however use the first person singular as it is my experiences which are the focus of the study. I am a high school teacher responsible for teaching biology at Matric level. The research that is reported in this paper was motivated by the insights that I got from the study that I did as the research project for my Honours degree. In my Honours project, I investigated learners’ understanding of meiosis after I had taught them the topic. In the research project, I had asked my learners to respond to the question: Describe your understanding of the process of meiosis. During the analysis of learners’ responses with input
from Eunice, I observed that learners’ descriptions of the process of meiosis contained similar incorrect aspects which pointed to the fact that I could actually have passed on that incorrect content to learners. An example of the incorrect content was a description of what meiosis is that was present in 12 of the 40 learners’ responses in the class which read: *meiosis is a type of cell division and it begins with interphase*. This observation motivated me to do this study in which I used the self-study methodology and concept map construction to improve my content knowledge of meiosis. The aim of the study was to investigate the effectiveness of a self-study methodology and use of concepts maps as a professional development activity that can be used for developing a teacher’s content knowledge of a biology topic in this case the topic of meiosis. The questions that guided the study were:

1. How does the construction of concept maps improve my content knowledge of meiosis?
2. To what extent is self-study effective as a methodology for a teacher’s self-improvement?

**LITERATURE REVIEW AND THEORETICAL FRAMEWORK**

**Professional development (PD)**

According to Bruce & Calhoun (2010), Professional Development describes opportunities for learning that are made available to educators to help them to develop or to improve their professional knowledge, competences, skills and effectiveness. PD is therefore about learning. In education, PD takes a variety of form; workshops, conferences or degree programs. PD can also take a form of individual inquiry or action research (Bruce & Calhoun, 2010; McNiff, 2010). A variety of topics can be covered under PD such as PD for purposes of improving a teacher’s content knowledge in a subject area (content knowledge) or PD for improving the teaching of specific content (pedagogical knowledge). In this study, I undertook self-study for purposes of improving my content knowledge of meiosis which in South Africa is a topic that is taught at Matric level.

**Self-study**

Self-study is a study of the self by the self. It is about researching practice by teachers/teacher/educators interested in better understanding and developing their knowledge of practice (Berry, 2008). Self-study has been defined by Samaras (2011) as a component of reflection in which teachers systematically and critically examine their actions and the context of those actions as a way of developing a more consciously-driven mode of professional activity. Self-study seeks to improve one’s teaching as well as improve students’ learning. According to Samaras & Freese (2006) self-study is a powerful vehicle that can also help to renew one’s passion for teaching. It has a direct and immediate impact on one’s classroom. For example, upon learning the main concepts and the subordinate concepts making up a particular topic which is called curricular saliency (Mavhunga & Rollnick, 2013), the teacher can then immediately implement the new knowledge in the classroom by organising the teaching starting with main concepts and bringing in subordinate concepts as the teaching continues.
The aims of self-study include the development of practical knowledge for personal, professional, and classroom improvements; to investigate one’s own questions situated in one’s particular context; to improve teaching and to conduct research with colleagues (Samaras & Freese, 2006). I therefore chose to do a self-study so that I could develop my content knowledge for teaching meiosis and then use that understanding to improve my teaching.

**Concept maps**

Concept maps are graphical tools in which concepts are linked by lines and words indicating the relationships between concepts. According to Novak (1991), concept maps are a powerful tool for organizing and representing knowledge. Concept maps are also effective in identifying both valid and invalid ideas held by students (Novak & Canas, 2008). In addition concept maps serve as a kind of scaffold that helps to organize knowledge and to structure it, even though the structure must be built up piece by piece with small units of interacting concepts (Novak & Canas, 2008). Because creating concept maps requires the builder to identify concepts and to indicate the relationships between those concepts, it can be challenging to people who are used to learning by rote (Novak & Canas, 2008). While the context for using concept mapping as described by Novak was in the classroom with students, in this study, the context for using concept mapping was in organisation and presenting one’s content knowledge as a teacher. According to Mavhunga and Rollnick (2013), knowledge of concepts that make up a topic and the relationship between them (curricular saliency) is fundamental to a teacher if correct content is to be chosen and to be taught to learners. The content knowledge of a topic must be transformed into a teachable form if it is to be understood by learners and that transformation begins with the identification of concepts.

**Theoretical Framework**

The focus of the study was to investigate the effectiveness of concept mapping as a professional development activity aimed at improving a teacher’s content knowledge. Therefore the theory that guided this study comes from the literature on content knowledge. In 1986, Shulman identified three categories of content knowledge which he referred to as subject matter content knowledge, curricular knowledge and pedagogical content knowledge commonly known by the acronym PCK. In his 1987 paper (Shulman, 1987) he then separated these three categories of content knowledge and listed them as distinct categories in the knowledge base for teaching with subject matter content knowledge simply listed as content knowledge. It is the development of this content knowledge which was the focus of this self-study. The key question in the development of the theoretical framework for this study was: What constitutes content knowledge?

According to Collette (1989), content knowledge is made up of substantive and syntactic knowledge. Substantive knowledge refers to the body of knowledge that is made up of facts and concepts that make up the subject. Scientific facts are descriptions of data that come from observations of the
natural world and are therefore viewed as truth, reality or actuality (Collette, 1989). Because they are said to be directly observable and can be demonstrated at any time, scientific facts should be characterised by name/s of the scientist/s, dates, events, terminology (etymology), conventions, propositions of rules, laws, theories (Van Aswegen et al., 1993). In science, factual knowledge is presented in science textbooks (Hestenes, 1987) and other sources like scientific journals.

Collette (1989) asserts that facts provide the raw materials for the development of concepts and generalisations whereby the concepts are be understood as an abstraction of a class of events, objects or other phenomena that have particular characteristics in common. Those common characteristics would have emerged as a result of the accumulation of facts about those events, object or phenomena. Concepts therefore represent manageable clusters of condensed masses of raw data (carefully thought out and selected facts) which help to organise science into a comprehensive description of natural phenomena (Aswegen et al., 1993). Content knowledge however, extends beyond the facts and concepts to syntactic knowledge which is knowledge of the rules by which “truth or falsehood, validity or invalidity” are established (Shulman, 1986, p. 9). In science, this kind of knowledge is described as procedural knowledge or the scientific method i.e. knowledge of the strategies, tactics and techniques for developing, validating and utilizing factual knowledge (Hestenes, 1987). This description of content knowledge is represented diagrammatically in figure 1 below and was used as a lens that guided the analysis of concept maps in this study and the evaluation of the quality of my content knowledge.

![Figure 1: Components of what constitutes content knowledge](image)

As asserted by Ball, Thames, and Phelps (2008), content knowledge is central to the work of a teacher and is one kind of knowledge that student teachers must have before their certification. However, as indicated in the introduction above, the analysis of data that I collected for my Honours project showed that even after teaching meiosis for over 15 years, my content knowledge of the topic could be questionable. In this study therefore, I was determined to change that through some form of professional development. My lack of adequate content knowledge was not an isolated case in the South African context. Research has shown that many South African science teachers lack content knowledge as a result of the inadequate training of teachers that happened during the apartheid era and this lack of content knowledge is reflected in the poor performance of learners in the national examinations (Kriek & Grayson, 2009; Mavhunga & Rollnick, 2013).
**Why the topic of meiosis**

I chose the topic of meiosis because in South Africa, it features in both Paper 1 and Paper 2 of Life Sciences National Senior Certificate carrying 44 marks of the total examination which makes it imperative for teachers of Life Sciences to have a good grasp of it if Life Sciences Matric results are to improve. In addition, meiosis has been described as a difficult topic to understand and to explain to learners especially the first part of meiotic division (Oztap, Ozay & Oztap, 2003). The terminology used in the topic such as chromosomes, haploid and homologous chromosomes has also been seen to present a serious challenge to South African learners’ understanding of the topic because the terminology is not related to language learners use daily (National Senior Certificate diagnostic reports (2013-2017). According to Knipples, Waarlo and Boersma (2005), learners often have a poor understanding of the purpose, process and products of meiosis. The poor understanding is further magnified by the fact that the underlying behaviour of chromosomes during meiosis occurs at micro level and therefore difficult to comprehend. Incorporating microscopy so that learners can actually view and see the chromosomes at different stages can go a long way in promoting their understanding of the topic. This can however be done if the teachers have a robust understanding of the content i.e. an understanding of both the facts and the syntactic knowledge associated with the topic of meiosis.

**RESEARCH DESIGN AND METHODOLOGY**

**Methodology**

This study was a self-study which was guided by the methodological features of a self-study namely that the work was *self-initiated and focused*, the work was *improvement aimed*, *interactive*, used *multiple, primarily qualitative methods* and *validity was exemplar based* (LaBoskey, 2004). I will explain these characteristics below.

*Self-initiated and focused* means that the teacher was the researcher and the researched (Samaras, 2011). The work was *improvement aimed* means that the work of the teacher was aimed at improvement not only of himself but also of his students (LaBoskey, 2004). Since in self-study, the researcher and the researched are one and the same, the study was *interactive* at one or more stages of the process. The interactive nature of self-study describes the monitoring process whereby critical friends, colleagues and students get involved in the self-study project (Samaras & Freese, 2006). Critical friends with their alternative views improve the process and colleagues ask for clarifications and can offer alternatives (Samaras & Freese, 2006). The interactive nature of self-study also entails interaction with the literature and helps to guard against the possible limitations of individual interpretation (LaBoskey, 2004). In the study, I used *multiple qualitative methods* for gathering data. The use of multiple methods provided opportunities for me as the researcher and for others to gain different angles or viewpoints on the educational processes that I was investigating thereby providing a more comprehensive view of the process. *Validity was exemplar based.* Exemplars of practice are
concrete documents and artefacts from practice that are presented as exhibits to allow members of a relevant research community to judge for themselves the trustworthiness and validity of the observations and interpretations. In this study, exemplars were in the form of constructed concept maps and verbatim feedback and questions from the content expert.

**Participants**

This study had one participant, a collaborator and a critical friend. Being a self-study I the researcher was the participant who was using concept mapping to assess and to develop my content knowledge of meiosis. The collaborator was a Life Sciences colleague Simon (not his real name). Collaboration is when you enlist a colleague or colleagues to engage in conversations with you about your practice. Simply put, collaboration means teamwork (Thesaurus: English-UK). I therefore, chose Simon because he was also teaching the same topic at his school which provided an opportunity for us to work together as a team. Simon helped with the identification of concepts and linking words as I was constructing the concept maps. The critical friend was my supervisor Eunice who is the second author in this paper. In self-study, critical friends are crucial as they provide opportunities for support and new insights into one’s work as well as offering different perspectives. As such, a critical friend is expected to ask probing questions which offer the researcher opportunities for clarification and alternative explanations. A critical friend’s participation in a self-study therefore contributes to the validation of the findings because the insights from the analysis of data extend beyond one’s personal views, thus addressing potential biases (Samaras & Freese, 2006). In this study, Eunice also played the role of a content expert. As a content expert, she provided me with feedback on the content of the concept maps that I was constructing.

**Data collection**

**Sources of data**

As required in self-study, one has to collect multiple forms of data. The sources of data in this study were: concept maps, notes from my discussions with the collaborator, and feedback from the content expert and journal entries of my reflections. The content expert provided both written and oral feedback. The oral feedback was audio-recorded and later transcribed. After the feedback session, I would listen to the recorded audio and reflect on it. I would journal my own reflections and feelings from the comments and discussions. The journal entries also included reflections on the process of construction of the concept maps. Below I described each of the data sources and provide examples.

**Concept maps**

Concept maps were chosen as a source of data because they are made up of propositions which can be used as the unit of analysis. A proposition is made up of two concepts and a word or phrase in-between them. Examples of words in-between concepts include words such as; *causes, requires or contributes to*. These words in-between two concepts on the line are referred to as linking words or
linking phrases and they specify the relationship between the two concepts (Novak et al. 2012). An example of a proposition is:

*Meiosis produces haploid nuclei*

In this example, *meiosis* and *haploid nuclei* are the two concepts that are linked by the word *produces*. A meaningful proposition is the basic unit of knowledge according to the theory of meaningful learning and Ausubel’s assimilation theory (Novak & Gown, 1984). In this study, I also scored the concept maps, a process that provided quantitative data. Burton, Brundrett, and Jones (2008), argued for a combination of quantitative and qualitative approaches in research as a way of strengthening the arguments that the researcher makes from the research. Numerical data gives immediate point of impact to the reader whilst the quantitative evidence give meaning to the numbers thereby enriching the interpretation of and analysis (Burton et al. 2008). The numbers of correct propositions were used as a measure of the content knowledge I was developing. The number of correct propositions was used to determine both the quality and quantity of content knowledge and to trace my knowledge development.

**Feedback from content expert**

Feedback from the content expert focused on the quality of the concept map. Quality of the concept map was determined by the correctness of the identified concepts and the constructed propositions and coverage of the meiosis content. Below is an excerpt from the first feedback session after the construction and submission of my first concept map.

**Author 2:** *I am not in agreement with some of the concepts in your concept map. Define what a concept is for me?*

**Author 1:** *A concept, uuum, I don’t think I can define it. Actually I don’t know what it is, I have never thought about it.*

**Author 2:** *Strange isn’t it how we unknowingly take things for granted. The reason for asking you this question is that you have used in your concept map words that are not concepts. So I suggest that when you go back, you must first find out what a concept is and revisit your map and correct it yourself.*

The excerpt above shows an example of the kind of discussion that would take place after each concept map submission. The other things that we discussed included my understanding of what makes up content knowledge of a science topic and how one would determine if a word in biology textbook is a concept or just a word.

**Journal entries**

Journal entries refer to what I would record in my book which is referred to as a journal in self-study literature. The journal entries would include descriptions of my thoughts, my feelings, dilemmas, insights and knowledge gained during my interactions with Simon, Eunice and literature. I provide an example of a journal entry below. This entry was made after my first feedback session.

*Concept mapping is a challenging activity. I really need to go back to the basics and read widely on meiosis. Who would have known that content knowledge means so much?*
The data collection process

I constructed a total of three concept maps in three cycles of four steps each. I describe the four steps below:

- **Step 1**: Construction of the concept map
- **Step 2**: Discussion of the concept map with the collaborator and incorporation of the collaborator’s contributions into the concept map
- **Step 3**: E-mailing of the concept map to the content expert
- **Step 4**: Feedback from and discussion with the content expert which then signalled the end of a cycle

As indicated below, step four was the end of the cycle. The feedback from cycle 1 informed the construction of the second concept map. Feedback and reflections from cycle 2 informed cycle 3. The number of concept maps was not predetermined. The number of concept maps to be constructed depended on feedback from the content expert. If she had confirmed that I had identified a satisfactory number of concepts in the first concept map it could have ended there. If the content expert was still not satisfied after concept map three, I would have constructed more concept maps until that time when I would have identified a satisfactory number of concepts that cover meiosis content knowledge.

DATA ANALYSIS

In self-study, data collection and data analysis are not linear processes whereby you collect data first then do data analysis after, rather preliminary data analysis occurs concurrently with data collection. Samaras (2011, p. 197) described this characteristic of self-study as a hermeneutic process: a dance of data collection and data analysis. In this study therefore, data collection and preliminary data analysis happened concurrently. The main form of data was the concept maps. The second form of data was in the form of the feedback comments that I got from the content expert. Therefore, by giving me feedback on my concept maps, the content expert contributed to both data collection and analysis. This is because commenting on the concept maps required the content expert to do a thorough and comprehensive look at the concept maps. Reflecting on the feedback was also an analysis process as it was during the reflective processes on the feedback from Eunice that I was able to assess the quality of my content knowledge.

Scoring of concept maps

Scoring involved coding the maps followed by counting of concepts and propositions in each of the created categories. The codes that were used for coding the maps were deductively formulated before the scoring process. The codes are shown and described in Table 1 below.
Table 1: Descriptions of codes/categories and symbols

<table>
<thead>
<tr>
<th>Description of code/category</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct concept</td>
<td>✔</td>
</tr>
<tr>
<td>Incorrect (non) concepts</td>
<td>X</td>
</tr>
<tr>
<td>Correct proposition</td>
<td>✔</td>
</tr>
<tr>
<td>Incorrect proposition</td>
<td>X</td>
</tr>
<tr>
<td>Partially correct</td>
<td>I</td>
</tr>
</tbody>
</table>

I used concept map 1 to illustrate the coding and scoring process. Figure 1 below shows concept map 1 after coding it. On the map all words/phrases which were used as concepts in constructing the concept map are circled and are numbered 1 to 13. Each circled word/phrase was treated independently of the other. For examples in concept map 1, concept 10 and 11 were treated as different concepts. The coding shows that the map has 13 concepts. From the thirteen concepts identified only eight concepts were considered correct in terms of meiosis content knowledge and are marked with the correct concept code as shown in Table 1 above. Examples of correct concepts are concept 5 - crossing over, 6-genetic variation, 12-haploid sperm and 13-haploid egg. Five concepts were coded as incorrect. The concepts which were coded as incorrect were words or phrases which are not concepts but were used in the concept map as concept. Examples of such a word and a phrase from concept map 1 are randomly (concept 7) and correct number of chromosomes in the offspring (concept 11) respectively.

Figure 1 also shows a list of 16 propositions that have been extracted from the concept map. Of these 16 propositions, seven are correct and are indicated by a tick. Examples of the correct propositions are:
1-Meiosis – is a – nuclear division
2-Crossing over – provides - genetic variation.

These propositions were coded as correct because the two concepts meiosis and nuclear division for proposition 1 and crossing over and genetic variation for proposition 2 are correct meiosis concepts and the linking words is a and provides build up propositions that correctly describe meiosis content.
Figure 1: Concept map 1

**Propositions in concept map 1**

1. Meiosis – *is a* – nuclear division ✔
2. Crossing over - *provides* – genetic variation ✔
3. Meiosis – *produces* – 4 cells (X)
4. 4 cells – *which can be* – haploid sperm (I)
5. Nuclear division – *which is part of* – cell division ✔
6. 4 cells – *with* - half the number of chromosomes (X)
7. 4 cells – *with* - one member of each homologous pair (X)
8. 4 cells – *with* – half the number of chromosomes (X)
9. Crossing over – *involves* - exchange of segments on homologous chromosomes (X)
10. 4 cells – *which can be* – haploid ova ✔
11. Meiosis – *permits* – crossing over ✔
12. Meiosis 1 & 11 – *results in* - haploid sperm ✔
13. Meiosis 1 & 11 – *results in* – haploid egg/ovum (I)
14. Cell division – occurs as – meiosis 1 & 11 (X)
15. Meiosis 1 & 11 – *brings about* – genetic variation ✔
16. Genetic variation – *provides* – randomly (X)
Seven of the propositions were incorrect. The incorrect propositions could be as a result of:

1. Use of words which are not concepts i.e. non-concepts in a proposition e.g. proposition number 16 which reads *genetic variation – provides - randomly*. Randomly is not a concept but was incorrectly treated as a concept. The other propositions in this category are propositions 6, 7, 8 and 9.

2. Use of a linking word or phrase which results in an incorrect description of meiosis content e.g. proposition number 3 which says *meiosis produces 4 cells*. The content reflected in this proposition is incorrect because meiosis is a process of nuclear division which results in the production of four nuclei at the end of Telophase 1 and Telophase II. Only after the process of cytokinesis which follows the nuclear division are the four cells produced.

Figure 1 has two partially correct propositions which are propositions 4 and 13. These two propositions were coded as partially correct because the concepts haploid sperm and haploid egg in this proposition while they are correct, the proposition itself implies that meiosis occurs in animals only as it is only in animals that the 4 cells produced are called sperms. Different terms are used in other organisms e.g. pollen grains in plants.

There were some challenges with the coding of some propositions. For example propositions 8 and 9 are a continuation of an incorrect proposition number 8. To overcome this challenge, each proposition was considered a unit of analysis and was treated independently of the other propositions linked to.

**PRESENTATION OF RESULTS**

As indicated above, data collection and analysis happened at the same time in this study. This means that after constructing concept map 1, it was discussed and analysed and the insights from the discussions informed the construction of concept map 2 and so on. Below I use tables to present quantitative results. Table 1 below shows the results of scoring each of the three concept maps that were constructed.

<table>
<thead>
<tr>
<th>Concept map</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of concepts on the map</td>
<td>13</td>
<td>18</td>
<td>42</td>
</tr>
<tr>
<td>Total number of correct concepts</td>
<td>7</td>
<td>17</td>
<td>38</td>
</tr>
<tr>
<td>Total number of incorrect (non) concepts</td>
<td>6</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 1 show that concept map 1 was made up of very few concepts (13 in total). Of these, only 7 were correct and 6 were incorrect. Table 1 also shows that the total number of concepts making up each map as well as the total number of correct concepts increased from map 1 to 3. This can be attributed to the knowledge that I was gaining at the end of each cycle from the discussions with the
content expert and from extensive reading of research literature and tertiary biology text books. Next I present results of scoring the propositions. Table 2 below shows the results of proposition scoring of the three concept maps.

Table 2: Results of scoring propositions in the three concept maps

<table>
<thead>
<tr>
<th>Map number</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propositions making up each concept map</td>
<td>16</td>
<td>17</td>
<td>42</td>
</tr>
<tr>
<td>Correct propositions</td>
<td>7</td>
<td>14</td>
<td>38</td>
</tr>
<tr>
<td>Incorrect propositions</td>
<td>7</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Partially correct propositions</td>
<td>2</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 2 shows a pattern similar to that in table 1 as the number of propositions and of correct propositions increased from concept map 1 to 3.

**FINDINGS AND DISCUSSION**

In this study I investigated the use of concept mapping as a possible professional development activity for developing a teacher’s biology content knowledge (my content knowledge in this case) with a specific focus on meiosis. The first thing that I learnt is that I lacked the knowledge of what I knew and what I didn’t know about biology as a subject. For example, my first concept map had very few concepts (13) and I had used words which were not concepts such as the word *randomly* in my construction of the map and had presented this concept map to Eunice with confidence thinking that I had constructed a comprehensive map. It was only after discussing the map with Eunice and reflecting on the feedback that I became aware of my lack of knowledge. Firstly, I did not know what a concept is and secondly I did not know what makes up content knowledge of a science subject such as biology. By embarking on this self-study, I gained the knowledge of what makes up content knowledge of biology (see the theoretical framework section) and what a concept is which in turn helped me to identify concepts making up the topic of meiosis. Knowledge of what content is and what a concept is was gained from extensive reading of literature which revealed to me the importance of research literature as a source of information that can improve one’s teaching. The knowledge of what a concept is provided me with the knowledge that I needed to correctly identify the meiosis concepts. For example, when I was constructing concept map 2, I first put down meiosis 1 as a concept. I then progressively broke down the concept of meiosis 1 into facts that were used to describe it? For example, I listed the following words one by one: Prophase 1- homologous chromosomes come together through the process of synapsis-crossing over of non-sister chromatids occurs and so on. For each fact, I would then ask myself, what does this fact represent or describe? Is it an event/s or an object/s? Answers to these questions helped me to identify the subordinate concept being described by the listed facts. As a result of this process, I was able to eventually identify and list 10 concepts under meiosis 1 which I added to concept map 3.
Before embarking on this study, I regarded facts and concepts that are described in biology textbooks as what constituted content knowledge. I had not considered other aspects like history of science as part of content knowledge e.g. history of how chromosomes came to be known and how they were identified. I also did not know that the activities and processes that are done by scientists to validate scientific knowledge form part of content knowledge. Now I know that content knowledge is not just about facts and concepts but also procedures or the scientific method. I now use scientific procedures like microscope work and the historical facts linked to meiosis topic to support my teaching and mediation of learning of meiosis content.

The construction of concept maps helped me to identify subtle gaps of understanding and/or misconceptions in my content knowledge, e.g. until the content expert pointed it out and explained, I could not see what was wrong with the proposition *meiosis produces four cells called sperms*. This proposition portrays that meiosis only occurs in human beings. It was at this point that I realised that until this study, my focus when teaching meiosis was on human beings only yet meiosis occurs in many other living organisms. The concept maps that I was constructing also exposed my lack of knowledge of the concepts making up the topic of meiosis thereby confirming the assertion by Canas, Novak and Vanheer (2012) that concept mapping reveals the builders’ cognitive structures and thus portray their understanding or lack thereof, of the domain depicted in the map.

As can be seen in the findings presented in the paragraph above, a combination of the use of concept maps and self-study made my understanding of the topic meiosis or lack of it public thereby making correction possible. This way, my needs as an individual teacher were catered for something that is not easily achievable when PD is done in the form of workshops, conferences and road shows as the misunderstandings and knowledge gaps that one teacher has would not be the same as those of other teachers. This same tenet of self-study; making your thinking public whilst it made correction of incorrect content possible, it also made me to feel very vulnerable as I was making my ignorance public. There were times in this study, when I would feel embarrassed when incorrect knowledge manifested in my maps. Fortunately, my supervisor helped me to feel secure as I was going through these embarrassing moments by assuring me that it was not about me but rather about my content knowledge. A self-study therefore calls for the development of trust between critical friends and the self-study researcher if it is to provide a platform for meaningful and fruitful discussion of content gaps, misunderstandings and misconceptions that are revealed on the concept maps.

**CONCLUSION**

In conclusion, I answer the two research questions. This study showed that the use of concept maps with the help of the content expert can reveal the content gaps that a teacher may have and the misunderstandings about a topic that s/he may be harbouring in his/her cognitive structures. Embarking on concept map construction within the self-study methodology can provide a teacher with opportunities to improve one’s content knowledge. Therefore, the self-study methodology and concept mapping can be an effective way of improving one’s content knowledge of a biology topic.
provided that there is a content expert to work with and a trusted person who can play the role of a critical friend.

REFERENCES


ID9971

PRE-SERVICE TEACHERS’ CONCEPTUALISATION OF THE INTEGRATION AND PROGRESSION OF LIFE SCIENCES CONCEPTS FROM GRADE 10 TO 12

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ABSTRACT
When scientific concepts are learned as discrete science concepts learners fail to know how the concepts are related to each other. Learner conceptual understanding is enhanced when teachers develop a sense of continuity and coherency in learners as they teach one topic to another. After realising that pre-service teachers compartmentalise concepts and fail to show relationships between concepts as evidenced from their failure to teach the concepts accordingly, the researcher tasked 115 pre-service Life Sciences teachers to conceptualise and articulate the integration and progression of Life Sciences concepts from Grade 10-12 in groups of six. The study investigated how pre-service teachers articulated the way they conceptualised this integration and progression. Thematic analysis of the responses, from the 10 groups who selected the topic Cells, showed that pre-service teachers could articulate the integration and progression of concepts from Grade 10 - 12 to a certain extent. It was evident that they needed to acquire a deeper understanding of Life Sciences concepts in order to explicitly interconnect them. The study informs teacher professional development programmes of strategies that engage teachers in activities that stimulate them to identify areas for development.

Key words: Integration, progression, pre-service teachers, Life Sciences.

INTRODUCTION
This paper introduces the strategy of developing pre-service teachers to view and teach Life Sciences concepts in a holistic manner rather than as codified, discrete sections or categories. It is believed that learning results from the integration between what the learners are taught and their current ideas or concepts (Ausubel, 1968). Development of continuity and coherency in understanding scientific concepts is key throughout high school years (American Association for the Advancement of Science [AAAS], 1999, 2007).

Integration acknowledges and builds on the relationships which exist among all concepts within and across grades. The most important single factor that influences learning is what the learner already knows (Ausubel, 1968), which the teacher should take into consideration when planning and teaching. As such, Ausubel suggested that when meaningful learning occurs, it produces a series of changes within the learners’ cognitive structures, thereby modifying existing concepts and forming new linkages between concepts. There is an emphasis on the influence of learners’ prior knowledge on subsequent meaningful learning.
LITERATURE

The longitudinal development of big ideas has been promoted through learning progressions, which are described as successive and sophisticated ways in which one thinks about the topics that follow one another during the learning process (National Research Council, 2007). In the current study, the researcher is not assessing learning progressions of learners but is rather assessing pre-service teachers’ abilities to identify, conceptualise and articulate the progression of concepts within and across three grades in a particular Life Sciences topic. An assessment approach intended for measuring a construct called knowledge integration (Lee & Liu, 2010) will be used. Knowledge integration construct is defined as knowledge and ability to create and relate science concepts when explaining a scientific phenomenon or justifying claims for a scientific problem (Liu, Lee, Hofstetter, & Linn, 2008). In this case pre-service teachers’ development or progress in understanding is seen as they elicit and elaborate more connections among scientific concepts.

The study used the spiral curriculum as the conceptual framework which was first described by Bruner (1960). A spiral curriculum is where concepts, themes, topics or subjects are revisited iteratively throughout the learning programme (Harden & Stamper, 1999). Therefore the content is not repeated at different stages but rather deepened with each successive level by building on the previous one. As such, operational rigour, level of abstraction and comprehensiveness of the concepts increase (Harden & Stamper, 1999). They found that spiral curriculum is relevant in integrated and problem-based courses or subjects. This is important in Life Sciences because the subject integrates concepts from environmental science, medical field when dealing with diseases and utilises context issues from the different communities. Hence the value of a spiral curriculum comes from the reinforcement of concepts, coverage from simple to complex and integration (Harden & Stamper, 1999). As such, progression is ensured.

To ensure meaningful integration of progression of content coverage teachers should use tools such as concept mapping. Concept maps are defined as diagrammatic representations showing meaningful relationships between concepts in the form of propositions (Stoica, Moraru & Miron, 2011). Vanides, Tomita and Ruiz-Primo (2005) noted that concept maps allow learners to understand the relationships between concepts of science as learners get involved in creating the visual maps of the connections between science concepts. Teachers can use concept mapping as important teaching and learning tools and evaluation techniques that provide evidence about what learners know and understand as a result of instruction received in the classrooms (Hilbert & Renkl, 2008). Often learners engage with the learning of science concepts but fail to know how the concepts are related to each other. As such, Akcay (2017) acknowledged the important role concept mapping plays in aiding learning by explicitly integrating new and old knowledge. Through the use of concept mapping learners visualise the relationships between science concepts in a systematic way. Concept maps can be used as an evaluation tool to determine changes and growth in the learners’ conceptual understanding. Teachers can also use concepts maps as tools in planning curriculum and instruction in order to represent the structure of science content.
In the current paper information on only one topic (Cells: The basic units of life) is reported. The task was meant to gauge pre-service teachers’ mastery of the concepts they teach and to examine their understanding of learners’ conceptions of the cell. The cell concept is considered unifying because it provides connections between and among all Life Sciences topics. Specific Aim 1 of the Curriculum and Assessment Policy Statement (CAPS) stipulates involvement of learners in knowledge construction, understanding, and meaning making hence enabling learners to make many connections between the ideas and concepts (Department of Basic Education, 2011).

PURPOSE OF STUDY

CAPS stipulates that in the process of acquiring knowledge learners should be assessed to determine whether they “understand and make connections between ideas and concepts to make meaning of Life Sciences” p.14. Mindful of this, the current study aims to determine pre-service teachers’ conceptualisation of the Life Sciences curriculum in terms of integration and progression of topics. It is only when teachers can articulate the connections between concepts that they can teach and assess appropriately to achieve the curriculum requirements.

To achieve this aim the following research questions were set:

1. How do pre-service teachers conceptualise and articulate the integration and progression of the concept of the cell from Grade 10-12?
2. What pedagogical and content knowledge aspects can be drawn from such an analysis for the development of pre-service Life Sciences teachers?

METHODOLOGY

In preparing pre-service teachers in their final year of study, the researcher realised that these pre-service teachers compartmentalise concepts and fail to show relationships between concepts as evidenced from their failure to teach the concepts accordingly. The researcher’s concern was also pointed out by Sadler (2013) that many college-level educators and scientists worry that weaknesses exhibited by high school learners in science knowledge are as a result of a lack of that knowledge by their science teachers.

Using qualitative case study research design, all 115 Bachelor of Education 4th year students enrolled for the module methodology and practicum FET Life Sciences were selected to take part in the study. In the previous three years, they studied the theories of teaching and learning and content on all the topics in the CAPS Life Sciences document.

In groups of six the pre-service teachers were tasked to select a single topic in grade 10, show how the concepts within the topic were integrated within other topics/concepts in grade 10 (horizontal integration) and within other topics/concepts in grade 11 and 12 (vertical integration). The task was twofold, firstly the researcher intended to determine the level of conceptual understanding of the
topic they selected and secondly to enable them to build a holistic approach in teaching Life Sciences. Each group had to produce a report of their conceptualisation after two weeks. Figure 1 below shows the conceptualisation of the expected integration and progression.

Figure 1: Diagrammatic representation of the conceptualisation of the expected integration and progression

This was a compulsory activity as it prepared and familiarised the pre-service teachers with the Life Sciences curriculum document and the relationship between concepts. Out of a total of 115 pre-service teachers (19 groups), 10 groups selected the topic Cells. This became the sample because their topic is considered important as the foundation of all other Life Sciences concepts. Table 1 shows the summary of the group members who were all Black Africans of mixed abilities.

Table 1: Summary of participants

<table>
<thead>
<tr>
<th>Group</th>
<th>Gender</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males</td>
<td></td>
<td>Females</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>2</td>
<td></td>
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<tr>
<td>2</td>
<td>3</td>
<td>3</td>
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<td>8</td>
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<tr>
<td>9</td>
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</tr>
<tr>
<td>10</td>
<td>5</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>32</td>
<td>28</td>
<td></td>
</tr>
</tbody>
</table>

After submission of the reports, in a process to enhance learning through self-assessment (Boud & Falchikov, 2006), the pre-service teachers compared their group’s report with the other groups’ reports, which the researcher reproduced for the whole class. The participants were guided by the following questions ‘how did I do it?’, ‘was this enough?’, ‘was this right?’, ‘how can we tell?’, ‘Should we have gone further?’ (Boud, 1995). Boud and Falchikov defines self-assessment as “a process of
formative assessment during which students reflect on and evaluate the quality of their work and their learning, judge the degree to which they reflect explicitly stated goals or criteria, identify strengths and weaknesses in their work, and revise accordingly” (p. 160). In this act of questioning and judging themselves and making decisions, the researcher then engaged the participants in a reflection discussion where they were asked to share their experiences of conceptualising the horizontal and vertical integration of the topic Cells, to check for progression. These discussions were audio-recorded.

The reports and the feedback from discussions were analysed using thematic analysis (Lincoln & Guba, 1985; Nowell, Norris, White & Moules, 2017) and common patterns drawn. Analysis involved identifying aspects on integration between concepts, progression within topics and grades and pre-service teachers’ strengths and weaknesses in terms of conceptual and pedagogical understanding. This enabled the researcher to examine the perspectives of different pre-service teachers and to highlight the similarities and differences in their responses (Braun & Clarke, 2006; King, 2004). To ensure validity and reliability of the analysis, the researcher involved a colleague to analyse separately and discussed any differences that arose. The participants were allowed to engage with the findings. This was done as feedback to enhance further professional development and at the same time to authenticate the analysis. To establish trustworthiness during thematic analysis the six phases of thematic analysis by Nowell et al (2017), were followed.

FINDINGS AND DISCUSSION

From the analysis of the pre-service teachers’ reports and reflections, findings on how pre-service teachers conceptualise and articulate the integration and progression of the concept of the cell from Grade 10-12 is presented in Tables 1, 2 and 3. The pedagogical and content knowledge aspects of the pre-service teachers were also drawn from the reports and their reflections of the activity, which provided an opportunity for their professional development. Whilst working on that task, the participants engaged with the Life Sciences content, interpretation of the curriculum and also in metacognitive reflection of how best the concepts could be taught to the learners meaningfully. It was notable that such a task provided the participants with an opportunity to enhance both their content and pedagogical knowledge of the subject.

Whist the reports were not exhaustive of the different ways that the topic Cells is integrated with other topics in Grade 10-12, the participants showed quite a reasonable level of integration. Table 1 shows how concepts are connected to other Grade 10 concepts under eight other topics: molecules of life, cell division, plant and animal tissues, support and transport systems in plants and animals, biosphere to ecosystems, biodiversity and classification and the history of life on earth.
### Table 1: Horizontal Integration with other Grade 10 topics/concepts

<table>
<thead>
<tr>
<th>Topic</th>
<th>Connections with the cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecules for life</td>
<td>Carbohydrates, lipids, proteins and nucleic acids are constituencies of cell organelles. Cells are made up of organic and inorganic compounds. Cell membranes consist of the phospholipids. Molecules relate to cells in that monomers are produced within the cell.</td>
</tr>
<tr>
<td>Cell Division: Mitosis</td>
<td>Occurs in the somatic cells. Focuses on the nucleus more than any other organelle of the cell. Allows growth and multiplication of somatic cells. Aids in the replacement of worn out or damaged cells. Enables growth and reproduction of unicellular organisms.</td>
</tr>
<tr>
<td>Plant and animal tissues</td>
<td>Tissues are made up of a combination of cells, which perform similar functions. Connective tissue, red and white blood cells. Macrophages and lymphocytes are specialised cells involved in the immune system. Epidermal tissues (upper and lower epidermal cells of the leaf), play an important role in life processes.</td>
</tr>
<tr>
<td>Support and transport systems in plants</td>
<td>Xylem and phloem vessels are made of specialised cells to perform various functions in transporting substances and providing support.</td>
</tr>
<tr>
<td>Support systems in animals</td>
<td>Skeletal tissues (bone, muscle, cartilage) are made up of specialised cells. Skeleton in animals serves as the production site for blood cells.</td>
</tr>
<tr>
<td>Transport systems in mammals (Human)</td>
<td>Blood (medium of transport) is made of cells (red and white blood cells). Blood vessels (capillaries, veins, arteries), are made of cells.</td>
</tr>
<tr>
<td>Biodiversity and classification</td>
<td>Biotic factors such as producers, consumers and decomposers, which represent different trophic levels, are made of different cells specialised for particular functions.</td>
</tr>
<tr>
<td>History of life on earth</td>
<td>Evidence of certain key events in life’s history are based on the cell e.g. evidence of earliest forms of life such as single-celled fossilised bacteria and early plant life.</td>
</tr>
</tbody>
</table>

In trying to show the relationship, one group wrote, *The monomers of molecules can be compared to cells, where the monomers are building blocks of polymers, cells are the building blocks of organs*. Another group likened cells to atoms in that as atoms form molecules and then elements and compounds, cells form tissues, organs, organ systems and then organisms. These organisms are part of a population, a community, an ecosystem, biome and lastly biosphere. The plants and animals (made of cells), later form fossils, which are trapped under layers of sand and clay (Clitheroe, et. al., 2013), which becomes a topic of concern in Grade 10 under history of life on earth and in Grade 12 under evolution.

Table 2 shows how the topic Cells: The basic units of life, is integrated with eight other topics in Grade 11, which are biodiversity and classification of microorganisms, reproduction in plants, biodiversity of animals, energy transformations to sustain life (photosynthesis and respiration), animal nutrition (mammals), gaseous exchange and excretion in humans.
**Table 2: Vertical integration with Grade 11 topics/concepts**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Connections with the cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiversity and classification of microorganisms</td>
<td>Microorganisms are classified based on the number of cells they are made of e.g. unicellular, multicellular and also on whether their cells have true nucleus e.g. prokaryote and eukaryote.</td>
</tr>
<tr>
<td>Reproduction in plants</td>
<td>Asexual and sexual reproduction occur in different plant groups, identified by their cellular structures. Gametes are sex cells.</td>
</tr>
<tr>
<td>Biodiversity of animals with a focus on six of the major phyla</td>
<td>Specialisation of cells within different organisms as some micro-organisms have more specialised cells than others. Animal body plan is differentiated by the different cells in the different tissue layers developed from the embryo.</td>
</tr>
<tr>
<td>Energy transformations to sustain life (Photosynthesis)</td>
<td>Photosynthesis largely focuses on the chloroplast more than any other organelle of the cell.</td>
</tr>
<tr>
<td>Animal nutrition (Mammals)</td>
<td>Processes such as ingestion, digestion, absorption, assimilation and egestion occur as a result of specialised cells that form various organs and also those which secret required substances. Cells broadly discussed according to their functions.</td>
</tr>
<tr>
<td>Energy transformations to sustain life (Respiration)</td>
<td>More focus is on the mitochondrion as an organelle of a cell. Explores the cell structure, the organelles, and the different roles of the organelles. Cell structure is used to explain the three cellular respiration phases. Glycolysis takes place in the cytoplasm of the cell. Krebs cycle occurs in the stroma of the mitochondrion in the cell and the electron transport chain in the cristae of the mitochondria in the cell.</td>
</tr>
<tr>
<td>Gaseous exchange</td>
<td>Takes place between the blood, cells and the environment. Discussion of how different organisms have specialised cells (tissues) that allow gaseous exchange in different media e.g. fish in water; how plant cells are arranged for gaseous exchange.</td>
</tr>
<tr>
<td>Excretion in humans</td>
<td>How the different organs, the lungs; the kidneys and bladder; the liver; the alimentary canal (gut); and the skin, have specialised cells (tissues) that allow excretion of various waste substances. These waste substances are products of life processes that take place in various cells.</td>
</tr>
</tbody>
</table>

The different groups showed that basically, the Grade 10 topic, Cells: The basic units of life, forms the foundation knowledge to have deeper understanding of the different topics in Grade 11. They indicated that a learner who does not have firm knowledge about cells in Grade 10 would have difficulties in understanding all topics in Grade 11. To show this connectivity, patterns were drawn using the topic photosynthesis. They articulated in their reports how the concepts build from the cells to allow learners to understand the concepts once they are in Grade 11. For instance they mentioned that concepts on photosynthesis are relatable to the concepts learned at Grade 10 level where the focus is on cell organelles that differentiate the plant cell from the animal cell, and then explore the cell structure, the organelles, and the different roles of the organelles. Then, later in the same grade learners explore the process of transpiration in relation to how it supports the process of photosynthesis in terms of osmosis and diffusion that occurs in cells. In grade 11, cells are further explored along with photosynthesis where the focal point is on how specialised leaf cells and tissues are involved in photosynthesis for example mesophyll cells containing a dense network of chloroplasts arranged systematically to trap light (light dependent reaction) and guard cells controlling the opening and closing of stomata to allow gaseous exchange (carbon dioxide for the
light independent reaction). Such articulations showed how the pre-service teachers drew on their content and pedagogical knowledge.

There were other examples articulated in the reports which showed connections between the cells and other Grade 11 concepts. These included topics such as respiration, which the pre-service teachers mentioned that from the very beginning of Grade 10, as learners engage with content on cell organelles, they already focus on how the structure of the cell and mitochondria, are suitable for the various stages of cellular respiration. The cells are shown in gaseous exchange where ventilation of lungs relies on the specialised cells that should facilitate gaseous exchange for example the alveoli of the lungs and the one-cell thick epithelial cells of the blood capillaries. They indicated that in classification, the cell concept is further broadened in topics such as biodiversity of plants where plants are classified based on the presence or absence of certain tissues such as xylem, phloem, epidermal tissue, ground tissue to name a few, which form part of the vascular tissue (conducting and transporting tissues) and supporting tissues such as collenchyma tissues. Under biodiversity of animals, cells are used to classify animals where the number of tissue layers in the body plan classifies organisms into different phyla. One of the groups wrote, ‘Even though the study of cells is not covered directly as a topic in Grade 11, there is evidence of how it is covered throughout other topics as the learners are forced to always go back to different types of cells in different organisms, both plants and animals’.

Table 3 shows how pre-service teachers articulated the integration of the cell with concepts covered in Grade 12 under seven topics: DNA: The code of life; meiosis; reproduction in vertebrates and humans; genetics and inheritance and the nervous system.

One of the patterns well-articulated by pre-service teachers was the relationship between cells, particularly the chromatin material and other topics/ concepts in Grade 12. Figure 1 shows the integration and progression.

![Diagram](image)

**Fig. 2: A pattern drawn to show connections between the cell and other topics in Grade 12**

The figure shows clearly how from the nucleus of the cell (work covered in grade 10) learners were made aware of the two types of cell division. In grade 12 they now go deeper into Meiosis which is a specialised type of cell division that reduces the chromosome number by half, creating four haploid cells, each genetically distinct from the parent cell that gave rise to them.
On this note, Wessels (2014) recommended that at the beginning and conclusion of each lesson, teachers need to engage learners in integrating the background knowledge to the newly acquired content knowledge.

Table 3: Vertical integration with Grade 12 topics/concepts

<table>
<thead>
<tr>
<th>Topic</th>
<th>Connections with the cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNA: The code of life</td>
<td>Found in the nuclei of cells. Controls the activities of the cells. DNA replication and transcription occur in the nuclei of the cells. Protein synthesis involves the organelles of the cells (e.g. nucleus, mRNA, tRNA, Endoplasmic reticulum, ribosomes, and Golgi apparatus).</td>
</tr>
<tr>
<td>Meiosis</td>
<td>Plant and animal sex cells undergo meiotic division. Gametogenesis involves formation of gametes, sex cells.</td>
</tr>
<tr>
<td>Reproduction in vertebrates</td>
<td>Diversity of reproductive strategies is as a result of various specialised cells which allow for ovipary, ovovivipary, vivipary for example.</td>
</tr>
<tr>
<td>Human reproduction</td>
<td>Egg and sperm are cells which fuse to form a diploid zygote, which then develops into an embryo, foetus and eventually an infant.</td>
</tr>
<tr>
<td>Genetics and inheritance</td>
<td>Genes are on specific portions of DNA, which is in the nuclei of cells. Sex chromosomes, and sex-linked alleles and sex-linked diseases are all as a result of DNA in the nucleus of a cell. Mutations occur on genes in the cells.</td>
</tr>
<tr>
<td>Nervous system</td>
<td>It is because of special cells (nerve tissue) which can respond to the changes in their environment that the nervous system exists. Discussion of the structure of nerve tissues such as sensory neurons, relay neurons and motor neurons refers to the general structure of the cell covered in Grade 10. All receptors (e.g. eye, ear, skin) are organs made up of cells.</td>
</tr>
<tr>
<td>Human endocrine system</td>
<td>Endocrine cells and tissues e.g. Islets of Langerhans, pituitary gland cells produce and secrete hormones. These hormones stimulate other cells to initiate the required response.</td>
</tr>
<tr>
<td>Homeostasis in humans</td>
<td>Maintenance of a constant, optimal internal environment occurs because of specialised cells in particular organs e.g. the skin and the pancreas.</td>
</tr>
<tr>
<td>Plant responses to environment</td>
<td>Plant hormones e.g. auxins effect changes in other plant cells in terms of growth and responses to different stimuli such as light.</td>
</tr>
<tr>
<td>Evolution by natural selection</td>
<td>Evolution (change) through natural selection is linked to genetics, which involves DNA. Speciation is a biological process, which comes about because of various cells and tissues. These cells enable interbreeding producing viable off springs in a species.</td>
</tr>
<tr>
<td>Human evolution</td>
<td>Based on anatomical differences and similarities between African apes and humans. Genetic evidence: mitochondrial DNA.</td>
</tr>
</tbody>
</table>

**Pre-service teachers’ shortcomings**

Analysis of the reports helped to unravel the pre-service teachers’ lack of understanding of scientific concepts, which were not anticipated. Examples of such pre-service teachers’ shortcomings are presented in table 4 as use of non-scientific terminology, which is critical as Life Sciences has its own language (Wessels, 2014), and misconceptions which previous research has labelled as critical as teachers have been found to be possible sources (National Research Council, 1997).
Table 4: Pre-service teachers’ shortcomings

<table>
<thead>
<tr>
<th>Use of non-scientific terminology</th>
<th>Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Identical cells that were produced during the process of mitosis are now being reduced during the process of meiosis</td>
<td>• That the cells in the small intestines also secrete hormones that regulate pancreatic activity</td>
</tr>
<tr>
<td>• Referring to a haploid cell as a half-cell.</td>
<td>• Referring secretion of gastric juices in the stomach as excretion</td>
</tr>
<tr>
<td>• Neurons are data handling cells of the nervous system</td>
<td>• Referring to a leaf as an organelle or organism</td>
</tr>
<tr>
<td>• The single DNA strand picks up free nucleotides from the nucleotide pool</td>
<td>• Chromosomes are one of the organelles</td>
</tr>
<tr>
<td>• Digestion is the conversion of large insoluble molecules into smaller molecules</td>
<td>• The DNA of a prokaryotic cell consists of a solitary chromosome</td>
</tr>
<tr>
<td></td>
<td>• Equating mitosis with cell division</td>
</tr>
<tr>
<td></td>
<td>• Islets of Langerhans are cells of the pancreas that excrete the hormone insulin and glucagon.</td>
</tr>
<tr>
<td></td>
<td>• Equating a plant to a tree.</td>
</tr>
<tr>
<td></td>
<td>• Discussing protein synthesis under nutrition</td>
</tr>
<tr>
<td></td>
<td>• Viruses are not cells, but they are made up of a single cell (unicellular).</td>
</tr>
<tr>
<td></td>
<td>• Organs may be made of single or many cells.</td>
</tr>
</tbody>
</table>

Because science presents a language that is very distinctive in itself, as learners engage with new concepts in science, it is important that they learn new vocabulary to go along with those concepts (Wessels, 2014). Bravo, Hiebert and Pearson (2007) noted that as a content area, science is unforgiving in terms of the constant need to build knowledge and the technical terminology needed to express that knowledge. Therefore, it is important for Life Sciences teachers to use the right scientific terminology when teaching. The pre-service teachers failed to use proper scientific terms which if not corrected, can be transferred to the majority of their learners. Examples include: ‘The cell membrane form a bilayer that separates the inner contents of the cell from the outer and is responsible for every transaction between the neuron and its surroundings’. The use of the word transaction to depict the movement of neurotransmitter substances in and out of the neuron distorts the meaning of neurotransmission. At the same time misconceptions affect in a fundamental sense how learners understand natural phenomena and scientific explanations. Treagust, Duit and Fraser (1996) consider concept maps to be an invaluable aid to concept formation.

Pre-service teachers had problems in that instead of articulating the integration, they resorted to giving details of the content of the different topics. It was noted that some of the pre-service teachers simply showed the topics and concepts where cells are involved. They did not make an effort to explicitly explain the integration yet the task did not require the details of each content as such but conceptualisation of how cells are integrated in each topic. They failed to show the integration and progression of concepts, which could be problematic when they are teaching these concepts to their learners. According to Zirbel (2001) learning is a mental process, which is dependent on how addition of new ideas get integrated into the old knowledge (a process Piaget called ‘assimilation’). Therefore, the whole learning process involves the integration, re-organization and creation of new mental structures (Zirbel, 2001). Deep understanding of concept refers to how concepts are “represented” in the learner’s mind and most importantly how they are “connected” with each other (Grotzer & Mittlefehldt, 2012). As such, Boardman, Arguelles, Hughes and Klingner (2005) posited that teachers should provide learners with a concrete system to process, reflect on, and integrate information.
Analysis of the reports also revealed how teachers sometimes fail to accurately provide definitions appropriate for the level they are teaching. It is unfortunate that they think the use of descriptions done at lower levels can be referred to as use of prior knowledge. Examples include where one group surprisingly defined photosynthesis as, “a process whereby carbon dioxide combines with water, using light energy to form glucose and oxygen”. In as much as such a definition made sense at lower grade level, at high school level, it is a misrepresentation of the process of photosynthesis, and it brings a lot of misconceptions in learners. Another example is of one group which defined sexual reproduction as, “a process of the production of new living organisms by combining genetic information from two individuals of different types (sexes)”.

**Pre-service teachers’ reflections after the analysis activity**

In a lecture after reports had been presented, the researcher engaged the pre-service teachers in a discussion where they reflected on their experiences in doing the activity. The following questions (Boud, 1995) guided the reflection as indicated in the methodology section: ‘how did we do it?’, ‘was this enough?’, ‘was this right?’, ‘how can we tell?’, ‘Should we have gone further?’ One of the participants stated, ‘In all the years I have been taught Biology, it never occurred to me that these concepts are so interconnected though at the back of my mind I knew they did’. The participants mentioned that relating concepts and tracing the progression of the concepts from one topic or grade to another is more likely to ensure learner acquisition, comprehension, retention and application of the scientific concepts taught. They were also convinced that the task improved their content knowledge as they were forced to engage with the content and curriculum thoroughly in order to deduce the interconnectedness of concepts. It is clear that the task required pre-service teachers to interpret the Life Sciences CAPS document in a meaningful way, which prepared them for the real classroom teaching process.

Some of the concluding remarks drawn out by the participants were that: 1. there is evidence that the cell is a topic that integrates with all concepts and topics; 2. the concepts and terminology taught with regards to the cell are vital and should be emphasised, as content progression occurs throughout the grades; 3. because the CAPS document sets out topics in a coherent, logical manner allowing for the scaffolding of new knowledge, teachers should be skilled in interpreting the curriculum properly; 4. teachers should teach in such a way that learners understand and relate to new content taught; and 5. learners need an in-depth understanding of prior topics taught for them to engage meaningfully with new concepts.

From these reflections it shows that the pre-service teachers realised the knowledge and skills they still needed to acquire and develop respectively to prepare them fully for the real classroom situation. Through this self-assessment, the pre-service teachers identified their shortcomings in terms of content knowledge and pedagogical skills. It is envisaged that they will continue to engage in such self-assessment practices in their teaching as qualified practising Life Sciences teachers. This is
because self-assessment goes beyond discussion of technique and strategy and it is more than simply an addition to the teaching and learning repertoire (Boud, 1995).

**CONCLUSION AND IMPLICATIONS**

The study sought to determine pre-service teachers’ conceptualisation of the Life Sciences curriculum in terms of the integration and progression of concepts under the topic Cells: The basic unit of life, with other topics and concepts in Grade 10, 11 and 12. The study investigated how pre-service teachers articulated the way they conceptualised this integration and progression and pedagogical and content knowledge aspects that could be drawn from such conceptualisation for the development of pre-service Life Sciences teachers.

An analysis of the reports from the 10 groups of pre-service teachers showed that they could articulate the integration and progression of concepts from Grade 10 to 12 to a certain extent. It was evident that they needed to acquire a deeper understanding of Life Sciences concepts in order to explicitly interconnect them. It could be interpreted that the findings portray a lack of teacher knowledge and skills to integrate Life Sciences concepts (in this case those that can be integrated with the cell concept) compromises teacher’s ability to teach the concepts meaningfully to the learners. There were some unanticipated issues that emerged from the findings that included pre-service teachers’ failure to use proper scientific terminology and how they portrayed misconceptions in their reports.

From the reflections pre-service teachers engaged in some self-assessment process where they realised their shortcomings. They itemised several practices that teachers must engage in to allow meaningful learner conceptual understanding, which they realised from the analysis activity. These included the need for teachers’ abilities to interpret the curriculum document properly, use of appropriate scientific terminology for the topic and a focus on learners’ need for an in-depth understanding of prior topics taught for them to engage meaningfully with new concepts.

The findings of this study inform teacher educators and in-service teacher professional development providers to engage teachers in self-assessment activities which enable them to identify their capabilities and shortcomings for professional development process. The study also informs both pre-service and in-service teachers of their role in ensuring learner understanding of concepts.

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THE CONTENT KNOWLEDGE TEACHERS USE WHEN TEACHING THE DOPPLER EFFECT

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ABSTRACT
The poor performance in physical science in South Africa is well documented. The low pass rate has been attributed to various factors like teaching strategies, learners’ interest and motivation, teachers’ subject matter knowledge, lack of resources and media of instruction. Even though science teachers’ knowledge has been researched in the South African context there is still a need for research on topics such as Doppler Effect. Teachers’ knowledge portrayed during teaching can be described in terms of its type and qualities. Types include conceptual and procedural while qualities include level, structure and modality. This was a case study focusing on teacher teaching Doppler Effect with the focus on type and qualities on their content knowledge-in-use. The results show that the two teachers’ content knowledge was mainly in conceptual form with some aspects of procedural. The results also show that the content knowledge was mostly of deep level, coherent and represented in multiple ways that are likely to encourage learners’ conceptual understanding.

Key words: content knowledge; knowledge types; knowledge qualities

INTRODUCTION AND BACKGROUND
The poor performance in physical science in South Africa is well documented. In the past few years the physical science average pass rate has hovered around 60%. These are learners who got 30% and above while only around 37% scored above 40% (Department of Basic Education, 2015). This low pass rate has been attributed to various factors among which are teaching strategies (Brodie, Lelliott & Davis, 2002), learners’ interest and motivation (Makgato & Mji, 2006), teachers’ subject matter knowledge (Pitjeng, 2014), lack of resources (Legotlo, Maaga, Sebego, van der Westhuizen, Mosoge, Nieuwoudt & Steyn, 2002) and media of instruction (Probyn, 2008). Even though science teachers’ knowledge has been researched in the South African context there is still a need for research on topics such as Doppler Effect.

This study is embedded in the theoretical idea that teachers draw on their knowledge base for teaching (Shulman, 2015; Mavhunga & Rollnick, 2013). Research in education has taken a seminal role in discussing the concept of teacher knowledge. The focus has been mainly on how such knowledge could be classified and categorised. Some researchers argue that such knowledge can be classified as either conceptual (knowing that, domain-specific content and facts, definitions and descriptions) or procedural (knowing how, production rules and sequences) (De Jong & Ferguson-Hessler, 1996, Jüttner, Boone, Park & Neuhaus, 2013). Others include other types like schematic knowledge (knowing why, principles and schemes) and strategic knowledge (knowing when, where
and how our knowledge applies, strategies and domain-specific heuristics) (Shavelson, Ruiz-Primo & Wiley, 2005; Solaz-Portoles & Lopez, 2007; Machluf & Yarden, 2013).

Even though different researchers identify different knowledge types, most agree on the conceptual and procedural types. These two are considered important in teaching. For instance, teachers need to have conceptual knowledge about problem situations, facts and principles, manipulations that are valid within the specific topic so that such knowledge can be shared with their learners. Conceptual knowledge provides an abstract understanding of the laws, principles and relationships between concepts as building blocks of knowledge in a specific domain (Yilmaz, 2012; Yilmaz & Yalcin, 2012). Procedural knowledge, on the other hand, enables the teachers to efficiently and proficiently solve problems related to science (Schneider & Stern, 2010) so that learners can learn such procedures.

Furthermore, conceptual knowledge is typified mainly as rich in relationships (Yilmaz, 2012) or a connected web of knowledge, a network in which the linking relationships are as important as the distinct pieces of information (Hiebert & Lefebvre, 1986). Relationships encompass the individual facts and propositions so that all pieces of information are linked to some network. It is therefore important that teachers’ conceptual knowledge shows links of concepts that are used to describe, define and explain the topic involved.

There are various ways through which a person comes to know of science concepts and procedures to be followed in demonstrating such knowledge (Star & Seifert, 2006). The authors further argue that skilful understanding of a problem could mean different things, one of which is being able to use procedures quickly, competently and with as marginal inaccuracies and concomitant attention as possible. This means teachers need to show such competency when demonstrating to their learners how to solve the problems. Secondly, scientific skills mean the person has the ability to choose appropriate procedures for specific problems, most of the time changing and adapting procedures when situations allow. It also means the person is able to elucidate and substantiate their actions to others. The procedure is also followed within an academic orientation, with all justification provided for the selection and application of the procedures. The research literature has indicated that the execution of the procedures is not always associated with memorization of routines (Star & Seifert, 2006) but can also be characterised by application of procedural understanding of the process of problem-solving. This is referred to as procedural knowledge.

Teacher knowledge can be represented at different cognitive levels (from superficial/surface to deep). The deep level is also called procedural understanding (Star, 2005). It can be cognitively represented on manifold levels. Firstly, it can be represented on a very superficial level where it is just a sequential list of steps followed. But it can also be represented on a more abstract level where it could include planning characterized by the reasoning used to transform the objectives and limitations that define the aims of the procedure into its surface structure (Vanlehn & Brown, 1980).
CONCEPTUAL FRAMEWORK

Knowledge is normally discussed from a general cognitive perspective as indicated in discussion above or from a perspective of knowledge-in-use. Knowledge-in-use refers to the knowledge that can be identified when performing a task (de Jong & Ferguson-Hessler, 1996). Content knowledge like any type of knowledge can be identified in this way. The focus of this study is on identifying teacher content knowledge-in-use observed during the performance teaching task. Such knowledge can be classified into different types such as conceptual knowledge, procedural knowledge, conditional knowledge, situational knowledge, strategic knowledge and others as indicated on figure 1 below.

![Diagrammatical representation of a conceptual framework](image)

Figure 1: Diagrammatical representation of a conceptual framework

Each of the knowledge types can be described in terms of their properties or what de Jong and Ferguson-Hessler (1996) refer to as knowledge qualities. These include level, structure and modality. The level can be surface or deep where deep knowledge refers to the extent that knowledge is firmly positioned in someone’s knowledge base. Deep knowledge of both concepts and procedures is preferred since it is linked with comprehension and abstraction with important elements of judgment and evaluation. On the other hand, surface-level knowledge is linked with rote learning, reproduction, and trial and error. Deep knowledge should therefore be the targeted aim and primacy of all science learning because it refers to a unified and efficient understanding of scientific ideas. The other knowledge quality is structure which is an indication of whether the knowledge is an aggregation of isolated facts and concepts or if there are links and relations indicated between concepts and facts that have such relations (de Jong & Ferguson-Hessler, 1996). The structured knowledge is also coherent as a whole. This enables learners to acquire new concepts by connecting them to the pre-existing knowledge structure (Kilpatrick, Swafford, & Findell, 2001). The other knowledge quality is modality which is a description of whether the knowledge is represented in words and symbols alone or in pictures and diagrams. Multiple representations are considered a
better quality since it promotes learners conceptual understanding (Adadan, 2013). It was therefore the aim of this study to find out the qualities of the content knowledge that was portrayed when teaching a science topic (the Doppler Effect). This study was guided by the following research questions;

- What are the types of content knowledge portrayed by the teachers?
- What is the quality of these content knowledge types?

**METHODOLOGY OF RESEARCH**

**General Research Background**

This was an empirical and interpretive qualitative case study focusing on two teachers teaching Doppler Effect to Grade 12 learners. The focus was on the in-depth analysis of teachers’ content knowledge portrayed during the teaching of the Doppler Effect. A case study was chosen because it would allow for deep analysis and understanding of case teachers’ content knowledge portrayed during teaching process (Maxwell, 2012).

**Research Sampling**

Purposive sampling was used to select the participants for this study to maximise the richness of information collected (Guba & Lincoln, 2005). The study was carried out in schools situated in Gauteng Province, South Africa. The two teachers were selected from two schools that have been performing well (75% and above) in physical sciences in the last seven years. These were also teachers with more than ten years of science teaching experience. The teachers were also willing to participate in the study.

**Data collection and instruments**

The two schools were visited before the data collection in order to get an insight into the ways the classes were conducted and familiarise with the context of each school. The classes were run as normal during the data collection period. The data collection took place in three stages: pre-observation interviews; classroom observation and post-observation interviews. The semi structured interviews were conducted at each teacher’s school and these took around twenty minutes each and the interviews were audiotaped. The pre-interviews were meant to capture teachers’ ideas about main concepts they were going to teach while post-interview was meant to clarify some issues that were not clear during the lesson but would help the researcher make substantial claims. Classroom observation of all the lessons on Doppler Effect was done. The focus of the observation was on capturing the content that was taught i.e. the facts, concepts and any connections made between them and any task performance related to such content. The classroom observation was captured on video. Both the audio and video recordings were then transcribed and analysed.
ANALYSIS AND DISCUSSION

Teacher content knowledge was characterised through de Jong and Ferguson-Hessler’s (1996) approach of knowledge analysis which includes knowledge types and qualities. These were applied across the analysis of the two teachers. Below the knowledge types and qualities of each teacher are discussed.

Teacher Libele’s content knowledge types and qualities

Conceptual knowledge and its qualities

The analysis of data collected revealed that teacher Libele’s content knowledge was mainly conceptual. This included the definitions, facts, principles and other such descriptors of conceptual knowledge. Teacher Libele was able to make links between some concepts relating to Doppler Effect, such as amplitude and loudness of sound. He showed how amplitude and loudness link to each other, that is, how change of the magnitude of one affected the other. He also showed the relationships among frequency, wavelength, the pitch and how the change of magnitude in one affected others. These concepts were then linked to relative velocity of listener and source which leads to the Doppler Effect.

Although teacher Libele accurately pointed out that frequency for the approaching source would be higher than for the receding source, it was not clear what his description was about the nature of frequency as observed from the listener. The confusion came from the statement he made: “What happens is that when the car is approaching the listener the frequency is gonna go high” and this was inaccurate as the frequency is always decreasing from the time when the listener hears the sound until it passes provided the source is moving with constant velocity (McBeath & Neuhoff, 2002).

From this discussion it is evident that some aspects that were taught indicated connectedness of content whereas others indicate inaccuracies. It is therefore argued that Libele’s conceptual knowledge was not comprehensive in all respects hence an indication that it could not be regarded as well-structured and pitched at a sufficiently deep level.

Procedural knowledge and its qualities

There were instances where teacher Libele used his procedural knowledge. For instance, it was depicted when solving problems related to the Doppler Effect. In one of such instances he solved the Doppler Effect problem in such a way that the steps could be outlined as:

- Analyse the question
- Identify the variables given in the question
- Identify the variable to solve for an unknown measure
- Substitute for the variables given
- Calculate the answer.
This is what De Jong and Ferguson-Hessler (1996) refer to as “recipe” and “isolated algorithm”. It was a multi-step procedure which learners could follow when solving any problem related to the Doppler Effect or even most other physics related problems. This is normally taken as an indication of surface or superficial procedural knowledge that existed in isolation from the main concepts being taught.

However, another look at the procedure showed that teacher Libele wrapped up this problem-solving by linking it with the concepts he had discussed earlier (shown below).

Teacher Libele: ok. So we are saying the answer is 548, 39 Hz. Is this value bigger or smaller than of actual frequency produced by the source?

Learners: it is bigger

Teacher Libele: it’s bigger. This shows that whenever the source is moving towards the listener then the frequency heard by the listener will be higher. Whereas it would be lower if it was moving away from the listener.

The perceived frequency calculated was compared to frequency produced by the source. The comparison was to reinforce the concept of perceived frequency being greater than frequency produced by the source when it approaches the listener. Therefore, the use of procedural knowledge to reinforce understanding of concepts is argued to be an indication of connectedness or coherence.

Content knowledge modality
Teacher Libele used different content representations, a quality referred to as modality in his lesson. Those were diagrams, demonstrations, examples, analogies and symbols. The content was mainly represented using examples, diagrams and symbols while there were few demonstrations and analogies used. This was expected since the textbooks used by teachers as teaching resources largely have diagrams and examples whereas symbols are the main feature of most of physics concepts. Below is a discussion of some of these representations as used by the teacher.

One of the demonstrations that Teacher Libele used was that of ripple tank showing wave fronts when the source is stationary and moving. This demonstration was also used to show the difference in wave pattern in front and at the back of a moving source. The pattern showing wave fronts could be clearly seen and the difference of wavelengths as shown by the distance between the wave fronts could also be clearly observed. This demonstration was used in the description of the Doppler Effect later in the lesson.

Even though the demonstration seemed to be properly planned and executed, Teacher Libele was aware of the possible shortfalls it could cause (indicated below).

Teacher Libele: Ok, for me I sometimes use demonstrations even though sometimes they are not enough. For instant, when I use water to make waves learners can at least see the difference in patterns of the waves when the source is moving but the limitation is that you can’t show the same thing when the listener is the one moving and the source is stationary or can you? I don’t think so but I think to a certain extent it does a trick [sic].

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Because the teacher was aware of the limitations, he used some explanations to make up for such limitations. For instance, the teacher explained to the learners that the patterns they saw with water could also happen in sound even though they were not as visible. In the other demonstration teacher Libele used a spring to show the properties of longitudinal waves. The intention was to start the disturbance on one end of the spring so that it could be transported along the length of the spring to the other end, showing areas of compression and rarefaction. The teacher held the spring with two hands and it hung downwards because of its weight. During the demonstration, the spring seemed to be moving up and down instead of disturbance from one end to the other. The teacher attempted several times to show patterns of compression and rarefaction without any success. It was evident that the teacher was not aware that with a hanging spring it would be difficult to make disturbance that would travel along the length of the spring without the disturbance that was perpendicular to the spring length. The teacher could have placed the spring on a flat surface preferably the table so that the whole class could see. Alternatively he could have inserted a long stick inside the spring so that it would not hang downwards.

There were a number of diagrams that the teacher used during the lesson. One of them was about the pattern of circular wave fronts originating from one point. This diagram was another way of representing difference in frequency when the source is moving which was first represented with the aid of the demonstration discussed previously. Whereas the use of the demonstration alone would make the learners believe that the observed pattern takes place in water only, complementing it with this diagram was likely to overcome such a limitation and lead to enhanced conceptual understanding amongst the learners (Adadan, 2013). This therefore highlighted the importance of using multiple representations in the actual teaching of any physics concept.

Teacher Libele went further to discuss wave front patterns by using an example (shown below):

*Teacher Libele:* it is shortened. It is shorter this side (in front) but at the back it is longer. At the back of the movement it is longer ok. Now if this was a sound and we got ...we have got someone standing there (in front). We got some standing there ok. Let’s say it was a sound...in this case we were using water...and we have got another mantsetserekwane (somebody) standing this side (behind). So we have got those two people. Now which of these two will hear a high pitch and which one will hear a low pitch? This one (in front) will hear...

*Learners:* high pitch

The choice of this example was an indication that Teacher Libele took advantage of the fact that learners had just successfully discussed the relationship between frequency and wavelength. It was also well timed because the scenario of wave patterns was still fresh in the learners’ minds hence a conceptual progression (Rata, 2015).
Furthermore, most of the examples that Teacher Libele used were those that learners were familiar with. For example, when explaining the Doppler Effect Teacher Libele used an example of a police car. The learners have had the experience of siren sound of police car in their everyday lives and they have probably also experienced the difference in pitch of an approaching and receding siren. So such examples meant the teacher considered learners’ prior knowledge in his choice of representation and this was effective in grounding conceptually deep knowledge.

Teacher Libele also used an analogy during the discussion. This was based on electromagnetic radiation that had the same speed, different wavelengths and frequencies. The learners could relate to this analogy even if they had never thought of it before because that happens in their everyday life. This analogy was also used in relation to the diagram of two waves of different wavelengths and frequencies drawn on the board. This meant the teacher multi-represented the same concept for learners to have better and deeper understanding (Adadan, 2013).

### Teacher Skeby’s content knowledge types and qualities

**Conceptual knowledge and its qualities**

Analysis of different sources revealed teacher Skeby’s knowledge was mostly conceptual. There was indication that the relationships among facts and some patterns were established by the teacher. The teacher showed the learners the relationships between concepts such as frequency and pitch. The frequency was described in terms of number of oscillations and time; and in terms of its relationship with wavelength. Moreover, the two concepts (frequency and pitch) relationship with the wave speed or velocity was described. The amplitude was also described as a characteristic of loudness. All these descriptions showed that concepts in discussion were not treated as isolated facts by the teacher. Teacher Skeby portrayed the content knowledge that was well structured, organised and connected. The connectedness is a characteristic that indicates deep understanding of the domain (De Jong & Ferguson-Hessler, 1996).

It is important to highlight that teacher Skeby’s conceptual knowledge was mostly portrayed verbally. This meant the knowledge could be depicted from what he was uttering. However, there were some instances where he used graphs. The use of graphs, pictures or diagrams enhances the deep understanding of a specific concept which De Jong & Ferguson-Hessler (1996) call ‘modality.’ Consequently, the use of graphs and pictures was likely to lead to a construction of rich analogue representations represented in multiple codes (De Jong & Ferguson-Hessler, 1996). The fact that Teacher Skeby had the same knowledge represented in many different ways was likely to deepen his learners’ conceptual knowledge.

Teacher Skeby derived definition of the Doppler Effect from the demonstration performed with the class. Part of the explanations and discussions that followed is given in the excerpt below:

> Teacher Skeby: the same thing happens with sound when the car is approaching you. The car is the source of sound, it is producing sound waves ok. So if it moves towards you what I heard is the
sound which says dum dum dum dum dum dum, it’s like now its rapid its changing, and then when it passes going away like that it becomes slower like duuum duuum duuum duuum....there is a distortion. Alright, what I have just described is called Doppler Effect...where we actually look at the change in pitch of the sound that you perceive or hear due to either the movement of the source or the movement of the listener, do we get it?

Teacher Skeby described the Doppler Effect (illustrated in the excerpt above) as a phenomenon where there is a change of perceived pitch due to the movement of source or the listener. This was the only instance in the whole class discussion where teacher Skeby actually tried to define the Doppler Effect. The learners could only figure the definition from the discussion as given in the excerpt above. Teacher Skeby was able to use the demonstration that the learners could see (using water) and linked it with what they could only hear (sound). In other words, he was able use a concrete example to explain one phenomenon that is abstract, which was likely to lead to good understanding of the concept.

However, following the explanation of the terms such as frequency, wavelength, wave speed and other characteristics of wave and how those terms were related to each other teacher Skeby asked the learners the question shown below.

Teacher Skeby: At times not always when the car is playing music loud dubdubdubdub! And then it is moving towards you at a high speed and then it passes you and goes with high speed, how do you hear the sound as it approaches you and then passes and moves away?

In this instance the teacher was introducing the Doppler Effect even though this was not mentioned in his introduction. He firstly made the learners aware that the phenomenon to be introduced did not always happen. But the description that followed indicated the moving source of sound and the listener. It was not clarified whether or not the source was stationary or moving. The description given as shown in the excerpt could be taken to mean that sometimes when the source of sound is moving relative to the listener the frequency hence the pitch is not the Doppler shifted. The fact is whenever there is a relative movement between the source and the listener there will always be a Doppler Effect regardless of how small the shift is. The statement made by the teacher about sound not being a Doppler shifted would only hold if there is no relative movement between the source and the listener. However, this was never stated throughout his lesson hence a possibility that his learners were not aware of the situation during discussion. This could ultimately lead to the learners having misconceptions about the Doppler Effect.

Teacher Skeby's knowledge was also assessed in terms structure (van Bommel et al., 2012). As indicated earlier, teacher Skeby was able to show how the concepts used were related to each other. However, there were some concepts that were related to each other but the teacher did not demonstrate, show or establish any links them between these during the lessons observed. One such omitted link was between longer wavelength and low (lower) pitch. Even though Teacher Skeby made it explicit that the longer wavelength would lead to low (lower) frequency, which in turn would lead
to lower frequency, he was not explicit about the direct link between longer wavelength and the lower pitch. The same trend was observed with shorter wavelength and higher pitch being linked through higher frequency. This means the link could only be inferred by those thoughtful learners since wavelength and pitch were only linked through frequency but not directly.

The discussions above could be seen as evidence that even though Teacher Skeby’s content knowledge of facts as presented to his learners was well structured and showed deep level qualities (Wheelahan, 2010) there were still some limitations. This shows that there could still be a need for improvement. It is worth emphasising that the researcher is not claiming that Teacher Skeby’s did not know that the concepts involved were related or that he did not know how to relate applications with the Doppler Effect. But it is argued that all these were not explicit during teaching which meant the learners might not be aware of the links between them.

Procedural knowledge and its qualities
As has already been mentioned, there was not much of procedural knowledge portrayed during the teaching of the Doppler Effect. However, there were few occasions where teacher Skeby showed what was classified as procedural knowledge. Most of this type of knowledge came out during his demonstration and problem-solving instances when he was using equations. One of such instances was when demonstrating the wave types and their different amplitudes. This demonstration was intended to introduce the concept of frequency which learners already did in Grade 11. He was showing the difference between high frequency and low frequency hence used his skills to instil into his learners an understanding of frequency. This could therefore be regarded as “meaningful action” (De Jong & Ferguson-Hessler, 1996; p111) which is characteristic of deep level procedural knowledge. Furthermore, this procedural knowledge could be classified as structured since the demonstration that the teacher was doing was related to the concept being taught (De Jong & Ferguson-Hessler, 1996; Zurawsky, 2006).

Content knowledge modality
The use of multiple representations (Kozman, 2003) of the content was found to be a common feature of teacher Skeby’s lesson. This was expected in the didactics as physics is a subject characterised by symbols, equations, graphs and other such representations. Even though the teacher used multiple representations in his lesson, he was also concerned about his learners’ understanding of how they are used. His use of representations included the desire to foster in his learners a fuller understanding and a quest to diagnose possible misconceptions.

One of the dominant representations observed during teacher Skeby’s lesson was examples. The examples he provided were used to explain concepts like change in frequency as heard by the listener, caused by the relative velocity between sound source and the listener. With this example, the teacher also used demonstration to convincingly show how the change in sound could be heard.
Looking deeper into the examples utilised by the teacher suggests that he took into account what the learners already knew and their everyday experiences as shown below:

*Teacher Skeby: I prefer teaching for understanding first, introducing the concepts mentioned above and then I give relevant practical examples. Children love cars and music. I then take advantage of this and I use an example of a car playing loud music.*

It was evident that the teacher used examples that the learners were familiar with in order to build on the knowledge that learners had. It is a constructivist view that this way of teaching leads to development of better understanding.

Furthermore, teacher Skeby used some demonstrations in his teaching. One of them is incorporated in the example discussed above. However, the main demonstration of the content was the one about using the ripple tank to show the pattern of wave fronts when the water inside the tank was disturbed with a finger. The wave front pattern was observed beneath the water tank with the help of a light projected from above the water. Normally, a ripple tank uses the oscillating paddle to make vibrations that form wave fronts but in this case the teacher decided to use his finger instead. The reason given by the teacher was that the pattern would be clearer when coming from a single point of disturbance.

Learners were brought closer to the ripple tank in groups of six so that everyone could observe. Therefore the demonstration was done repeatedly. Firstly, the teacher showed the learners the pattern of wave fronts when the source (which was his finger in this case) was stationary. This was followed by asking the learners to look at the pattern when a source was moving and compare the phenomenon to when the source was stationary. Learners were also requested to compare the patterns in front and behind the moving finger. The discussion of wave patterns observed on the ripple tank was further elaborated using a diagram drawn on the board. Teacher Skeby did not give any explanation behind the use of both representations. However, it can be inferred that it was because the two representations complemented each other. While demonstration helped the learners to have better idea of how change of frequency occurred in reality, it might also make learners believe that it could only happen in water. Therefore, the use of diagram showing patterns of wave fronts could be extended to other applications like sound on which the Doppler Effect is mostly based. Therefore the two representations were deemed necessary for learners' understanding.

Teacher Skeby also used position against time graph. This described the changes that happen to properties of waves which would lead to the Doppler Effect. The graph was used to show the changes that happen to frequency when wavelength was either increased or decreased. This graph was linked with demonstration and the diagram showing wave/time graph to show the crests and troughs to correspond with wave fronts. The teacher also used the graph to show how change in frequency would lead to a change of frequency observed in the Doppler Effect.
Detailed analysis showed that the representations used by Teacher Skeby were both concrete and abstract. He used concrete examples and demonstrations that learners could see and were familiar with followed by the more abstract representations of the phenomenon through a diagram and the graph. The understanding of the concrete representation would assist in the use of representations that needed higher order thinking (Holmes, 2012) used to explain the concept that was abstract in itself.

CONCLUSIONS AND RECOMMENDATIONS

It was shown in this study that Teacher Libele’s content knowledge of the Doppler Effect observed in class was mostly conceptual and scientifically acceptable. This conceptual knowledge was classified as indicating deep level. Teacher Libele’s content knowledge was also classified in terms of its structure and modality. It was found to be connected and coherent to some extent. He also used visual representations that were likely to promote learners conceptual understanding. The teacher also showed procedural knowledge with deep level and well-structured qualities. However, the study also revealed that there were some few shortcomings observed in his content knowledge portrayed, which suggested that it still needed some improvement.

The study revealed that teacher Skeby’s content knowledge was mostly in conceptual form and less in procedural. This knowledge was also found to be mostly scientifically acceptable, well structured, organised and connected, with all these likely to lead to a well-developed learners understanding. It was further revealed that teacher Skeby’s conceptual knowledge was represented by examples, demonstrations, diagrams and graphs. These were also found to be linked to each other an indication his learners were likely to acquire well-structured knowledge.

Even though this was not about the impact of teacher practice on learners’ outcomes the fact that these were teachers whose learners have been performing well for few years, means other teachers can learn from their practice. Therefore, it is recommended that the good knowledge qualities observed in study be shared with other teachers through interventions. It is also recommended that the impact of such an intervention be studied so that such a link can be made. It also recommended that a similar study aiming at documenting teaching practice of teachers like the ones studied in this research whose students are doing well be done over a longer period of time. This is likely to highlight if the knowledge qualities observed in this study are sustained for longer periods.

REFERENCES


THE RELATIONSHIP BETWEEN GRADE 12 LEARNERS’ UNDERSTANDINGS ABOUT SCIENTIFIC INQUIRY AND ACHIEVEMENT IN PHYSICAL SCIENCES

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ABSTRACT
Inquiry Based Learning (IBL) has driven curriculum reforms in science education globally, with many educators teaching science as inquiry, in the hope of improving learners’ understandings of scientific concepts and achievements in standardised tests. The curiosity of whether learners’ engagements and understandings of the Nature of Scientific Inquiry (NOSI) is capable of improving achievement in standardised Physical Sciences tests is important in validating the global emphasis on Inquiry Based Science Education (IBSE). The main aim of this study was to assess grade twelve Physical Sciences learners’ understandings about the NOSI using the Views About Scientific Inquiry (VASI) questionnaire and then compare VASI scores with achievement scores obtained from the National Senior Certificate (NSC) preparatory Physical Sciences examination, a standardised provincial test used in preparing matriculants for the final NSC grade twelve examinations. The study followed a cross-sectional survey design, and involved one hundred and seven (107) grade twelve learners from three Johannesburg high schools. Data were collected using the adopted VASI questionnaire. Responses from the VASI questionnaire were coded and scored with the aid of a rubric. VASI scores were compared against the NSC preparatory test scores using descriptive and inferential statistics. The results obtained from data analysis indicated a strong positive correlation between learners’ cumulative VASI scores and NSC preparatory scores. Group comparisons revealed no significant differences in VASI and NSC scores for male and female grade twelve Physical Sciences learners. These findings indicate that learners’ understandings about the NOSI have a positive influence on performance achievements in a standardised Physical Sciences test. The implications of these findings for practice and research are also discussed herein.

Keyword: Nature of Scientific Inquiry (NOSI), Inquiry-Based Learning (IBL), Standardised test, National Senior Certificate (NSC) examinations, VASI, Achievement.

INTRODUCTION
The South African Department of Basic Education (DBE) and its assessment regulator Umalusi have consistently reported poor performance in Mathematics and Physical Sciences for learners who write the National Senior Certificate (NSC) examinations and learners who participate in the Trends in
International Mathematics and Science Study (TIMSS). TIMSS data from the period 2003-2015 has shown that South African learners have consistently performed poorly in mathematics and science with South Africa falling in the ranks of the “five lowest performing countries including Saudi Arabia (396), Morocco (393), Botswana (392), Egypt (371) and South Africa (358)” (Reddy, Visser, Winnaar, Arends, Juan, & Prinsloo, 2016, p. 2).

The DBE formerly referred to as the Department of Education, has investigated some of the factors affecting performance in Mathematics and Physical Sciences both in national and international benchmarking assessments over the years. Some of the factors, implicated in these findings, have included the vast inequalities that were perpetuated within the education system in the previous political dispensation, lack of parental support for these subjects, poorly trained educators and the content-driven nature of the previous curricula (Lelliott, 2014; Reddy et al., 2016).

In an attempt to address these factors, several curriculum reforms have transpired and the nation has aligned with the global science education imperatives to teach science as inquiry with the ultimate goal of developing learners who are scientifically literate, can think critically, ask scientific questions, solve problems and distinguish unfounded claims from scientific evidence (DBE, 2011). The anticipated outcomes of these numerous national reforms in science education (from content-driven science education to IBSE), has been to improve achievement in science, promote interest in science and also address skill shortages in Science, Technology, Engineering and Mathematics (STEM) careers in the republic (Dudu, 2014; Mokiwa, 2014). Despite increased enactment of IBSE in South African science classrooms, findings from recent studies have showed that learners have mostly mixed and naïve understandings about the NOSI (Gaigher, Lederman & Lederman, 2014; Ramnarain & Hlatshwayo, 2018).

It can be presupposed that when learners engage in scientific inquiry and have a corresponding understanding of the nature of scientific inquiry, such experiences will enhance their understanding of scientific concepts, leading to a higher performance in science. When engaging in inquiry, learners describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. In this way, learners actively develop their understanding of science by combining scientific knowledge with higher order reasoning and thinking skills (National Research Council (NRC), 1996). However, some international studies have questioned the affordances of inquiry practices and understandings about the NOSI on learner achievements in standardised test. In fact, Anderson (2002) found that, inquiry-teaching approaches had no effect on learners’ achievements in standardised test. Gee and Wong (2012), also reported that upon analysis of Programme for International Student Assessment (PISA) 2006 results for eight countries, learners who engaged in discovery inquiry approaches, had lower achievement scores in science while those who engaged in model and application inquiry lessons tended to “have higher achievement” (Gee & Wong, 2012, p. 303).
Since there is a dearth of South African studies on the impact of inquiry-based learning on learners’ performances in standardised science tests, we seized this opportunity to exploit the research gap by investigating the possible relationship between learners’ understandings of the NOSI and achievement scores in standardised test. Accordingly, the study was guided by the following research questions:

- What is the relationship between learners’ understandings about the NOSI and achievement scores in standardised Physical Sciences test?
- Is there a statistically significant difference in VASI and NCS scores for male and female learners?

**LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK**

As defined by Meyer and Crawford (2015), scientific inquiry refers to learning activities that can equip learners with the relevant skills to investigate the natural world, engage in critical and analytical thinking geared at solving problems in authentic scientific context. The NOSI is characterised by eight core aspects, which should be exploited explicitly within science instruction, in science classrooms. These eight aspects include,

1. scientific investigations all begin with a question and do not necessarily test a hypothesis;
2. there is no single set of steps followed in all investigations (i.e. there is no single scientific method);
3. inquiry procedures are guided by the question asked;
4. all scientists performing the same procedures may not get the same results;
5. inquiry procedures can influence results;
6. research conclusions must be consistent with the data collected;
7. scientific data are not the same as scientific evidence; and that
8. explanations are developed from a combination of collected data and what is already known.

These eight NOSI aspects have their underpinnings in the five features of scientific inquiry (NRC, 2000), the eight practices outlined in the Next Generation Science Standards (NGSS Lead states, 2013) and contributions from the American Association for the Advancement of Science (AAAS, 1993). The aspects embody a complete representation of how scientists investigate the natural world and communicate their findings within specific communities of practice. The K-12 science education framework of the NRC (2011), adopted the broader term “scientific practices” in inquiry-based learning instead of the term “skills” to emphasize that “engaging in scientific investigation requires not only skill but also knowledge that is specific to each practice” (p. 30). This therefore implies that, it is not enough for science learners to acquire a set of investigative skills without really understanding the “whys?” and “hows?” of using acquired skills. Learners ought to acquire an understanding about the nature of scientific inquiry including, understanding the diverse methods that scientific investigations can follow, the role of scientific questions, ways in which procedures and human factors influence scientific conclusions, the relevance of data in making scientific conclusions, the differences between data and evidence and the place of prior knowledge in making conclusions.
THE NATURE OF SCIENTIFIC INQUIRY (NOSI)

The Nature of Scientific Inquiry (NOSI) simply refers to “what learners should understand about inquiry” (Leblebicioglu, Metin, Capkinoglu, Cetin, Eroglu Dogan, & Schwartz, 2017, p. 5). The NOSI derives its conceptual groundings from the “Knowledge about inquiry” notion within the populous National Science Education Standards (NSES) and the corresponding NRC (2000) document (Leblebicioglu et al., 2017). Several science education researchers globally and in South Africa, have referred to the term “inquiry” as a multifaceted construct (Crawford, 2014; Gaigher et al., 2014; Lederman et al., 2014; Ramnarain & Hlatshwayo, 2018; Senler, 2015). For the current study, we positioned the understandings about the NOSI, within the conceptual framework of the aforementioned eight core aspects about scientific inquiry proposed by Lederman et al (2014). In the section below, we provide a brief description of each of these core aspects.

Aspect 1: Scientific investigations all begin with a question and do not necessarily test a hypothesis, refers to the role of scientific questions as the starting point for every scientific investigation. What this means is learners need to understand that, stating a hypothesis is not the only drive for scientific investigations, rather posing a scientific question, should be the starting point of every scientific investigation. The scientific question is what propels the inquiry and guides the inquirer on the relevant procedures that should be followed in an investigation (Antink-Meyer, Bartos, Lederman & Lderman, 2016; Lederman et al., 2014).

Aspect 2: There is no single set of steps followed in all scientific investigations (i.e. there is no single scientific method), is an aspect which indicates that, the ideology of a scientific method described by a series of steps typically followed in the experimental approach is not the only way used in scientific investigations. Scientific investigations can follow numerous methods, including testing hypothesis, observational inquiry and non-experimental methods of inquiry (Yang, Park, Shin, & Lim, 2017).

Aspect 3: Inquiry procedures are guided by the question asked; refers to the idea that, the procedure selected for every scientific investigation should be carefully selected to ensure that it leads to obtaining answers to the scientific question, which was posed at the beginning of the inquiry (Yang et al., 2017)

Aspect 4: All scientists performing the same procedures may not get the same results; is a NOSI aspect, which refers to the human factors like creativity and imagination and how they influence the conclusions made by each individual scientist, at the end of an investigation (Gaigher et al., 2014; Lederman et al., 2014).

Aspect 5: Inquiry procedures can influence results; describes the role of procedure in scientific investigations. It can be noted that if different procedures are followed to investigate the phenomena the likelihood is that the results from these different procedures will be different even if the inquirers asked the same scientific question (Lederman et al., 2014)

Aspect 6: Research conclusions must be consistent with the data collected; for every conclusion made by a scientist there needs to be backing evidence derived from collected data. This aspect also emphasises the need for learners and scientists alike to be able to differentiate between unfounded
claims and scientific evidence derived from analysed data (Antink-Meyer et al, 2016; Lederman et al, 2014).

Aspect 7: Scientific data are not the same, as scientific evidence in that, the presence of data alone does not suffice as evidence in scientific investigations. The obtained data has to be analysed for the determination of patterns and relationships, which will be presented as evidence (Schwartz et al, 2008; Senler, 2015)

Aspect 8: Explanations are developed from a combination of collected data and what is already known is a NOSI aspect that describes the role of data and prior knowledge. Prior knowledge helps a scientist to be able to make interpretations on the data at hand in relation to what was already known (Lederman et al, 2014)

FACTORS THAT AFFECT THE UNDERSTANDINGS ABOUT THE NOSI

Several factors have been considered to affect the ways in which learners gain understandings about the nature of scientific inquiry. These factors include the manner in which learners are taught science as inquiry (Crawford, 2014; Osborne, 2014; Lederman et al, 2014), the nature of the engagement they have with inquiry (Leblebicioglu et al, 2017) and how well the NOSI aspects are planned, scaffolded and assessed as part of science content knowledge and instruction (Bartos & Lederman, 2014). In a study by Antink-Meyer et al, (2016) and another by Leblebicioglu et al, (2017), both Taiwanese and American learners reportedly registered more informed understandings about some NOSI aspects after engaging in explicit inquiry activities at a science camp. In both studies, the science camp was used as a platform to engage the learners in inquiry tasks and the associated reflective conversations, questions and answers, which describe the explicit instruction, associated with the intention of teaching the NOSI. Findings from these two studies are indicative of the fact, when teaching and learning activities are carefully planned to include tenets of the nature of scientific inquiry, there will be a positive impact on learners understandings about scientific inquiry. Several researchers also argue that if the understandings about the NOSI is not targeted, as part of inquiry instruction the likelihood is that learners will only develop knowledge of the science content (Leblebicioglu et al, 2017; Crawford, 2014; Osborne, 2014) and not the nature of inquiry. In addition, findings, from other studies have indicated that conceptions and understandings about the NOSI and the Nature of Science are bound to improve only when explicit approaches that treat these concepts as valuable subject matter are included in science instruction within the classroom (Antink-Meyer et al, 2016; Leblebicioglu et al, 2017; Lederman et al, 2014; Bartos & Lederman, 2014). It is therefore widely advocated that, teachers need not only engage learners in doing inquiry, but also purposefully include reflective questions and activities that will draw learners’ attention to the NOSI aspects embedded in any given inquiry task (Galano, Zappia, Smaldone & Testa, 2016; Lederman & Lederman, 2014).
RESEARCH DESIGN AND METHODOLOGY

The study followed a cross-sectional survey design to investigate the relationship between grade twelve learners’ understandings about the NOSI (assessed within the VASI) and achievement in a standardised test (NSC preparatory examination test scores). The survey design was most preferred because it was cost effective and facilitated the collection of large amounts of data at the same time.

Sampling

One hundred and seven (107) grade twelve physical sciences learners were randomly selected from a population of 203 learners from three Johannesburg high schools. We regarded these schools as representative of the socio-economic spectrum of schools in Gauteng. The sample was therefore comprised of learners at township, suburban and independent schools.

Data Collection

This study adopted the Views About Scientific Inquiry (VASI) instrument to assess grade twelve learners’ understandings about the NOSI. The questionnaire was developed and validated as reported by the authors in Lederman et al (2014), to ensure exclusive assessment of the NOSI without conflating with the Nature of Science. The VASI questionnaire is an improved version of the Views of Nature of Scientific Inquiry (VOSI) questionnaire (Schwartz, Lederman & Lederman, 2008), which is targeted at assessing eight NOSI aspects instead of five aspects as was previously assessed in the VOSI. The instrument has been used extensively at different levels and in different context including the South African context to assess learners’ views and understandings about the NOSI (Antink-Meyer et al, 2016; Gaigher et al, 2014; Yang et al, 2017). VASI consists of seven open-ended items, with question 1, 3 and 7 divided into sub-sections, targeted at assessing understandings about the eight NOSI aspects already described above.

Data on grade 12 learners’ performance in Physical Sciences was obtained as secondary data from participant schools. The NSC preliminary examination was written after the VASI had been administered. The preliminary NSC examinations are usually regulated for quality by the provincial department of basic education and comprises of two papers assessing physics and chemistry concepts scored at 150 marks each.

Data analysis

In order to ensure reliability in the coding of responses to the VASI questionnaire, a random 10% sample of the completed VASI questionnaires were read and coded independently by three different coders, including two of the researchers from the current study and one other science education expert. An inter-coder agreement of more than 95% was reached for each VASI item. Learners’ responses were either classified as naïve, mixed or informed. Naïve responses referred to responses,
which were not consistent with the NOSI aspect or were contradictory, while mixed responses referred to responses, which were only partially consistent with a NOSI aspect or were correct but learners could not provide a satisfactory explanation for their reasoning. Informed understandings on the other hand, referred to responses, which were completely consistent with a NOSI aspect and learners, could provide satisfactory explanations for their reasoning (Lederman et al, 2014). After the inter-coder agreement was satisfactorily reached, all 107 questionnaires were coded by the first authors. The coding agenda/rubric used for coding the VASI items is illustrated in Table 1 below.

Table 1: Coding agenda for the VASI item Responses (Adapted from Gaigher et al, 2014)

<table>
<thead>
<tr>
<th>VASI item &amp; NOSI Aspect</th>
<th>Naïve</th>
<th>Mixed</th>
<th>Informed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scientific investigations may follow different methods.</strong></td>
<td>1c: Only one Scientific method Or any two/more mistakes, e.g. 1b: yes, experimental and 1c: Similar or No Examples provided</td>
<td>No more than one of the following types of mistakes: 1b: Yes, it is an Experiment Or 1c: one general Method Or 1c: both examples are experimental Or 1c: both examples are non-experimental</td>
<td>All three answers must be appropriate 1a: Yes, the investigation is scientific as it aims to explain some aspect of the natural world 1b: No, it is not an experiment as there is no manipulation/control of variables/testing 1c: Yes, investigations can follow different methods: experimental/practical/testing as opposed to nonintrusive/non experimental/research/investigation/observation/theoretical/not-practical Two suitable examples required: one experimental and the other non-experimental</td>
</tr>
<tr>
<td><strong>2. A scientific investigation should begin with a question not necessarily be testing a hypothesis</strong></td>
<td>Investigation should start with a hypothesis; also questions are not essential</td>
<td>A question is useful, but is regarded as part of a formal structure, investigation may be undertaken first and questions formulated later</td>
<td>A scientific question is the main reason why an investigation is undertaken, a driving force to begin the investigation or inquiry.</td>
</tr>
<tr>
<td><strong>3a. All scientists performing the same procedures may not get the same results</strong></td>
<td>Similar procedures would always lead to the same results</td>
<td>Imperfect experimental conditions may lead to different results</td>
<td>The human factor may cause different interpretations of similar data, leading to different results</td>
</tr>
</tbody>
</table>
### 3b. Procedures followed in scientific investigations can influence results

<table>
<thead>
<tr>
<th>Description</th>
<th>Only one result is possible regardless of the procedure</th>
<th>Different results would be primarily caused by the different interpretations</th>
<th>Different procedures would yield different data-sets which would lead to different results</th>
</tr>
</thead>
</table>

### 4. Data are not the same as scientific evidence

<table>
<thead>
<tr>
<th>Description</th>
<th>There is no difference between data and evidence</th>
<th>Evidence differs from data; unclear/wrong/no explanation</th>
<th>Evidence is generated from data, to support a claim/conclusion</th>
</tr>
</thead>
</table>

### 5. Question drives the process of scientific investigations

<table>
<thead>
<tr>
<th>Description</th>
<th>Team B did better, illogical or no Explanation</th>
<th>Team A did better, no explanation/argues that the tire has a larger effect than road. Or, B did better and argues that the different roads have different effects on tires.</th>
<th>Team A did the best experiment because they addressed the investigative question</th>
</tr>
</thead>
</table>

### 6. Conclusions should be consistent with data collected

<table>
<thead>
<tr>
<th>Description</th>
<th>Option (a) is correct, with or without an explanation. Alternatively, option (c) with no or illogical explanation.</th>
<th>Option (c) is correct, i.e. ‘growth not related to sunlight’ with an explanation. Or, option (b) without explaining.</th>
<th>Option (b) is correct, i.e. ‘plants grow taller with less sunlight’ because the data showed such a trend. Speculations about the ‘unusual’ data are acceptable provided option (b) is chosen.</th>
</tr>
</thead>
</table>

### 7a & b. Explanations must be based on data and existing scientific knowledge

<table>
<thead>
<tr>
<th>Description</th>
<th>One or no relevant ideas.</th>
<th>Only two relevant ideas.</th>
<th>Three relevant ideas: Two reasons: function of ideas larger hind legs/comparison with existing models of dinosaurs/fitting of joints. One information type: existing knowledge of dinosaurs/skeletons/joints.</th>
</tr>
</thead>
</table>

The second phase of data analysis was aimed at transforming the data by quantifying the responses with scores. As proposed by Scherp (2013), the transformation of qualitative to quantitative data has been used extensively in education research to “facilitate discoveries of patterns in the data” (Scherp, 2013, p. 67). Numerical values were allocated to coded questionnaire items, in order to generate a cumulative VASI scores. Where no response was provided to a VASI item, the item was scored a zero (0), naïve responses scored a one (1), mixed responses scored two (2) and informed responses scored three (3). After this process was completed, the data was treated as quantitative data. VASI scores for each questionnaire were allocated out of 24. The scores for all 107 respondents were then captured on SPSS 25 and analysed for internal consistency and subsequently descriptive and
inferential statistics against the preliminary NSC test scores. VASI scores obtained for the entire
dataset were checked for inter-item internal consistency to ensure the reliability of the transformed
data. Cronbach’s alpha was calculated and an alpha coefficient of .61 was obtained indicating a
moderate internal consistency between the VASI questionnaire items.

RESEARCH QUESTION AND HYPOTHESES

The inquiry was guided by the following research questions.

- What is the relationship between learners’ understandings about the NOSI and achievement in
  Physical Sciences?
- Is there a statistically significant difference in VASI and NCS scores for male and female
  learners?

The stated hypotheses included,

Null Hypothesis 1 (H01): There is no relationship between NOSI understandings and achievement in
a standardized test.

Alternative Hypothesis 1(Ha1): There is a relationship between NOSI understandings and
achievement in standardized test.

Null Hypothesis 2 (H02): There is no difference in VASI and NCS scores for male and female learners.

Alternative Hypothesis 2(Ha2): There a difference in the VASI scores for male and female learners.

Results

VASI and preliminary NSC tests scores were analysed using SPSS 25. Descriptive and inferential
statistical tests were performed, to make meaning of the data. The section below reports on the
findings from the descriptive statistics. Pearson’s correlation coefficient, test for normality of data
and independent sample t-test for gender group comparison.

Mean scores

Table 2 below shows the sample mean VASI and NSC scores obtained by participant grade twelve
learners, with the mean VASI score M= 14.99, S.D =3.16 on a scale of 24 while the mean NSC
examination score M= 55.25%, S.D = 18.01.

<table>
<thead>
<tr>
<th>NCS SCORES</th>
<th>VASI SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>N Valid</td>
<td>107</td>
</tr>
<tr>
<td>Missing</td>
<td>0</td>
</tr>
<tr>
<td>Mean</td>
<td>55.25</td>
</tr>
<tr>
<td>Median</td>
<td>57.00</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>18.006</td>
</tr>
<tr>
<td>Skewness</td>
<td>-.198</td>
</tr>
<tr>
<td>Std. Error of Skewness</td>
<td>.234</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>-.674</td>
</tr>
<tr>
<td>Std. Error of Kurtosis</td>
<td>.463</td>
</tr>
</tbody>
</table>
Relationship between VASI scores and preliminary NSC scores

In answering the first research question, Pearson’s correlation coefficient was used to assess the relationship between VASI scores and NSC Pre examination scores. Pearson’s correlations are expressed as a coefficient between +1.00 to -1.00. A coefficient near +1 has a high size and a strong positive correlation, while coefficients closer to .00 show that variables are most likely unrelated (Pallant, 2010). The results of Pearson’s are displayed on Table 3 below.

Table 3: Pearson’s correlation between VASI scores and preliminary NSC scores

<table>
<thead>
<tr>
<th>Descriptive Statistics</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>VASI SCORE</td>
<td>14.99</td>
<td>3.158</td>
<td>107</td>
</tr>
<tr>
<td>NCS Pre-Score</td>
<td>55.25</td>
<td>18.006</td>
<td>107</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Correlations</th>
<th>VASI Score</th>
<th>NCS Pre-Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Correlation</td>
<td>1.000</td>
<td>.687**</td>
</tr>
<tr>
<td>Sig.(2-tailed)</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>N</td>
<td>107</td>
<td>107</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (2-tailed).

The results displayed on table 3 show a strong positive correlation between VASI score and the NCS pre-score, with Pearson’s r(107) = .687, p < .01. This observation alone does not indicate a causal relationship for the two variables, NCS score and VASI score. Therefore to establish the direct causal relationship, we calculated the coefficient of determination $r^2 = \text{square root} \text{ Pearson’s correlation coefficient. This determination coefficient describes the percentage to which a variable affects another. Our computation showed the value of } r^2 = (.687)^2 = .472. \text{ The value of } r^2\text{ (Coefficient of determination) in percentage indicates that 47.2% of the variation in the NCS pre-score can be explained by the variance in the VASI score while the remaining 52.8% of variance would be explained by other factors.}

Gender differences

In our quest to answer the second research question, and establish whether there are possible statistically significant differences between male and female learners’ scores, we firstly determined the normality of the data, which is the primary assumption for parametric testing. Table 4 below shows the results of normality distribution table against gender for both the VASI and the preliminary NSC scores.
The table above shows the results for the Shapiro-Wilk test. If the significance (p) value of the Shapiro-Wilk Test is > 0.05, it indicates that the data is normal. If it is ≤ 0.05, the sample data significantly deviates from a normal distribution (Fields, 2009). In this case, the p value for both females (.235) and males (.079) exceeded .05, suggesting a normal distribution of scores for both datasets.

After the normality was established, the data was then subjected to an independent sample t-test to establish if there was any significant differences in the VASI and preliminary NSC scores for gender. The result of the t-tests are illustrated on Table 5 below.

### Table 5: Independent sample t-test

<table>
<thead>
<tr>
<th>Participant Gender</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>VASI Score</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>61</td>
<td>14.48</td>
<td>3.102</td>
<td>.397</td>
<td>-1.97</td>
<td>.82</td>
</tr>
<tr>
<td>Male</td>
<td>46</td>
<td>15.67</td>
<td>3.134</td>
<td>.462</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NCS Pre-Scores</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>61</td>
<td>52.85</td>
<td>18.152</td>
<td>2.324</td>
<td>-1.59</td>
<td>.91</td>
</tr>
<tr>
<td>Male</td>
<td>46</td>
<td>58.43</td>
<td>17.500</td>
<td>2.580</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As seen on the table above, the results of the t-test revealed that there is no statistically significant difference (at the 95% level of confidence) in the test scores between females and males learners for the VASI score \( t(105) = -1.97, p = .82 \) and for the preliminary NSC score \( t(105) = -1.59, p = .91 \).

**DISCUSSION AND CONCLUSION**

The findings from the above results reveal that, there is a strong positive correlation between grade twelve learners’ understandings about the nature of scientific inquiry as assessed by the VASI and Physical Sciences achievement scores as assessed in the preliminary NSC preliminary examination. These findings suggests that, if learners acquire understandings about the nature of scientific inquiry, this understanding tends to increase conceptual understandings and may contribute positively to performance in physics and chemistry standardised tests. Although this study did not directly investigate the effects of inquiry-based learning experiences on science achievement, the finding on the relationship between learners’ understanding of scientific inquiry and achievement, are in
harmony with other studies where the effects of inquiry-based learning were investigated directly. For example, research by Maxwell, Lambeth and Cox (2015) with 5th grade learners showed that learners in the inquiry-based learning group scored higher than learners in the traditional group on the academic achievement post-test. Similarly, studies by Han, Capraro and Capraro (2015), Gee, and Wong (2012) revealed that inquiry related learning in science and STEM education has the ability to improve learners’ achievement scores in science.

These findings provide motivation for why learners need to make deliberate efforts and ask questions relevant for their understandings of the NOSI. The findings also suggest that, teachers who aspire higher achievements in standardised science test should nurture learners understanding about the NOSI through inquiry-based experiences as this could improve learners’ achievement in science. From the findings, we recommend that teachers explore inquiry-learning strategies, which will assist learners to reflect on aspects of the NOSI. The focus should not be to inform or tell learners what should be known, but rather to scaffold learners through open classroom conversations about the NOSI and the ways through which scientists investigate the natural world. As postulated by Hodson (1992), the mastery of science process skill alone will not suffice when a learner is expected to recall information, for instance when writing standardised tests. Over and above the acquisition of science process skills, learners should be aware of why they choose procedures, do experiments, collect data using specific procedures and how explanations are formulated. In a South African study, as well as a comparative study by Wang and Zhoa (2016), findings further indicated that, teachers lack informed understandings about certain aspects of the nature of scientific inquiry (Dudu, 2014; Dudu & Vhurumuku, 2012; Wang & Zhoa, 2016. This raises concerns, because according to Fraser (1998) learners’ conceptual understandings are a direct reflection of teacher practice. We therefore recommend that teacher educators also lay emphasis on not only inquiry pedagogic strategies but also on teachers’ understandings of the NOSI.

For researchers we recommend larger scale research on learners and teachers’ understandings about the NOSI inquiry and the implications for conceptual and procedural understandings in science education. Emanating from this study, we propose extensive research (larger sample sizes) aimed at explaining “why” and “how” understandings about the nature of scientific inquiry may contribute to achievement in science.

REFERENCES


ID10153

THE MEASUREMENT OF THE IMPACT OF TEACHING ON ATTITUDES BY USE OF THE COLORADO LEARNING ATTITUDES ABOUT SCIENCE SURVEY IN PHYSICS

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ABSTRACT

Student attitudes is the extent to which students hold an expert-like belief about their approaches to physics studies (Cahill et al., 2018). In this respect, an instrument specifically designed to measure the attitudes towards physics and physics learning called the Colorado Learning Attitudes about Science Survey (CLASS) has been used for that purpose. The survey questionnaire is comprised of 42 Likert-type of questions and is used to probe students’ attitudes about physics. In particular, the focus of this research is to examine the extent to which focussed pedagogical instruction to three groups of students, namely, the Extended Engineering Metallurgy group (EXT-physics 1), the Bachelor of Engineering Technology group (BET-physics 1) and the Analytical Chemistry group (AC-physics 2), is succeeding in improving student learning and transcending their thinking towards an expert-like thinking after a semester of instruction. Results reveal that after a semester of instruction, students’ beliefs shifts towards a novice-like belief for the EXT group and an intermediate belief between novice and expert-like belief for the BET group and an expert-like belief for the AC group in the categories of beliefs mentioned above.

Key words: attitudes, beliefs, learning, pedagogical and physics

INTRODUCTION

Interest about attitudes (a way to express beliefs) towards physics is a subject of interest in literature (Cahill et al., 2018; Brewe et al., 2013). According to Cahill et al. (2018), having a positive attitude towards physics may be congruent with higher achievement in the subject. Thus the development of a positive attitude towards a subject can be taken as an important step in undergraduate student experience. Attitudes is comprised of two components, namely, the cognitive component (what one thinks about studying physics) and the affective component (how one feels about studying physics) (Brown et al., 2015; Rosenberg & Hovland, 1960). The affective components reflects one’s emotional responses of the stimulus while the cognitive component reflects an individual’s belief and knowledge about the stimulus (Xu et al., 2012).

Nowadays physics education is geared towards the development of the students’ conceptual knowledge to a deeper more expert-like level (Semsar et al., 2011). The question of interest is whether pedagogical instruction in the classroom is having any impact in advancing students’ perceptions to that of an expert (Knight, 2010; Semar et al., 2011). It is of interest to note that from research that those involved in teaching physics for life science students (non-physics majors) have...
to make an extra effort to make the subject interesting, engaging and relevant in order to capture their attention (Geller et al., 2018). Because life-science students have a negative perception of physics, special effort is required to make these students appreciate physics. The same could be said of students in extended programs that have performed badly because of their negative attitude towards the subject.

Over the years there has been various instruments that have been used to measure students’ attitude towards physics. To mention a few are the CLASS instrument and the MPEX (Maryland Physics Expectation Survey) instrument. Of these instruments, the CLASS questionnaire was developed and rigorously tested and validated for use in evaluating novice-to-expert levels of perceptions in the discipline of physics (Semsar, et al., 2011). It is of interest to note that not all pedagogical instruction in the classroom leads to positive shifts in attitudes or beliefs. Data has revealed that students’ beliefs has become novice-like over a semester of instruction (Redish et al., 1998; Perkins et al., 2004).

The purpose of this study is to get a perspective of the students’ attitude towards physics and physics learning and to differentiate the views held by both experts and novices in the field of physics. In this study, we look at the impact of focussed teaching practices on students’ beliefs after a semester of instruction. These beliefs are likewise compared to experts in the field of physics.

**RESEARCH QUESTION**

This research is underpinned by the following questions:

1. To what extent student’s beliefs match those of experts in physics, and
2. To what extent focussed pedagogical instruction impacts on student’s beliefs after a semester of instruction?

**THEORETICAL FRAMEWORK**

The framework for this study is taken from Hammer (1994), who proposed various dimensions about how novices and experts view the discipline of science. These dimensions are characterized as:

(a) Content and Structure of Physics knowledge,
(b) Source of knowledge, and
(c) Problem solving approaches.

In the first area, experts believe that physics ideas and facts are connected in a coherent and fluent framework, while novices believe that physics is a collection of discrete and unrelated facts. In the second area, experts believe that the source of knowledge is obtained from empirical experiments while novices believe that such knowledge is handed down by authority (teacher) with no real world connections (Semsar et al., 2011). In the third area, experts follow a scientific way in their approach to problem solving while novices rely on surface features. An analysis of the above reveals that experts have a deep conceptual understanding in their approaches to problem solving while novices rely on surface features in their approaches to problem solving (Semsar et al., 2011).
METHODOLOGY

This study makes use of a survey developed by Adam et al., (2006), called the CLASS attitudes survey. Researchers have reported the psychometric properties of the CLASS survey amongst 5000 students abroad (Douglas et al., 2014) in quantifying student attitudes in undergraduate physics studies. The purpose of using this survey is two-fold; firstly, it is used to gain a better understanding of the students’ beliefs about physics and learning physics and secondly, it is used to differentiate between beliefs held by novices on the one hand and beliefs held by experts on the other hand about physics (Douglas et al., 2014). In respect to beliefs held by experts (those with PhDs in physics) use is made of experts from an international platform. The survey itself consists of 42 Likert-type questions, ranging from Strongly Disagree (+1) to Strongly Agree (+5) from which mean values are obtained for each item. Administration of the survey took place during two phases of instruction; firstly at the beginning of the semester (pre-instruction) and secondly at the end of the semester (post-instruction). The survey was administered to three groups of students both at the beginning of the semester and again at the end of the semester. The students that were involved in this research were: The Extended Engineering Metallurgy group (EXT- 54 students), the Bachelor of Engineering Technology group (BET- 42 students) and the Analytical Chemistry group (AC- 43 students). The number of students that participated in the second round of the survey were 41, 44 and 33, respectively for each of the above groups. Three different lecturers taught each of these groups. Of the 42 items of the survey, 26 of them were grouped into one of eight overlapping factors pertaining to attitudes about physics and learning physics (Adams et al., 2006 & Douglas et al., 2014). These factors are Real World Connections (4 items), Personal Interest (6 items), Sense Making & Effort (7 items), Conceptual Connections (6 items), Applied Conceptual Understanding (7 items), Problem Solving General (8 items) and Problem Solving Confidence (4 items) and Problem Solving Sophistication (6 items). Each of the 42 items are slotted into one of these factors, with each factor having between four to eight items. After this procedure, a further optimization was done to cluster the items into three broad factors, namely, Personal Applications and Relation to Real World (6 items), Problem Solving/Learning (5 items) and Effort /Sense Making (4 items). Further, a comparison is made between favourable responses from the students and these are matched to the favourable responses from experts in the field of physics. For the reliability of the data, the Cronbach Alpha was computed. In this respect, the Cronbach Alpha for each of the groups during the pre-instruction phase were AC (0.765), EXT (0.753) and BET (0.669) and for the post instruction phase: AC (0.828), EXT (0.761) and BET (0.738). These values are acceptable as they are above 0.5.

RESULTS AND DISCUSSIONS

Comparisons of the favourable mean scores between the experts in the field of physics and the students

The experts have characterized various items of the survey questionnaire into fewer factors, namely, Real World Connections, Personal Interest, Problem Solving General, Problem Solving Confidence and
Problem Solving Sophistication. The mean values for the student’s responses that corresponds to the expert’s favourable responses are given in the table below.

**Table 1: Comparisons of the favourable mean scores between the experts and students in four categories listed in the table.**

<table>
<thead>
<tr>
<th>Categories</th>
<th>Favourable Expert responses (items)</th>
<th>Group 1: EXT</th>
<th>Group 2: AC</th>
<th>Group 3: BET</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre mean</td>
<td>Post mean</td>
<td>Pre mean</td>
<td>Post mean</td>
</tr>
<tr>
<td>Real World Connections</td>
<td>28, 30, 37</td>
<td>3.45</td>
<td>3.61</td>
<td>3.80</td>
</tr>
<tr>
<td>Personal Interest</td>
<td>3, 11, 14, 25, 28, 30</td>
<td>3.66</td>
<td>3.67</td>
<td>3.82</td>
</tr>
<tr>
<td>Problem Solving General</td>
<td>15, 16, 25, 26, 34, 42</td>
<td>3.75</td>
<td>3.63</td>
<td>4.00</td>
</tr>
<tr>
<td>Problem Solving Confidence</td>
<td>15, 16, 34</td>
<td>3.84</td>
<td>3.52</td>
<td>3.95</td>
</tr>
<tr>
<td>Problem Solving Sophistication</td>
<td>25, 34</td>
<td>3.45</td>
<td>3.32</td>
<td>3.75</td>
</tr>
</tbody>
</table>

A favourable mean score (approximately 3.5 and above) from the students’ point of view would mean that their response to an item is what an expert – physicist would score. In this respect, in order to measure how substantially the pre and post instruction scores differ by, the Cohen number d is used as a yardstick for such measurements. This can be seen from the table below (www.phyport.org/expert/effectsize):

**Table 2: A Cohen range of measurement**

<table>
<thead>
<tr>
<th>Effect /Size</th>
<th>Cohen d score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large</td>
<td>Approximately 0.8</td>
</tr>
<tr>
<td>Medium</td>
<td>Approximately 0.5</td>
</tr>
<tr>
<td>Small</td>
<td>Approximately between 0.2 and 0.3</td>
</tr>
</tbody>
</table>

From table 1, we see that the differences between the pre-instruction score and the post-instruction scores appears to be small between groups 1 and 3, but in line with what an expert-physicist would score them.

It appears that the BET group of students maybe having some difficulty in relating the course curriculum to real world applications, while the extended group of students may lack the sophistication required for solving real world problems. On the other hand, group 2 appears to agree with expert’s point of view in many of the categories of table 1, except for the Problem Solving Sophistication category, where a mean score of close to the medium is observed. For group 2, all the post-instruction scores are above the pre-instruction scores and indicative of their thinking being in
alignment with the beliefs of experts in the field of physics. This suggests that the course presentation has promoted expert-like thinking for this group of students in the various categories of table 1.

**Influence of teaching in improving students’ beliefs**

Table 3 presents the mean scores (both pre and post instruction) for three groups of students, taught by three different lecturers, aimed at improving students’ beliefs in each of the eight belief categories from Real World Connections to Problem Solving Sophistication.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Student’s responses to statements</th>
<th>Group 1: EXT</th>
<th>Group 2: AC</th>
<th>Group 3: BET</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre Mean scores</td>
<td>Post Mean scores</td>
<td>Pre Mean scores</td>
<td>Post Mean scores</td>
</tr>
<tr>
<td>Real World Connections</td>
<td>28, 30, 35, 37</td>
<td>3.41</td>
<td>3.51</td>
<td>3.69</td>
</tr>
<tr>
<td>Personal Interest</td>
<td>3, 11, 14, 25, 28, 30</td>
<td>3.67</td>
<td>3.67</td>
<td>3.83</td>
</tr>
<tr>
<td>Sense Making Effort</td>
<td>11, 23, 24, 32, 36, 39, 42</td>
<td>3.75</td>
<td>3.66</td>
<td>3.97</td>
</tr>
<tr>
<td>Conceptual Connection</td>
<td>1, 5, 6, 13, 21, 32</td>
<td>3.12</td>
<td>2.94</td>
<td>3.20</td>
</tr>
<tr>
<td>Applied Conceptual Understanding</td>
<td>1, 5, 6, 8, 21, 22, 40</td>
<td>2.89</td>
<td>2.59</td>
<td>2.79</td>
</tr>
<tr>
<td>Problem Solving General</td>
<td>13, 15, 16, 25, 26, 34, 40, 42</td>
<td>3.68</td>
<td>3.60</td>
<td>3.88</td>
</tr>
<tr>
<td>Problem Solving Confidence</td>
<td>15, 16, 34, 40</td>
<td>3.85</td>
<td>3.44</td>
<td>3.87</td>
</tr>
<tr>
<td>Problem Solving Sophistication</td>
<td>5, 21, 22, 25, 34, 40</td>
<td>3.22</td>
<td>2.94</td>
<td>3.24</td>
</tr>
<tr>
<td>Not Scored</td>
<td>4, 7, 9, 31, 33, 41</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

In particular lecturers for each of these groups focussed on conceptual understanding and problem-solving strategies for the development of expert-like beliefs amongst students over a semester of instruction. For group 1, we see learning gains and a positive belief in one of the eight categories, namely, Real World Connections. For these groups of students, the physics that they learn does not translate to improvements in their personal lives (zero gain). Of the other categories in table 3, for group 1, there appears to be a regression of gains in six categories with a much lower regression in two categories, namely, Problem Solving Confidence and Problem Solving Sophistication. This implies that students lack the confidence and sophistication for problem solving inspite of a semester of focussed instruction. For these students, it appears that their beliefs have become more novice-like after a semester of instruction. Similar results have been obtained by Redish et al., 1998 & Redish,
2003. In the latter case it was found that despite reformed instruction in the classroom practices, students beliefs did not improve. According to Perkins et al., 2004, there appears to be a relationship between learning gains and students’ beliefs i.e. larger student gains corresponds to a positive student belief.

For students in the upper division of the course curriculum (group 2: physics 2), there appears to be a more significant shift towards expert-like perceptions in all categories of beliefs in table 3. Although these students are specialising in chemistry, explicit real life examples of relevance to chemistry had a positive impact on their studies. A Cohen d value of close to medium (approx. 0.4) is observed in two specific categories, namely, Conceptual Connection and Problem Solving Sophistication. In this sense, students are finding connections of the curriculum with their field of study. They also were found to display a high level of sophistication in their problem solving strategies. For the rest of the categories, a range from small to medium of the Cohen number is observed. These students have put much effort to make sense and understand the ideas, connections of the curriculum that was presented in class. In another category, Personal Interest, students have tried to think about the benefits of physics in their personal lives. In a sense, these students seem to be enjoying the curriculum that is presented in class. They are trying to make a link or connection to the real world from the knowledge they received in physics. On the downside of things, one category that has appeared to cause much concern to all groups of students is the category Applied Conceptual Understanding. Although this category displays an upward shift in the mean score after a semester of instruction, it is an area of deliberation in our future endeavours. Thus, for this group of students, focussed teaching instruction has led to learning gains with improved student beliefs in virtually all categories of table 3.

For group 3, we see marginal differences in the mean scores between the pre-instruction score and the post instruction score in each of the eight categories of beliefs in table 3. For these engineering students, it appears that the physics course material did not fully describe their understanding of the world (Real World Connection) and at the same time it did not have an interest in their personal lives (Personal Interest). On the other hand, there appears to be learning gains in some categories such as Sense Making Effort, Conceptual Connection and Problem- Solving Sophistication. In these scenarios it appears that these students did put an extra effort to make sense of the course material presented in class (Sense Making Effort). They also understood that the physics modules presented to them is based on some conceptual framework and that there is a relationship between the various concepts (Conceptual Connection). Whilst they may lack Problem Solving Confidence in general, they nevertheless have some Problem Solving Sophistication. Of concern to us is the category Applied Conceptual Understanding which appears to be low in the pre and post instruction scores.

**Optimisation measurements of student attitudes about physics and learning physics**

Optimisation of the items of the questionnaire has resulted in three factors which correlates well with each other about the general attitudes towards physics and they are Personal Application and
Relation to the World (6 items), Problem Solving and Learning (5 items) and Personal Effort and Sense Making (4 items). The results for the pre-instruction and post-instruction mean scores are shown in Table 4 below.

Table 4: Optimising the items of the questionnaire into three categories of attitudes listed in the table. Note in the discussion below, reference is made to the mean scores from items of the CLASS questionnaire, not shown in this paper.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Items</th>
<th>Group 1: EXT</th>
<th>Group 2: AC</th>
<th>Group 3: BET</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre Mean scores</td>
<td>Post Mean scores</td>
<td>Pre Mean scores</td>
<td>Post Mean scores</td>
</tr>
<tr>
<td>Personal Application and relation to the World</td>
<td>3, 14, 25, 28, 30, 37</td>
<td>3.48</td>
<td>3.55</td>
<td>3.73</td>
</tr>
<tr>
<td>Problem Solving and Learning</td>
<td>5, 21, 22, 34, 40</td>
<td>3.16</td>
<td>2.86</td>
<td>3.13</td>
</tr>
<tr>
<td>Personal effort and Sense Making</td>
<td>23, 24, 29, 32</td>
<td>3.85</td>
<td>3.71</td>
<td>4.00</td>
</tr>
</tbody>
</table>

From the table, it is pleasing to see higher post instruction mean scores in all categories for the analytical chemistry group of students. A Cohen difference of between small to medium is observed in the Problem Solving and Learning category. In particular, this group of students think about physics in their everyday life (mean (pre) = 3.34, mean (post) = 3.79) and use the knowledge of physics learnt in class to empower their lives outside of their school life (mean (pre) = 3.86, mean (post) = 4.12). Most of the students appear to enjoy themselves in the physics class (mean (pre) = 3.79, mean (post) = 4.33) and most of all it seems that learning physics changes their perception about how the world works (mean (pre) = 3.95, mean (post) = 4.09). Further, the skills that they use to analyse physics can be regarded as useful in their everyday lives (mean (pre) = 4.25, mean (post) = 4.29). In general, these students think about their personal experiences in life and try to relate them to the topics being analysed in class (mean (pre) = 3.20, mean (post) = 3.60).

On the issue of problem solving for the analytical chemistry students, they appear to have made great improvements from their pre instruction scores. They find that if they have studied and understood a particular topic in physics then they did not have any difficulty in solving a similar problem with different parameters (mean (pre) = 3.00, mean (post) = 3.93). In line with this problem, students are of the opinion that if another problem has to be solved, then the problem must have similar situations (mean (pre) = 2.18, mean (post) = 2.57). This particular item has a mean scores below 3.00 and is a cause for concern. Theoretically physicist solve problems at a deeper level than rely on surface features or memorization of the solutions of model problems (Douglas et al., 2014). On this aspect we think the approach by students in this regard is novice-like. In contrary to this item, students feel that formulas need to make sense before they are applied correctly to problems. Students strongly disagree with the notion that if they get stuck with a particular problem in physics, they will have to
seek help from authority (mean (pre) = 3.63, mean (post) = 3.73). Thus on the aspect of Problem Solving and Learning, the approaches of students in this category is generally towards expert-like in their approach of learning physics.

On the issue of Personal Effort and Sense Making, students have likewise made improvement from their pre instruction scores. Students are in disagreement with the notion of if an answer is obtained through calculations and if this answer is in disagreement of what is supposed to be expected, they would rather inspect their calculations for errors instead of taking their initial calculations for granted (mean (pre) = 3.93, mean (post) = 4.09). Formulas need to make sense to these students before they are applied correctly to physics problems (mean (pre) = 4.58, mean (post) = 4.51). For these students the statement “To learn physics, I only need to memorize solutions to sample problems” did not make sense but must be looked at in the context to another statement “If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations”. Although the post mean scores (3.65) for this particular item is much higher than the pre instruction mean scores (4.03), students may be confused with these two statements and may rely on their intuition to solve problems of an unknown nature. Students are also in disagreement with the statement “Spending a lot of time understanding where formulas come from is a waste of time”. This means that they are concerned about how formulas are derived from first principles because they might have to derive it if faced with a situation. Thus on the aspect of Personal Effort and Sense Making, the approaches of students (analytical chemistry) in this category is generally in between that of an expert and novice in their approach of learning physics.

For the extended engineering group of students, we notice a marginal improvement in the post instruction mean scores compared to the pre instruction mean scores for the category Personal Application and Relation to the World. For this group of students they also do think and appreciate the value of physics in their everyday lives (mean (pre) = 3.27, mean (post) = 3.34). They are also in agreement that the knowledge obtained from physics in school will empower them in their lives outside of the school (mean (pre) = 3.76, mean (post) = 3.82). On the downside they never seem to enjoy solving physics problems in class as reflected from their post instruction scores (mean (pre) = 3.52, mean (post) = 3.34), but however learning physics in class to an extent changes their perspective of how the world works (mean (pre) = 3.77, mean (post) = 3.78). Reasoning skills required to understand physics also in relation to the previous item helps them in their everyday life experiences (mean (pre) = 3.77, mean (post) = 4.00. Thus on the aspect of Personal Application and Relation to the World, the approaches of students (extended engineering) in this category is generally in between that of an expert and novice in their approach of learning physics.

On the issue of Problem Solving and Learning, these mean scores for these students after a semester of instruction seems to have gone down quite a bit. They nevertheless seem to have a lot of difficulties in solving problems on the same topic after doing a number of problems of a similar nature in the same section (mean (pre) = 3.09, mean (post) = 2.48). For these students if they are unable to remember an equation to solve a problem during an examination session, they simply give up without
trying or making an attempt (mean (pre) = 3.05, mean (post) = 2.93). Problem solving from one scenario to another gives these students a lot a problems. They will only feel comfortable if the given problem involves very similar situations with similar methods to be used (mean (pre) = 2.41, mean (post) = 2.43). Against this backdrop they usually struggle to figure a way to solve a given physics problem (mean (pre) = 3.37, mean (post) = 3.29). Thus on the aspect of Problem Solving and Learning, the approaches of these students in this category is towards novice-like approach in their approach to learning physics.

For the category, Personal Effort and Sense Making, the students’ pre instruction mean scores have decreased slightly. The extended engineering students in general do not check their calculations if their answers do not agree with the answers given (mean (pre) = 3.88, mean (post) = 3.59). They just proceed with the next problem without giving due consideration with the correctness of their calculations. From an expert point of view, formulas need to make sense before they are used. These students appear to be in agreement with the statement “To learn physics, I only need to memorize solutions to sample problems” ((mean (pre) = 3.59, mean (post) = 3.87). This approach of learning physics is pertinent to a novice-like approach to learning and these students may be inclined to be in this direction of learning. Further, these students are of the opinion that spending a lot time in understanding where formulas came from is a waste of time (mean (pre) = 3.59, mean (post) = 3.14). They are only interested in applying them to problems. Thus on the aspect of Personal Effort and Sense Making, the approaches of these students in this category is towards novice-like approach in their approach to learning physics.

On the issue of Personal Application and Relation to the World, the BET group of students have performed worse in the post instruction mean scores than the pre instruction mean scores after a semester of instruction. This group of students gave little attention to the experiences of physics in their everyday life (mean (pre) = 3.76, mean (post) = 3.61) and presumably use less of the knowledge of physics outside of school (mean (pre) = 4.07, mean (post) = 3.91). It is no surprise that these students lack enjoyment in solving physics problems in class (mean (pre) = 3.73, mean (post) = 3.59). However, on the contrary, for them learning physics changes their idea about how the world works (mean (pre) = 3.66, mean (post) = 3.86). It is interesting to note that the skills that they acquired in understanding physics was helpful in their everyday life usage (mean (pre) = 3.83, mean (post) = 3.90). For these students, the knowledge from their personal life experience was not transferred to the topics being analysed in class (mean (pre) = 2.81, mean (post) = 2.57). Thus on the aspect of Personal Application and Relation to the World, the approaches of these students are novice-like in learning physics.

In respect to Problem Solving and Learning, these students appear to have improved after a semester of instruction. For these students when a section is done in class and if they have understood it may be assumed that they presumably have little difficulty in solving problems on the same topic (mean (pre) = 2.57, mean (post) = 2.72). Solving problems in this context may be of a lower order (mean scores less than 3) than what experts in the field assume. There is overwhelming disagreement by
these students on the fact if they cannot remember an equation in the examination, then nothing can be done about it (mean (pre) = 3.31, mean (post) = 4.47). However, there is little more agreement on the statement “If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations” (mean (pre) = 2.60, mean (post) = 2.38) but at a lower level of understanding (mean scores less than 3). It appears that these students have a way of figuring a way to solve physics problems on their own (mean (pre) = 3.26, mean (post) = 3.63), but interestingly when they get stuck on a physics problem they will have require help from authority (mean (pre) = 3.16, mean (post) = 2.36). Overall, for this category student approaches to learning maybe classified as in between novice-like and expert-like.

On the aspect of Personal Effort and Sense Making, there has been a decrease in the mean score in the post instruction mean scores compared to the pre instruction mean scores for this group of students. Students are reluctant to check their calculations to problems when their answers differ from what is expected in the text (mean (pre) = 3.86, mean (post) = 3.29). Further, for this group of students the formulas need to make sense before they are applied to problems in physics (mean (pre) = 3.92, mean (post) = 3.97). Thus on the aspect of Problem Solving and Learning, the approaches of students in this category is generally towards novice-like in their approaches to learning physics.

CONCLUSION

The CLASS questionnaire in this research was used to firstly characterise how students’ perception match those of the experts in the field of physics and secondly to determine the impact of pedagogical instruction on students beliefs after a semester of instruction. Data in this research has revealed that only the analytical chemistry (physics 2) have acquired an expert-like belief in all the clustered belief categories, while the extended engineering group and the BET group have only shown glimpses of expert-like beliefs. Further, it is revealed that focussed pedagogical instruction has had a detrimental effect in some categories of beliefs for the extended engineering and BET groups of students but a positive effect for the analytical chemistry students. In most categories of beliefs, teaching of first year physics courses has caused a drop in the pre instruction mean scores and this has resulted in a novice-like approach to thinking and learning physics. Thus in improving students’ expert-like perception in physics will require pedagogical instruction that explicitly targets epistemological issues (Semsar et al., 2011).

REFERENCES


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ANNEXURE

1. A significant problem in learning physics is being able to memorise all the information I need to know.
2. When I am solving a physics problem, I try to decide what would be a reasonable value for the answer.
3. I think about the physics I experience in everyday life.
4. It is useful for me to do lots and lots of problems.
5. After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic.

6. Knowledge in physics consists of many disconnected topics.

7. As physicists learn more, most physics ideas we use today are likely to be proven wrong.

8. When I solve a physics problem, I locate an equation that uses the variable given in the problem and plug in the values.

9. I find that reading the text in detail is a good way for me to learn physics.

10. There is usually only one correct approach to solving a physics problem.

11. I am not satisfied until I understand why something works the way it does.

12. I cannot learn physics if the teacher does not explain things well in class.

13. I do not expect physics equations to help my understanding of the ideas; they are just for doing calculations.

14. I study physics to learn knowledge that will be useful in my life outside of school.

15. If I get stuck on a physics problem my first try, I usually try to figure out a different way that works.

16. Nearly everyone is capable of understanding physics if they work at it.

17. Understanding physics basically means being able to recall something you’ve read or been shown.

18. There could be two different correct values to a physics problem if I use two different approaches.

19. To understand physics I discuss it with friends and other students.

20. I do not spend more than five minutes stuck on a physics problem before giving up or seeking help from someone else.

21. If I don’t remember a particular equation needed to solve a problem on an exam, there’s nothing much I can do (legally) to come up with it.

22. If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations.

23. In doing a physics problem, if my calculation gives a result very different from what I’d expect, I’d trust the calculation rather than going back through the problem.

24. In physics, it is important for me to make sense out of formulas before I can use them correctly.

25. I enjoy solving physics problems.

26. In physics, mathematical formulas express meaningful relationships among measurable quantities.

27. It is important for the government to approve new scientific ideas before they can be widely accepted.

28. Learning physics changes my ideas about how the world works.

29. To learn physics, I only need to memorize solutions to sample problems.

30. Reasoning skills used to understand physics can be helpful to me in my everyday life.
31. We use this statement to discard the survey of people who are not reading the questions. Please select agree-option 4 (not strongly agree) for this question to preserve your answers.

32. Spending a lot of time understanding where formulas come from is a waste of time.

33. I find carefully analysing only few problems in detail is a good way for me to learn physics.

34. I can usually figure out a way to solve physics problems.

35. The subject of physics has little relation to what I experience in the real world.

36. There are times I solve a physics problem more than one way to help my understanding.

37. To understand physics, I sometimes think about my personal experiences and relate them to the topic being analysed.

38. It is possible to explain physics ideas without mathematical formulas.

39. When I solve a physics problem, I explicitly think about which physics ideas apply to the problem.

40. If I get stuck on a physics problem, there is no chance I’ll figure it out on my own.

41. It is possible for physicists to carefully perform the same experiment and get two very different results that are both correct.

42. When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented.
EXPLORING INQUIRY-BASED PRACTICAL WORK FACILITATION BY PRE-SERVICE TEACHERS: A TOPIC SPECIFIC PEDAGOGICAL CONTENT KNOWLEDGE LENS

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ABSTRACT
One of the challenges in the implementation of inquiry-based practical work (IBPW) is achieving an alignment of the assessment practices to the instructional strategy. The use of paper and pen examinations is prevalent as a form of assessment. Pre-service science teachers learn how to facilitate IBLW in methods courses. This paper explored the development of an alternative tool to assess how final year science teachers use topic specific pedagogical content knowledge (TSPCK) to facilitate IBPW for learners at one University in South Africa. Using a multiple case study design, data were collected by requesting 34 participants to plan a lesson that they would use to facilitate inquiry-based practical for learners. The participants organised themselves in 5 groups which constituted the cases. Each group cooperatively planned a lesson that was taught by one of the pre-service teachers to the rest of the group members. The lessons were captured on video and submitted to the researcher together with the lesson plans. The data were analysed through inductive content analysis techniques and ultimately by cross-case analysis. For IBPW facilitation two forms of content knowledge and four forms of TSPCK were identified. The identified forms of knowledge informed the recommendation of an assessment tool to measure pre-service teachers’ abilities to facilitate IBPW in science classrooms.

Keywords: Assessment; assessment tool; inquiry learning; inquiry-based practical work facilitation; physical sciences pre-service teachers

INTRODUCTION
Curriculums guide both instruction and assessment. However, one of the gaps in the implementation of inquiry learning has been the misalignment between instruction and assessment (Liu, Lee & Linn, 2010; Kim & Tan, 2013). The misalignment manifests as the absence or limited assessments that reflect the inquiry-based learning. The failure for the inquiry theme to be reflected in assessment may lead to the undervaluing of the instructional strategy by teachers. In South Africa, Ramnarain (2014) analysed inquiry-related questions in three Grade 12 pen and paper examinations and identified a number of threats to validity. Accordingly, Harrison (2014) argues that amidst calls to develop students’ abilities for conducting scientific investigations, valid assessments should also be developed for proper measurement.

In efforts to measure inquiry-based practical work in particular during assessments some rubrics can be constructed. One such rubric has existed for more than five decades and places inquiry-based
practical work on a scale that moves from simple to complex. The scale of inquiry as developed by Schwab (1962) and further emphasised by Herron (1971) has four points that use question formulation, procedure design and solution articulation as descriptors. Bretz and Fay (2008) refer to the four points on the inquiry scale as levels 0, 1, 2 and 3. In level 1 the teacher provides the question, the procedures of the experiments and the solution to the question during practical work. In level 1, the learners receive the question and the procedures from the teacher and they find the solution to the question. In level 2 learners are provided with the question and they are required to figure out the procedure and the solution to the question. In level 3 learners are required to control all the three inquiry processes. The four levels of inquiry may be referred to as confirmation/verification, structured, guided and open inquiry respectively (Cheung, 2007).

The above-mentioned rubric does not exhaust all the processes involved in inquiry learning. There are more inquiry processes that will be discussed further in the literature review section below. Accordingly, in the assessment of inquiry activities there are several variations of rubrics that can be constructed for different purposes. However, Beck, Butler and Burke da Silva (2014) concede that assessments on inquiry are rarely based on published instruments after reviewing literature on inquiry-based teaching in undergraduate biology laboratory courses. The study further recommends the development of instruments that can be used across a range of courses and institutions in order to obtain some generalizable results. Following the above-mentioned line of argument, the puzzle in this study is how pre-service science teachers’ IBPW facilitation abilities can be assessed through alternative approaches to pen and paper examinations. Hence, in this study I recommended a tool that serves as an alternative to pen and paper examinations by answering the question, *How do physical sciences pre-service teachers use TSPCK to facilitate IBPW for learners?*

**LITERATURE REVIEW**

From the literature reviewed, inquiry is defined by a set of processes that constitute what it entails. Bell, Urhahne, Schanze, and Ploetzner, (2010) conclude that the process of inquiry is understood differently according to the emphasis put on certain processes. Bell *et al.* (2014) reviewed literature in order to summarise what they term main inquiry processes. These are (i) orientation/question, (ii) hypothesis generation, (iii) planning, (iv) analysis/interpretation, (v) model, (vi) conclusion/evaluation (vii) communication and (viii) prediction. The several processes encompassed in inquiry complicate the assessment procedures. Accordingly, the science curriculums may have to clearly spell out the inquiry processes for different school levels and tertiary programmes. Similarly, science curriculum implementation should take cognisance of how the inquiry processes can be assessed.

Sometimes, the implementation of inquiry learning may involve a whole set of supporting structures that include aligned assessment tools. Hofstein, Shore and Kipnis (2007) studied the opportunities to develop learning skills by implementing inquiry-type laboratory activities for some Israeli high school chemistry learners. The implementation of the inquiry-type laboratory activities was supported by the development of a set of inquiry-type experiments, assessment tools to monitor the learners’
achievements and progress, and a continuous professional development for teachers. In line with establishing support structures to ensure effective implementation of inquiry learning this paper explored the assessment of pre-service science teachers’ abilities to facilitate IBPW in the classroom. An assessment that is aligned to the learning of inquiry facilitation is important in the preparation of science teachers for practice.

From the literature reviewed, most of the studies focused on the assessment of pre-service science teachers’ and learners’ inquiry abilities through laboratory activities. The inquiry abilities assessed were varied since they focused on some and not all of the processes from the inquiry activities spectrum. Ozdem, Ertepinar, Cakiroglu and Erduran (2013) explored the argumentation schemes generated by pre-service teachers during an inquiry-based practical work activity. The study highlights the epistemic dimension of inquiry by noting that preservice teachers used different kinds of sources other than the observations to construct and explain scientific knowledge claims. Similarly, a number of assessment rubrics have been developed to measure students’ different inquiry-competences. Arnold, Kremer, and Mayer (2014) used an assessment tool that measured the students’ competences in designing experiments. The study concluded that scaffolding was necessary for the students to successfully complete some of the inquiry tasks such as the designing of dependent and independent variables and the designing of experiment procedures. In addition, Gobert, Sao Pedro, Raziuddin, and Baker (2013) developed an automated tool to measure the inquiry skill of designing controlled experiments. The assessment tool is able to give real-time, automated support and feedback as the learners engage in inquiry activities. Therefore, information and communications technologies (ICTs) can also be employed in the assessment of learners’ inquiry skills. The use of ICTs-based assessment tools for inquiry skills contributes to the generation of published assessment tools. Harrison (2014) developed and validated a simulation-based assessment of inquiry abilities (SAIA) which they applied to 48 Grade 12 learners at one high school. The study approved the assessment tool for criterion-related, construct and content validity.

The inquiry competences and levels of achievement have to be determined beforehand in the assessment tools. For example, the assessment rubric developed by Toth, Suthers and Lesgold (2002) measured students’ reasoning skills during a scientific inquiry using a number of pre-determined categories. The students’ performance and display of the different inquiry processes were coded as ‘not at all’, ‘some of the time’ and ‘always’. The rubric also included assessor comments on students’ improvement needs and their strong points. It follows that the assessment rubric is important not only for summative assessment but also for formative assessment. The assessment rubric was significant in that it spelt out the inquiry competences expectations that the students had to reflect on. The assessment rubrics that can be made available to the students at the time they receive an assignment on IBPW can be very useful in providing the competence expectations required.

There are some significant findings on some pre-service teachers’ abilities when engaging IBPW. I will discuss some findings from a few studies. Garcia-Carmona, Criado and Cruz-Guzman (2017) found that primary pre-service science teachers at a Spanish university struggled to complete scientific
inquiry tasks that included formulation of hypotheses, design of the experiment, data collection, interpretation of results, drawing conclusions. Talanquer, Tomanek, and Novodvorsky (2013) explored what pre-service science teachers prioritised when assessing the learners’ inquiry skills. It was found that the pre-service teachers focused on assessing process skills without paying attention to the epistemological validity or scientific plausibility of the learners’ ideas.

It has been established that learners and students need to be scaffolded when conducting inquiry-based activities. Kirschner, Sweller and Clark (2010) discuss why minimal guidance may not work when facilitating inquiry activities for learners if they have not yet developed sufficient prior knowledge. The prior knowledge will provide internal guidance (ibid). In literature, Arnold, Kremer and Mayer (2014) conducted a study to understand learners’ experiments by establishing the kind of support they need in inquiry tasks. The study concluded that the learners needed scaffolding when they are tasked with designing experiments. Similarly, in science education van Uum, Verhoeff and Peeters (2016) outline a pedagogical framework that can guide primary school pre-service teachers as they facilitate IBPW. The pedagogical framework which has four dimensions in the conceptual, epistemic, social and procedural may serve as a scaffold by way of providing guidance. This study explored the use of TSPCK by 34 physical sciences pre-service teachers during IBPW facilitation. In recognition of the importance provided by scaffolding or guidance in inquiry activities, this study further explored a rubric that may be used to both guide and measure pre-service teachers’ facilitation abilities.

THEORETICAL FRAMEWORK

**Topic specific pedagogical content knowledge (TSPCK)**

The study used a hallmark framework of pedagogical content knowledge (PCK) to understand teaching. The PCK theoretical model as pronounced by Shulman (1987) helps us analyse how teachers are able to transform the content knowledge so that it can be understood by learners. For science teaching Magnusson, Krajcik and Borko (1999) specify nine ways in which science teachers can transform the content knowledge to facilitate learning. The nine science teaching orientations have been placed in three groups by Friedrichsen, van Driel and Abell (2011). Firstly, there is a group of teacher-centred orientations in which we find approaches that are didactic and some that have a focus on academic rigour. Secondly, there is a group of orientations that are reform and curriculum projects-based. The approaches in this group focus on process, conceptual change, discovery and are activity-driven. The third group of orientations is based on current reforms and curriculum projects. The approaches contained in this group are the project-based science, guided-inquiry and open-inquiry. This study focused on the facilitation of inquiry-based activities in practical work which fall under the current reforms and curriculum projects according to the classification by Friedrichsen et al. (2011). From the literature review section, it could be seen that the inquiry processes in science can both be a method for learning and also a subject matter to be taught and learnt. The development of assessment tools to measure the learners’ abilities to engage in inquiry processes places inquiry
as a subject or content knowledge (CK). Since inquiry processes have to be learnt it follows that assessment tools that put particular emphasis on certain inquiry skills have to be developed. In this study the exploration of an assessment tool on how pre-service science teachers are able to facilitate inquiry through practical work required the understanding of how pre-service teachers were able to transform (PCK) the content knowledge (inquiry processes) so that they could be learnt in classrooms. On that note, Mavhunga and Rollnick (2016) assert that different science topics require specific PCK which is termed topic specific pedagogical content knowledge (TSPCK). The evolved theoretical framework has been useful in understanding how the effective teaching of certain science topics develops in teachers. Hale, Lutter and Schultz (2016) studied how graduate teaching assistants (GTAs) developed TSPCK in the teaching of thin layer chromatography. Both the inexperienced and the experienced GTAs were found to possess sound CK. In contrast, the inexperienced GTAs had low levels of PCK. However, experienced GTAs demonstrated higher levels of PCK suggesting that PCK is acquired over time. Similarly, Davidowitz and Potgieter (2016) confirm that unlike PCK, CK can be acquired with limited experience. However, it is asserted that sufficient CK is a premise for the development of PCK.

METHODOLOGY

A case study design was selected for this qualitative study. The use of multiple cases was a methodological choice according to Creswell (2007). The multiple cases for this study were made up of five lessons that were delivered to peers by the physical sciences pre-service teachers and the corresponding lesson plans. Creswell (2008) explains that several cases may be used to provide data that can be used to elucidate an issue. The five lessons (multiple cases) were used in an explorative way to develop an assessment tool that can serve both for assessment and as pedagogical guide for pre-service science teachers. Thirty-four 4th year pre-service physical teachers from both the Bachelor of Education degree (BEd) and post graduate certificate in education (PGCE) programmes agreed to be participants in this study resulting in convenience sampling. The pre-service teachers were requested to form five groups and three groups with 8, 7 and 6 members were formed by the PGCE participants. Two groups of 7 and 6 members were formed by the Bed participants. Data were generated when the groups of participants were requested to plan an inquiry-based practical work activity of their choice that was to be facilitated to the rest of the group members. One group member played the role of a teacher whilst the other members played the roles of learners. The lessons were video-recorded and handed over to the researcher together with the corresponding lesson plans. The groups were coded Case A, B, C, D and E by the researcher. Cases A, B and C were constituted by PGCE students and Cases D and E contained BEd students. The ‘teachers’ would be at times be referred to as Teachers A, B, C, D and E respectively.

Data analysis

The videos of the lessons were transcribed and researcher notes were also compiled from what was observed. Conventional content analysis techniques were used to make sense of the data. Since the
study was exploratory and in line with the multiple-case study approach, categories were not made beforehand but were allowed to emerge for each case. Ultimately a cross-case analysis to build broader themes was conducted. The in-depth approach to data analysis and the use of multiple cases were ways to ensure the quality measures of rigour and dependability during the processing of the data collected.

FINDINGS OF THE STUDY

The results are first presented on a case basis. After the cases have been presented according to their uniqueness, the results from the cross-case analysis were presented under broader themes. According to their uniqueness the cases were assigned with identifying tags that showed how the teacher sought to transform the CK for learner understanding. The cases are labelled as follows, Case A-the demonstrator, Case B-the ‘wow’ factor demonstrator, Case C-the relevance of science demonstrator, Case D-the transmitter and Case E-the facilitator.

Case A-the demonstrator

The topic of the lesson was written in the lesson plan as, “The use of the scientific method to show a chemical reaction.” Accordingly, Teacher A introduced the lesson in the following way,

During today’s lesson we will be looking at the reactions between acids, bases and neutral substances. We will be using the scientific method during the experiment to explain the different steps.

The teacher had put materials for the experiment on his table. He provided the investigative problem by formulating a question in the following way,

Will the reaction be different when using baking soda and vinegar instead of baking soda and water?

He asked the learners to provide a hypothesis of what would happen if he mixed soda and water, and also when he mixed soda and vinegar. One learner presented the following hypothesis,

Water will change colour from transparent to a white mixture. By mixing baking soda and vinegar a chemical reaction will take place.

Teacher A proceeded to conduct the experiment as a demonstration after explaining the importance of observing the safety precautions when working in a science laboratory. In a one-way discussion (teacher to learners) he showed how the results of the experiment confirmed the hypothesis. However, according to the lesson plan the lesson activities were supposed to unfold differently. According to the lesson plan the learners were supposed to actively engage in the inquiry processes. Below is an extract of the lesson plan with the lesson aims.

Lesson Aims for learners
  • Organise and manage themselves and their activities responsibly and effectively;
  • Collect, analyse, organise and critically evaluate information
Of the lesson objectives in the lesson plan only one was achieved. Teacher A allowed one of the learners to state the hypothesis. The lesson objectives were as follows,

Objectives
- Learners must be able to state a hypothesis
- Use the scientific method to do the experiment
- Formulate a conclusion about the results

Two of the objectives for the learners were not achieved. The learners were not given an opportunity to conduct the experiments and therefore they could not explore other inquiry processes. They did not get a chance to draw conclusions from the observations as this was done for them by the teacher.

Case B-the ‘wow’ factor demonstrator

Using a similar experiment to that used in Case A, Teacher B mixed vinegar and baking soda in a jam jar covered by a latex hand glove. CO$_2$ gas collected in the hand glove. As the gas filled the glove it got raised like a hand showing the five fingers. There was no learner participation. However, the lesson objectives suggested that the learners would participate actively in the inquiry process. Below are the objectives,

Specific objective (s) for the lesson:
- Learners must be able to master the following at the end of the lesson:
  1. Understand and practise the scientific method
  2. Formulate a hypothesis and test it
  3. Conduct the experiment and follow instructions
  4. Critically analyse and process data
  5. Understand chemical reactions.
  6. Apply sustainable chemistry and biochemistry

There was no evidence that most of the objectives intended for the learners were achieved except that teacher managed to impress on the learners by showing what happened to the glove as the CO$_2$ filled it.

Case C-the relevance of science demonstrator

From the lesson plan it could be surmised that Teacher C as in Case B considered the scientific method to constitute the inquiry processes. The teacher began the lesson by using a PowerPoint presentation to give an overview of how the experiment is conducted. The presentation included pictures of the steps of the experiment. The presentation was guided by the following introduction in the lesson plan.

Learners should be able to understand the reaction between carbonates and acids by applying scientific research methods. The problem must be identified by asking the question "do egg shells contain carbonates?" The problem statement is answered by practical processes eg. experiment. To [learners should] know where the skills learned are found [applied] in daily life. Understanding
the influence of acid rain on buildings. Solutions for problem. At the end of the lesson, the learner should be able to complete the activity [answer questions] on the worksheet.

After completing her exposition on how to conduct the experiment, Teacher C conducted the experiment as a demonstration. Efforts were made to achieve the expected outcomes as set out below without the learners engaging in any form of active participation.

Expected outcomes of the lesson:
Learners must be aware of:

- How does a scientific investigation work?
- The reaction between acid and carbonate.
- Examples of acids and carbonates.
- Egg shells contain a carbonate.
- Practical application: Cement contains carbonates therefore acid rain has a negative effect on buildings.
- Complete an activity [post-experiment questions on a worksheet]

This case was unique in that the teacher wanted to demonstrate the relevance of science in the learners’ everyday lives.

**Case D-the transmitter**

Teacher D started by reviewing ‘a previous lesson’ on how sound waves travel in different materials. The review was conducted as a one-way conversation in which the teacher recounted what was discussed in the previous lesson. The teacher was using the chalkboard to write some important facts that included the formula to calculate wavelength. Teacher D indicated to the learners that the topic of the lesson was “How to use an oscilloscope to analyse sound waves.” The teacher put on a video that explained how the analysis is done. After showing the video to the learners the teacher concluded the lesson by asking a question on the relationship between the pitch of a sound and the shape of the waves. There was no lesson plan submitted for this case. Teacher D merely used his exposition and the video to transmit knowledge to learners.

**Case E-the facilitator**

Teacher E introduced the topic of the lesson which was “Density”. He organised the learners in groups and set out materials on a table for them to use. The materials included, methylated spirit, canola oil, water, liquid dishwasher and sugar syrup. Learners took turns to compare the densities of the other four substances with that of water in a measuring cylinder as requested by the teacher. Learners were asked to report on their observations. It could be surmised as observed from the lesson video that the practical activity was about comparing the densities of the different liquids. Ultimately, the learners were requested to measure amounts of the five liquids, put them in one measuring cylinder, shake the mixture and leave it to stand for a few minutes. After settling the liquids were
floating at different levels. The learners were given an opportunity to discuss and record their observations.

This case study was one in which the teacher stuck to the script of his lesson plan which is described in the lesson plan except below. The except says,

Learner Activities:
Each learner [in the group] is expected to perform an experiment with two household fluids to determine its density (water + oil, water + dish soap, water + syrup and water + methylated spirit). Learners must ask what they want to test and make a prediction and draft a hypothesis. After learners have determined what they are going to test and put a hypothesis, they must physically perform the experiment and discuss and compare their results with their group members. The learners should then ask a question again about what the possible results will be if they add the various household fluids in a glass bottle. The learners should compile a hypothesis and illustrate their prediction by drawing a sketch. The learners should then perform the second experiment in group context, analyse the results and make a final conclusion. The final results must also be shown in the form of an illustration. Learners should then, after the experiment, draw up a short report on their findings. It is important that they follow all the steps of the scientific method in order to make a conclusion. In this way the learners have an overview of what the scientific method entails and knowledge about the density of different fluids.

The learner activities laid out corresponded with what the planned teacher activities as shown in the lesson plan excerpt below,

Teacher activities
The teacher must divide the learners into groups of four, after which the necessary material is provided to the learners. The teacher should briefly explain the density of the different fluids to learners. The density of a liquid will determine whether it will drift or sink. If the liquid drifts, it is less dense than the liquid in which it is placed. If the liquid is sinking, it is more dense [denser] than the liquid in which it is placed. After the teacher has explained the density quickly, the instructions for the experiment must be handed out and they should be explained exactly what is expected of them, such as the steps of the scientific method.

Unlike the previous cases, the learners were engaged in hands-on activities, worked in groups and were given opportunities to hypothesise (although the investigative questions were posed by the teacher), test their hypotheses, make and record their observations, discuss the observations and reach conclusions.

CROSS-CASE ANALYSIS

The cross-case analysis yielded four major themes. The four themes are as follows, (1) pre-service teachers possess the knowledge of the inquiry processes CK as the scientific method, (2) pre-service teachers possess limited TSPCK for IBPW facilitation, (3) ICT tools strengthened teacher-centred science teaching orientations and (4) Integrating socio-scientific issues in IBPW for relevance and implications.
Pre-service teachers possess the inquiry processes CK as the scientific method

The evidence presented in the cases above suggest that pre-service teachers are aware of some of the inquiry processes as defined by the scientific method. Cases A, B, C and E were very specific in mentioning that the learners must learn and practise the scientific method. In Case E the pre-service teachers made an effort to explain how the learners should learn and practise the scientific method. The extract from the lesson plan says,

During the lesson about density of different fluids, learners should execute experiments to learn the scientific method as an investigative method in science. Learners must follow all the necessary steps of the scientific method to make a conclusion in the end and to know about the different density of fluids. Therefore, after completion of the experiment, learners will be able to define density, determine the different densities [compare the densities of different liquids] and draw conclusions. Learners will also master all the steps of the scientific method.

Some of the inquiry processes that the pre-service teachers considered that the learners should be able to engage in were the asking of questions, predicting, formulating hypotheses, analysing results and drawing conclusions.

Pre-service teachers possess limited TSPCK for IBPW facilitation

According to the lesson plans the pre-service teachers displayed a CK of what constitutes scientific inquiry. Additionally, they considered that the learners were supposed to learn and practise the inquiry processes. However, in four of the cases A, B, C and D, there was a limited facilitation of the inquiry processes practice by the teachers. The evidence seemed to suggest that the pre-service teachers placed importance for the learners to be aware of the scientific method than for them to learn the inquiry processes through practice. In Case A, the learners were only allowed to state the hypothesis. However, in Case E the teacher not only gave the learners an opportunity to be hands-on but also to practise a number of inquiry-processes. The teacher provided the initial orientation for the inquiry and the steps of the experiment procedures.

ICT tools strengthened teacher-centred science teaching orientations

The integration of ICTs only worked to support the teacher-centred methods in Cases C and D. In Case C, the PowerPoint presentation was used to explain the experiment according the steps of the scientific method. The presentation included pictures of apparatus set-ups. In Case D, the teacher chose to play a video that showed the practical work activity. The video, the pictures and the PowerPoint presentation were not used in such a way that the learners could engage in some of the inquiry actions.
Integrating socio-scientific issues in IBPW for relevance and implications

There is evidence to suggest that the pre-service teachers consider it important to integrate some socio-scientific issues in IBPW. The use of household materials such as vinegar, bicarbonate of soda, eggshells, dish washer liquid, sugar syrup and canola oil is one way to observe sustainable/green chemistry as suggested by the teacher in Case A. In Case C the teacher emphasised the importance of showing the application of scientific phenomena in the learners’ everyday lives by explaining the implications of using building materials that contain calcium carbonate.

DISCUSSION AND CONCLUSION

The study set out to explore how pre-service teachers used their TSPCK to facilitate inquiry-based practical work for learners. The findings of the pre-service teachers’ use of TSPCK were used to suggest and recommend an alternative assessment tool to measure the pre-service teachers’ abilities to facilitate IBPW for learners. The possession of CK by pre-service teachers is an important premise for the development of PCK which is termed more accurately termed TSPCK (Mavhunga & Rollnick 2016). Likewise, in this study the pre-service teachers had a conception of the inquiry processes in practical work as the scientific method. The list of inquiry processes was limited to the following, asking question, formulating the hypothesis/predicting, analysing the results and drawing of the conclusion. Question posing was used by the pre-service teachers as way of providing orientation since this was conducted by the teacher. From the main inquiry processes by Bell et al. (2014) which are (i) orientation/question, (ii) hypothesis generation, (iii) planning, (iv) analysis/interpretation, (v) model, (vi) conclusion/evaluation (vii) communication and (viii) prediction, the pre-service teachers did not make reference to the processes of planning, communication and predictions made at the end of the inquiry process. However, the planning could be assumed to have been conducted by the teacher. The pre-service teachers demonstrated another form of CK. They were able to integrate some important current socio-scientific issues into IBPW. The issues included the practice of sustainable/green science by substituting chemicals that are difficult to dispose with household materials and the need to highlight the relevance of science to the learners’ everyday lives.

The pre-service teachers demonstrated limited TSPCK for the IBPW facilitation. The evidence was overwhelming because the teachers in four out of the five cases sought to teach the inquiry process through transmission modes. It was interesting to note how the displayed PCK was didactic and emphasised academic rigour according to science teaching orientations by Magnusson et al. (1999). Only one case demonstrated that the TSPCK has the potential to grow by being able to facilitate more inquiry processes for learners. Hale et al. (2016) claim that sufficient exposure ensures the development of TSPCK. Additionally, the ICTs (the video and the PowerPoint presentations) that were integrated in the IBPW were used to strengthen the teacher-centred science teaching orientations. The finding contrasts scenarios in which ICTs are used to enable the practice of inquiry through simulations for example (Harrison, 2014).
In the development of competences (categories) to be measured during IBPW facilitation by pre-service this study identifies two forms of CK. These are CK of science topics and CK for inquiry processes. The study also draws attention to two forms of PCK which are TSPCK addressing the CK of science topics and TSPCK addressing the inquiry processes in IBPW facilitation. In addition, to ensure successful classroom learning, the pre-service teachers needed the TSPCK to transform the CK through ICTs integration and the TSPCK to transform inquiry processes in IBPW through ICTs integration. From the findings the study suggests an assessment tool to measure competences and guide pre-service teachers during IBPW facilitation as a shown in Table 1 below.

Table 1: Inquiry-based practical work facilitation assessment rubric

<table>
<thead>
<tr>
<th>IBPW competence</th>
<th>Highest possible score</th>
<th>Not at all</th>
<th>Few times</th>
<th>Most times</th>
<th>Always</th>
<th>Assessor notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>CK for science topics</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CK for inquiry processes</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSPCK</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSPCK for IBPW facilitation</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICTs mediated TSPCK</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICTs mediated IBPW TSPCK</td>
<td>10</td>
<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

Key

Not at all: 0-1 marks out of 5 or 0-3 marks out of 10
Few times: 2-3 marks out 5 or 4-6 marks out 10
Most times: 4 marks out of 5 or 7-9 marks out 10
Always: 5 marks out 5 or 10 marks out 10

REFERENCES


TECHNOLOGY EDUCATION LONG PAPERS
ABSTRACT
The purpose of the study reported on in this paper was to answer the research question: To what extent is learner-centred education created on the Learning Management System (LMS) for first year programming subjects in an Open Distance e-Learning (ODeL) environment adopted by learners? The importance of this is justified in that the study responds to a call for improved learner pass rates, especially for Information Technology (IT) subjects offered in ODeL environments. A literature review drawing on the latest and most relevant research results on the topic investigates issues related to learner-centred education and open distance e-learning. The study is located within a relevant theoretical conceptual framework regarding LMS technologies, including learning units, announcements, discussion forums, online meetings, self-assessments, and blogs. The importance of issues of dependability and interpretation were considered in terms of the qualitative design used as research methodology. The discussion of the findings from the empirical research undertaken is based on the responses received from participants, relating to learner-centeredness and the adoption of LMS technologies. The paper suggests what the implications of the results could be for possible future use in these and related subjects. By contextualising the teaching approach in terms of the value of the findings, recommendations are made that are applicable and useful to the wider e-learning community, on the use of LMS tools in a fully online environment for the implementation of learner-centred teaching in a programming subject. In conclusion, the research question set for this study is answered. Proposed future research on the adoption of learner-centeredness makes an original contribution towards scholarly debates in the field, including for IT subjects presented in ODeL environments.

INTRODUCTION
Learners under investigation in the research reported on this paper study first year programming subjects, like ‘Introduction to Interactive Programming’, presented at an undergraduate level, which forms part of the first year of the Diploma in Information Technology (IT) at the University of South Africa (UNISA). On completion of these subjects, learners should be equipped with the knowledge, skills and values needed to develop a working website, as well as add interactive functionality through structured object-oriented programming. According to Frank, Lavy and Elata (2003), a social constructivist approach should be followed, which is learner-centred and requires learners to actively engage with their study material, as the subjects prepare learners for a particular vocation. The outcomes of the subject enable learners to show that they understand problem statements provided
by users in various industries, apply fundamental programming principles and JavaScript in the development of a working website, and use Web design tools to develop a solution to the satisfaction of the client.

UNISA invested quite heavily in a Learning Management System (LMS), called myUNISA, in an attempt to overcome some of the challenges faced in providing learner-centred education in an Open Distance e-Learning (ODeL) environment. The diverse learner population, with many historical, technological and infrastructural impediments, must always be considered when looking at the implementation and adoption of LMS tools for learner-centred education.

The research question being asked is: To what extent is learner-centred education created on the LMS for first year programming subjects in an ODeL environment adopted by learners?

Relevance to the themes of this conference, and potential usefulness of the content for the intended audience, lies in presenting original work. Similar to what was indicated by Goosen and Van Heerden (2017, p. 87), the significance of the paper results from “the research reported on in this paper” making a contribution to academic debate in the fields of ODeL and higher education, by closing gaps regarding quality research.

Similar to the purpose of the research reported by Goosen and Van Heerden (2016, p. 275), this paper relates to providing qualitative perspectives on e-learners’ uptake of LMS technologies towards effective teaching for e-learning, addressing challenges relating to an IT subject “taught in an online and open distance education context.” The objective of both studies was helping learners in accessing the assessment and support, which were provided via the LMS towards effective teaching for e-learning, thereby possibly improving the pass rates of the subjects. Qualitative findings will be presented on the LMS tools e-learners used, including to, for example, contact their e-learning teacher and tutors.

Statement of the problem

Programming is a complicated task that ought to be taught through the use of authentic exercises and including both supportive and procedural information. In the Computer Science field, few examples can be found of procedural information guiding learners in proceeding when solving a problem. Like Passier, Stuurman and Pootje (2014), such guidelines were therefore developed for JavaScript programming tasks. These IT subjects had, however, despite such measures, throughout the years had a very low pass rate, which is a worldwide concern in higher education computer programming courses.

The advantages and disadvantages of using virtual learning environment technologies towards effective teaching and meaningful e-learning, as well as for assessment purposes and to provide learner support, have been investigated widely by researchers, such as Wang (2014), Kidd and
Beaudry (2013) and Merchant, Goetz, Cifuentes, Keeney-Kennicutt and Davis (2014). The latter authors conducted a meta-analysis on the effectiveness of virtual reality-based instruction on learners’ learning outcomes in K-12 and higher education, while Kidd and Beaudry (2013) tried to understand learners’ online communication preferences and the affordances of VoiceThread for formative assessment towards effective online teaching.

Numerous articles have also been written about learners’ and computer lecturers’ perceptions regarding the successfulness of the implementation of virtual learning environments in education, by, for example, Greenland and Moore (2014). While the latter authors performed a preliminary exploration regarding patterns of learner enrolment and attrition in an open and distance e-learning context, this was conducted in Australia.

When one, however, starts looking for these topics, specifically related to an African context, and/or especially looking at the open and distance e-learning context, very little information can be obtained. The majority of the research, including, for example, Hanson and Asante (2014) and Halabi, Essop, Carmichael and Steyn (2014), was carried out with regard to face-to-face institutions of tertiary education, using a blended model towards effective teaching and meaningful e-learning. Although Halabi et al. (2019) found preliminary evidence of a relationship between the use of online learning and academic performance in a South African first-year institution of tertiary education subject, this was for accounting learners. From this, it becomes clear that there is no research available to specifically address first year programming learners’ uptake of virtual learning environment technologies in an open and distance e-learning context in South Africa.

There are several articles, for example Bubas, Coric and Orehovacki (2012), indicating the improvement in the performance of students taking programming modules when project-based learning and assessment, e-learning and support technologies are implemented for Information Technology. Bubas et al. (2012) studied the integration and assessment of learners’ artefacts created with diverse Web 2.0 applications.

**LITERATURE REVIEW**

Costa (2013, p. 267) stated that finding an operational definition of what learner-centred learning is, looks problematic and elusive. Learner-centeredness “is multidimensional, as it relates to” subject “design and implementation, selection of relevant curriculum suited to the likely” subject needs, organisation of subject “materials and delivery of” subjects, which comply to current knowledge about e-learning, assessment, which steer e-learning and achieving “sustainable motivation and engagement of” e-learners. This statement will now be unpacked in light of learner-centred learning and the use of LMS tools in an ODeL environment.

The Diploma in Information Technology is considered as vocational education, as it concentrates on teaching relevant abilities to learners, which sets them up for specific employment. Such
concentration on vocational preparation is customarily non-academic. When considering learning hypotheses, vocational educating would fall in the domain of constructivism, which is a learner-centred approach, requiring active participation by learners (Huang, Rauch, & Liaw, 2010). In subjects where the constructivist approach is utilised, learners are required to learn by doing, actualizing what they are realizing for all intents and purposes, being dynamic members in their learning, and creating answers for given scenarios.

Finding reliable and valid techniques for assessing programming subjects in higher education have consistently been an issue (Sheard et al., 2011) and this is particularly so at ODeL institutions. The essential objective of an assessment is to pick an evaluation strategy that assesses the outcomes of the subjects most effectively. The selection of assessment strategies must be aligned with the frameworks and prerequisites of the institution. In picking the assessment strategies for the subjects, the outcomes for the specific subjects, the more extensive points of the qualification, and the characteristics of the graduating learner were considered, including the frameworks and prerequisites of the institution. The present qualities and capacities of learners were likewise considered when the assessment instruments were chosen, and how these instruments could be implemented as teaching and learning instruments, rather than merely for assessment (Chun, 2010). The implementation of online assessments in an online situation is driven by time and financial imperatives, and, in addition, by the simplicity of setting up and regulating assessments (Bennett, Dawson, Bearman, Molloy, & Boud, 2017). Project-Based Learning (PBL) is suited for evaluating learning in programming subjects, since learners effectively take an interest, learn by doing, execute their learning and take care of real or recreated scenarios (Hayes & Offutt, 2010).

Worldwide, programming subjects experience high drop out and failure rates. Nikula, Gotel and Kasurinen (2011, p. 1) found that the “lack of extrinsic and intrinsic motivators contributed to the high dropout rates”. Castillo-Merino and Serradell-López (2014, p. 483) observed that motivation “is the most important driving force to explain” e-learners’ ability to pass examinations. The learning units, announcements, discussion forums, online meetings, self-assessments and blogs tools in the LMS were used extensively to motivate learners to actively participate in the learner-centred learning environment created. Time management have been identified as one of the factors negatively influencing learner motivation in learning (Willman et al., 2015).

THEORETICAL AND CONCEPTUAL FRAMEWORKS

Learning units
The subjects under investigation were designed using a blended approach, as defined by Lim, Morris and Kupritz (2007, p. 28). The first of three representative definitions identified for blended learning state that it is “a learning method with more than one delivery mode … being used to optimize learning outcomes and to reduce cost associated with program delivery”. A blend of printed material, the prescribed textbook and online delivery of subject material through the learning units is used. Some face-to-face and ODeL institutions provide learners with a printed study guide that supports
their prescribed material or serves as a ‘wrap-around’. The efficacy of such study guides was demonstrated a long time ago (Maxworthy, 1993) and are presently implemented using the Learning Units tool.

Announcements, self-assessments and discussion forums
The second representative definition identified blended learning as any mix of ‘lecturer-led’ “training methods with technology-based learning”, implemented in these subjects by using online announcements, self-assessments and discussion forums (Lim et al., 2007, p. 28). Jabeen (2015, p. 5) found that the “perceived effectiveness of weekly announcements were strongly correlated in terms of academic support.” Self-assessment as means towards learner-centred learning have been proven to facilitate learning for improving programming declarative knowledge (Matthews, Hin, & Choo, 2015). Shana (2009, p. 227) showed that e-learners “do better because they participate more and are more actively involved in” discussion forums. Such forums, however, cannot merely be set up, but have to be actively monitored, and quality feedback provided, in order to be effective (Nandi, Hamilton, Harland & Mahmood, 2015).

Vodcasts
The third representative definition provided for blended learning indicates the use of a “mix of traditional and interactive-rich forms of classroom training with any of the innovative technologies such as multimedia, CD-ROM, video streaming, virtual classroom, email/conference calls, and online animation/video streaming technology” (Lim et al., 2007, p. 28). Van Heerden and Goosen (2012) provided a number of advantages to using vodcasts to supplement teaching material, such as acquiring knowledge, adding to e-learners’ understanding and serving as a revision tool.

Practical assignments
Frank, Lavy and Elata (2003) looked at implementing the project-based learning approach in an academic engineering course, in terms of effectively teaching learners the concepts of object-orientated programming, so that they can write functional programs. Goosen and Van Heerden (2013a) correspondingly investigated how project-based assessment influenced the pass rates of an IT subject at an ODeL institution. Wang (2014) applied constructivist instructional strategies to e-learning in a case study of a web development subject.

RESEARCH METHODOLOGY
Similar to the paper by Goosen and Van Heerden (2015, p. 116), this section specifies “how the empirical research was undertaken”, along with the research method in terms of the design used. Although, as suggested by Babatunde and Low (2015), qualitative and mixed approaches were considered in terms of research design and methodology of the educational research by Goosen and Van Heerden (2017, p. 78), and they adopted “a non-experimental quantitative research design”, as recommended by Johnson (2014), a qualitative research methodology was required to complete the study reported on in this paper. The sampling procedure was opportunistic: all students registered
for the course at the time of the survey were invited to take part, with those willing to participate forming the sample, representing nineteen percent of the population, details “regarding the validity and reliability of the instrument and data analysis” were also provided. The strategy of inquiry followed was that of repeated cross-sectional studies, conducted to estimate the prevalence of the outcome of interest for a given population. In line with Johnson (2014), data were collected on individual characteristics, including risk factors, alongside information about the outcome.

Sarker, Tiropanis and Davis (2014) linked data, data mining and external open data for better prediction of at-risk learners. In line with suggestions by Sarker et al. (2014), in order to answer the research question, quantitative data were extracted from the institutional assessment database and the learner database.

For investigating the influence of various interventions for enhancing learner success, the journal article by Goosen and Van Heerden (2013b) described their methodology, with the data collection instrument used for the research reported on in this paper also including an online survey.

Enabled “by information that had been collected in an online” computer-aided e-learner assessment, a discussion of the findings by Goosen and Van Heerden (2015, p. 116) started with “demographic details in terms of the e-learner characteristics for the sample of 107 respondents from three different countries.” They provided “an evaluation of the usability of e-learning technologies found on the” e-Learning Management System (e-LMS), “and to what extent the e-LMS had been used to support” a particular subject.

A case study research design studies a restricted system (the so-called ‘case’), that employs numerous sources of data located in the situation. Both Greenland and Moore (2014), as well as Wang (2014), used case studies in their respective research efforts. In the project described in this paper, each case was selected for use as an example of a particular instance, representing this particular subject. Aspects of an interactive qualitative research design are also used in the form of a phenomenological study, which attempt to describe participants’ perceptions, perspectives and understandings.

Thematic analysis procedures and categorisation of data obtained from the survey were carried out.

**DISCUSSION OF RESULTS**

This section presents the results of the study in terms of the survey, including descriptions of the types of e-learning technologies used; each e-learning technology is presented in an own sub-section.

*Learning units*

The Learning Units tool serves as an online ‘study guide’ that can contain any type of resource to accommodate different learning styles to help learners progress through their prescribed material.
The 'Important Information' learning unit contains all the information that would normally be placed in a printed tutorial letter, such as the subject outcomes, lecturer contact details, prescribed book information, administrative information, assignment and examination information etc.

A ‘How to study this subject’ learning unit was created to specifically address the problems of learners, who have never programmed before. This information can, however, also be used by those learners who are experienced programmers, to reinforce and/or improve their own skills. In general, learners who have no programming experience do not understand that learning a programming language cannot be achieved through memorizing of theoretical concepts, but is rather learnt by practise. This section provides them with a quick ‘how to’ overview, links to resources they need to complete the tasks, where and how to ask questions, and how to go about assessing themselves.

For each chapter within the prescribed book, an individual learning unit was created. This can be equated to the printed study guide, with the difference being that it is somewhat more interactive. The first two sections of each Learning Unit provide the learner with an overview of the chapter, as well as the objectives of each chapter. Next is an approximate time layout of how much time should be spent on certain tasks in the chapter. Learners need to spend as much time on each of their subjects as they would if they were attending classes as a fulltime residential learner. Considering that the majority of learners doing the subjects are employed, time management is an important factor to success when studying in an ODeL environment.

Links to Open Education Resources (OERs) regarding a specific topic are also made available in the ‘Study Activity’. Considering the rapid changes in the World Wide Web (WWW) environment, these links provide the most up-to-date information regarding a specific topic. The ‘Additional Resources’ section in the Learning Units provides links to general OERs, which are related to the given chapter. Again, these are quite important in the field of study, due to rapid changes in the WWW.

Specific questions related to a chapter are provided to learners in each chapters’ learning unit, which are discussed in the Discussion Forum.

When the learner profile was considered, it became clear that, for the majority of learners, English is not their first language. In light of this, a glossary was created, with the assistance of the second author’s colleagues, containing keywords in each chapter, explained in English, Northern Sotho and isiZulu.

The final section in each chapter’s learning unit contains the assessment information for that particular chapter. This information pertains to self-assessments learners need to complete, where to find them, as well as where to find the answers to the self-assessments. It also includes information regarding learners’ formative assessments: where, how and by when these should be done.
**Announcements**

There are two types of announcements on the myUNISA LMS, with the first being pre-set announcements. These are announcements that can be set by the lecturer at the start of the semester and are then sent to learners automatically on a specified date at a specified time. The second type is the ‘just-in-time’ announcements, which are sent to learners when important information needs to be communicated at short notice. All announcements are sent to learners’ official university myLife e-mail accounts.

At face-to-face universities, lecturers provide learners with information on the work they will be studying during a particular week or on a particular day. On conclusion of a lecture or class, learners are required to self-study, complete homework, do practical work and/or they are assessed.

In the first week after registration closes, learners receive two pre-set announcements: the first is to welcome them to the subject and inform them of everything they need to get in place during that week, to start working on the subject. The second pre-set announcement tells learners a bit more about the myUNISA LMS and how the different tools in the subject will be used. After the first week, learners receive weekly announcements informing them of what they need to study during that particular week; these announcements include the self-study and assessment activities for the week.

**Discussion forums**

The Discussion Forum is similar to a ‘class room’ or ‘cafeteria’ area that residential learners use to communicate with the lecturer and fellow learners. Residential university learners attending face-to-face classes can raise their hand during a class, to ask a question regarding work they do not understand, which is not the case in an ODeL environment. The application of peer discussions in computing subjects consistently benefitted learners, and thus many universities incorporate such discussions as part of their teaching practices. The Discussion Forum technology in the LMS provides for an environment similar to this, offering learners the opportunity to create a knowledge community where they can share their learning programming experiences.

Specific topics related to specific learning activities are created; in these, learners can ask questions or add topics of their own related to the activity. Learners are also encouraged to share code on these forums when they are experiencing problems with it. Similar to face-to-face classes, all learners in a group benefit from the question asked by a particular learner, from answers supplied by the lecturer and guidance received from fellow learners.

The forums are monitored at least three times a day, every day, to ensure that learners who place a question, comment or query in any of the forums receive a quick response. This ‘quick response’ not only allows the learner to move forward faster, but also gives the learner the impression that there is no ‘distance’ in ODeL. It further shows learners that the e-learning teacher is interested in their studies, which, in turn, motivates them to participate. All negative, inappropriate, unsolicited and illegal posts (for example, sites where pirate copies of the prescribed book can be downloaded) are
also removed immediately. A learner who post such comments are contacted directly with stern warnings and referred to the information in the ‘Online Learning’ forum, which is dedicated to topics such as netiquette and being an adult learner. Learners on their part, mostly want to make use of the forums to create study groups; for that reason, a specific forum was created where they can ‘meet’ each other to create their study groups. All study group posts in other forums are removed, to ensure that they remain specific to the purpose they were created for.

In an attempt to inspire learners, a specific topic was created in the discussion forum, after assignments have been marked, in which the e-learning teacher lists the top performers in the subject - these are learners who achieved distinctions in their assignments. Learners get quite excited to find their names in the list and those who do not make the list can see that it is possible to achieve high marks, despite the heavy workload of the subjects. Learners who do not make the list are encouraged to work harder, so that their names can also appear in this list. Learners, who repeat these subjects, or who are registered for a different subject during a different semester, ask the e-learning teacher when she will be posting the top performers, to see whether they made the ‘cut’ in that subject.

**Vodcasts**

In an attempt to increase the uptake of the vodcasts, the normal internet link to Additional Resources was replaced by an image link to draw attention to the vodcasts. The number of vodcasts available for the chapter was included at the top to ensure that learners scroll down the window to view all the vodcasts available for the chapter. Instructions on how to go about downloading the vodcasts were also included in the introduction of the section. Learners thus do not need to be online to watch the vodcasts; they can download them and copy them to any of their devices to watch as many times as it takes for them to grasp a concept. After the learner has watched the vodcast, they must enter the code provided in their prescribed books and render the codes themselves. Should they experience problems with an activity’s code, the complete code for each activity is available in PDF format in the Additional Resources, for comparison.

**Meetings**

At residential universities, lecturers meet with their learner face-to-face a number of times during the week to present their classes. In an ODeL environment, this is logistically impossible, thus certain topics are selected, such as practical assignments and examination preparations, to be discussed in online meetings. In the myUNISA LMS, the BigBlueButton tool is used to facilitate such meetings. BigBlueButton is an open source web conferencing system for online learning, enabling academics to share documents (PDF and any Office document), webcams, chat, audio and the desktop.

This is probably the second author’s favourite tool on myUNISA to use, as it allows synchronised interaction with learners. Learners are able to attend the online meeting from any device, such as their tablet or cell phone, which has Flash Player capability.
As the e-learning teacher is aware that the majority of learners are part time and some of them only have access to the Internet at their offices, whilst others only have access from home, a UNISA computer lab or a Telecentre, four different time slots are arranged to have online meetings. These time slots are on a weekday morning, afternoon, evening and over the weekend. This results in four meetings per topic per subject, thus 24 meetings in total. The meetings are also recorded and made available as a vodcast for viewing for those who cannot attend any of the scheduled meetings. Feedback from learners, who attended the online meetings, were overwhelmingly positive and they indicated that it helped them in improving both their assignment and examination results.

**Self-assessments**

Programming learners need both theoretical, as well as practical, knowledge to be successful (Matthews et al., 2015). In order for a programming learner to apply specific practical concepts they have to understand the theory behind the concept. Learners should thus be assessed on both theory and practical aspects. Because of the practical nature of programming, learners are also prone to know how to implement practical concepts within a given context, without having the understanding as to why the concept works the way it works. If they do not understand the concept correctly, learners are unable to apply the concept when the context changes.

In an attempt to get learners to study the theoretical concepts, databases of multiple choice, fill in the missing word and true/false questions were created on the myUNISA LMS, using the Samigo tool, for each of the chapters in the prescribed book. The self-assessments were set up to create fifteen new questions from the database each time a learner attempts a self-assessment for a particular chapter. Learners can do the self-assessment for each chapter as many times as they prefer and feedback for each self-assessment is provided immediately upon submission. The feedback provided in the self-assessments for incorrect answers refer learners to the page number in the prescribed book where the correct answer can be located. This forces the learner to find the correct answer by having to re-read the section of work in order to facilitate learning through assessment, instead of merely giving the correct answer as feedback.

The self-assessments were created to provide learners with the opportunity to prepare for their assignments and their examinations. The same question pool is used in both cases, thus integrating formative and summative assessment. A further purpose of the self-assessments is to provide lecturers and e-learning tutors with the opportunity to identify learners who are not performing well. As an intervention strategy to improve assessment, learners who were not participating, or who under-performed in the self-assessments, were contacted and offered individual assistance. The statistical analysis provided by the self-assessment tool is also used to identify specific questions learners may experience problems with.
**Blogs**

With English not being the first language of communication for the majority of learners doing these IT subjects, the blog also allows them to improve their communication skills, especially in their field of study.

The blog assignments are meant to be fun, where learners get to have their say on what they have studied. For the assignment, learners need to write a blog on the work they studied in certain chapters. Learners are required to submit a single blog for every three chapters they covered.

This reflection must not be a summary of the prescribed book; it must be learners’ own reflection. After going through the chapter, the learner should close the book and then write down how they would go about explaining what they have just studied to a friend or family member. Lecturers and e-tutors use the blogs to gauge learners’ understanding of particular pieces of work and comment accordingly on the blogs.

The use of knowledge blogging in an ODeL situation is especially appropriate in early programming subjects when such blogging requests reflective activities and active engagement with the subject work. In particular, knowledge blogging are useful learning tools in the programming domain, since it advances metacognition and differentiated instruction by supporting numerous learning abilities (Van Heerden & Van der Merwe, 2014).

**CONCLUSIONS**

Goosen and Van Heerden (2016, p. 275) formulated recommendations with regard to theoretically improving the implementation of LMS technologies for effectively teaching an IT subject “in an online and open distance education context”. The implications for universities of such descriptions of LMS technology usage were also considered and discussed in the context of how reported usage informed and/or impacted on designing and implementing learner-centred and meaningful e-learning towards effective teaching with LMS technologies.

On embedding the virtual meeting technology in classrooms, like Wang and Lee (2013, p. 88), the authors concluded that in “an era of mobility and flexibility,” such e-learning technologies offered “an effective, affordable, green solution to many” of the challenges faced by today’s e-learning teachers.

The discussions are currently not compulsory and although some subjects within the university are already using the forums as part of their formative assessment, it does not yet form part of the requirements of these subjects. It is, however, another option of assessment that may be implemented in future.
REFERENCES


ABSTRACT
Technology teachers have been trained to use only western teaching pedagogies to teach design skills. This study sought to establish the role of other pedagogies such as culturally relevant pedagogy (CRP) in teaching design skills. The researchers used observations and interviews to collect data from Grades 7 – 9 Technology teachers. The four Technology teachers were interviewed in order to establish their beliefs and views about the role of CRP in teaching design skills. The participants were observed during their teaching design skills using CRP in order to find out the effectiveness of CRP. Qualitative methods were used to analyse data. The study found that the use of CRP can play a crucial role in the integration of indigenous knowledge (IK) in teaching design skills. The integration of IK through CRP can help motivate learners to acquire design skills. The findings also revealed that the use of CRP can enhance promote learners’ creativity. The observations showed that Technology learners are much captured in acquiring design skills when CRP is used to help learners to acquire design skills. The barriers to teaching through the CRP were discovered, such as Technology teachers’ inadequate knowledge of CRP and a lack of indigenous artefacts in schools. This paper concludes that Technology teachers should be conversant with the teaching strategies such as discussion and experiential teaching methods in order to be able to incorporate the CRP successfully in their teaching. This will help to achieve the main purpose of education in delivering relevant education for all learners.

Key words: Culturally relevant pedagogy, indigenous knowledge, design skills.

INTRODUCTION
The teaching of Technology mainly happens through the design process which pertains to the first of the three specific aims in the Curriculum and Assessment Policy Document Technology Grades 7 – 9. According De Vries (1996, p. 12), design is a key activity in Technology. The design process requires a specialised knowledge and a range of skills, e.g. processing, design, creativity, criticality, cooperation, collaboration, investigation, design, make, evaluation, communication and problem solving. These knowledge and skills should be applied in non-linear design stages of investigate, design, make, evaluate and communicate. The idea is for the learners to practically design, make and evaluate solutions to the technological problems from scenarios that a teacher could pose. DeLuca (1991, p. 2) states that design process is about ideation/brainstorm, identification of the possible solution, prototype and finalisation of the design. The end-product in a design project is an artefact which can be made from readily available (thrown-away) materials. However, indigenous scholars argue that
the concept of design resides in people and is therefore informed by culture (Micklethwaite, 2003; Moalosi, Popovich & Hickling-Hudson, 2007, & Moalosi, Selhatlhanyo & Sealets, 2016). With this said, the teaching of Technology to the predominantly indigenous learners in the South African context is skewed towards the non-indigenous approaches. Indigenous approaches could make a valuable contribution in the teaching and learning of the subject. Therefore, the study reported in this paper inquired into the teaching of Technology in the Senior Phase, i.e. Grades 7 – 9 from an indigenous point of view. Thus, the discussion in the paper focuses on the role that indigenous knowledge and skills can play in cultivating the design knowledge and skills in the intercultural classroom space which characterises the South African schools. Such pedagogical approach promises to offer multiple cultural lenses which are representative of the multicultural learner composition in the class, and which will enhance the understanding and relevance of the subject to the learners’ contexts. Shidza (2014) argues that pedagogies play a very crucial role in the learners’ academic performance and school achievements. The study has pertinent implications for the desired workforce of the future – artisans, engineers, architectures, etc who need skills such as cooperation, team work and collaboration, which the principle of botho/ubuntu can help cultivate in learners.

RESEARCH QUESTIONS

The main aim of this study was to determine the role that IK can play in teaching design skills in Technology Grades 7 – 9. The main research question is: What is the role that IK can play in teaching design skills in Technology Grades 7 – 9? The main research question is divided into two sub-questions:

- What do teachers see as the role of CRP in teaching design skills?
- What are CRP practices in teaching design skills?

THEORETICAL FRAMEWORK

Social constructivism

This study adopted the social constructivist theory in order to explore the role that IK plays in teaching design skills. This theory advocates that teaching by considering what learners already know can have a tremendous positive impact on promoting relevant education. Learners from indigenous African contexts possess a context-based and cultural knowledge, which is denied recognition in formal school settings. According to McNair and Clarke (2007), enabling learners to use their previous experiences can be a good starting point for design thinking. Bransford, Brown and Cocking (2004) concur that prior knowledge, skills, beliefs and concepts can affect learners’ abilities to remember, reason, solve problems and acquire new knowledge. Prior knowledge in this paper refers to the learners’ contextual knowledge, before the formal knowledge that they learn at school. The ability to link IK with the new situation may facilitate the acquisition of design skills in the learning of Technology. IK can play a crucial role in the acquisition of design skills in the Technology classes when
learners are afforded the opportunity to use it as prior knowledge to solve technological problems at hand.

The primary role of teachers should be to motivate learners to construct their own knowledge through their personal experiences (Weegar & Pacis, 2012). The best way to do this is when Technology learners are encouraged to relate their learning activities to IK. Turuk (2008, p. 247) states the constructivist theory emphasises the importance of what the learner brings to any learning situation as an active meaning-maker and problem-solver. This relates to the whole notion of constructivism, i.e. learners impose meaning on the world in accordance with their own unique experiences (Weegar & Pacis, 2012). In light of these assertions, Technology learners can use IK to connect to a new learning experience. They can use IK to design a new technological solution to a problem. The teaching of design skills in Technology should thus infuse IK in order to promote relevant learning to the learners’ cultural world. Bettencourt (1993) accepts that learners are like all human beings in that they construct knowledge from their experience, including their home and community experience.

Svinicki (1993) explains that when the new information gets hooked up with a particular rich and well-organised portion of memory, it inherits all connections that already exist. It follows that when learners learn new things which are similar to what they know already, they can easily remember them and enjoy learning. On the contrary, Svinicki (1993) argues that when a learner has nothing to hook new information to, he or she is obliged to use a rote memorisation of learning. In the context of the current developments in South Africa about decolonising education, it means that the teaching of Technology should be made relevant to the learners’ indigenous worlds. Applicable technologies and skills in such contexts can help enhance learners’ understanding of Technology. That is why technological learning activities should be linked to the things that are familiar to the learners. The familiar things can be anything that a learner has learnt from or can relate to his/her environment. It is imperative that Technology teachers should know the prior knowledge of learners so that they can design relevant lessons and employ suitable pedagogies. The next section discusses the CRP and other teaching strategies which can support it.

LITERATURE REVIEW

Culturally relevant pedagogy (CRP)

The acquisition of design skills in the Technology subject may be influenced by many factors such as the type of pedagogy, assessment, content modification, etc. One of the major factors which can influence the success or failure of learners to acquire design skills is the teaching methods that are not relevant to how learners learn in their own contexts. According to Shidza (2014), pedagogies play a very crucial role in the learners’ academic performance and school achievements. Technology teachers should be conversant with varied pedagogies in order to be able to select the suitable teaching pedagogies for particular learners. The usage of one-size-fits all teaching method is not
always successful as learners are human beings who will never be the same. Each learner is unique, therefore, Technology teachers should use different teaching methods in order to accommodate all learners in their classes. Teachers who aspire to be the best in delivering the relevant education should explore varied teaching methods in order to find the suitable teaching ones.

The CRP can play a role in assisting to solve the learning problems experienced by indigenous learners in Technology. Howard (2003, p. 196) defines CRP as an approach to teaching that incorporates attributes, characteristics or knowledge from the learner’s cultural background into the instructional strategies and course content in an effort to improve the educational outcomes. Technology teachers should be conversant with the CRP so that they can be able to accommodate learners from the diverse background. According to Biraimah (2016), in order to deliver quality, which we argue should be informed by relevancy, teachers need to understand and implement culturally relevant instruction. This implies a different view to the quality of education, that unless education and the methodology of teaching are jelled with the learners’ culture, it may just not be enough to talk about quality, no matter what aspect of education that may be applied to. Biraimah (2016) argues that culturally relevant instruction insists that all learners will achieve greater educational outcomes when the instruction includes and reflects their own cultural experiences.

Richter, Van der Walt and Visser (2004) advise that teachers should become more community conscious than in the past, while they simultaneously prepare to relate to the wider international and global community. A study by Wong and Siu (2012) reveals that Technology projects seldom link with the learners’ social and cultural backgrounds and seem to be irrelevant to their lives; this kind of projects might not be stimulating and interesting enough, therefore learners might lose their intrinsic motivation. Therefore, Technology teachers should give their learners projects which are related to their milieus in order to motivate them to learn new design skills. Howard (2003) asserts that one of the primary ideas behind the CRP is to create the learning environments that allow learners to utilise the cultural elements, capital cultural and other recognisable knowledge that they are familiar with to learn the new content and information in order to enhance their schooling experience and academic success.

Teaching strategies for promoting CRP

Social constructivism should be employed in education as part of a decolonial project. This claim finds tune with the fact that, in order to achieve the goals of educational transformation, one needs to consider the use of dialogic culture circles as dialogue encourages collaborative learning by limiting teacher-talk (Armstrong, Armstrong & Spandagou, 2010). Through the dialogic culture seems not a new idea, our view is that, considering the communal approach of indigenous African people towards life, one needs to employ it informed by the ubuntu principle or system. This means that teachers should make effort to learn about ubuntu and other dimensions of the educational philosophy from African perspectives. It allows learners to name their experience and encourages them to find their voice within the learning context. Morrow (2002) explains that dialogical education is contrasted with
This suggests that Technology learners can use discussion to learn from each other – discussion as facilitated from an ubuntu perspective.

Discussion promises to foster a spirit of social solidarity (Morrow, 2002) and can help Technology learners to work as a team and understand their different cultures. Klapwijk (2009) observes that although teachers ask learners questions, one can hardly speak of mutual dialogue. Specifically to South Africa, Venter (2004) advises that teachers should be assisted to broaden their cultural perspectives. Dialogue becomes one of the optimum strategies that Technology teachers can use to encourage learners to generate different ideas. In real projects are mainly performed by teams which contribute their varied knowledge and skills – Technology teaching should groom learners for collaborative engagements in the spirit of ubuntu (sharing, respect, caring, etc). Schiele (1994) indicates that the additional roles of the teacher, within an Africentric framework, would be that of an information provider and information receiver. It means that Technology teachers can exchange knowledge with their learners. They should give learners the opportunity to use IK in dialogues and learn from such dialogues. This will restrict Technology teachers not to act as paragons of knowledge which can make learners refrain from using IK to generating new ideas for solving a technological problem. Schiele (1994) explains that within an Africentric framework, learning is viewed as interdependent and bidirectional rather than independent and unidirectional. Technology teachers should be prepared to learn from their learners who come from different backgrounds. They should not undermine IK and other knowledges when learners are involved in design discussions.

METHODOLOGY

This qualitative case study investigated the role of the CRP in teaching design. According to Ritchie, Lewis, Nicholls and Ormston (2013), qualitative research aims to provide an in-depth and interpreted understanding of the social world of research participants by learning about the sense they make of their social and material circumstances, experiences, perspectives and histories. In qualitative research the views of participants are highly respected, thus the subjective views of participants in this study were solicited and highly respected. Hence, this study established the participants’ views about the role that the CRT can play in teaching design skills in the Technology subject. Purposive selection was used to select four participants for the study. All the four participants were teaching Technology and had a minimum of five years teaching experience in teaching Technology. Neuman (2011) explains that purposive sampling is appropriate to select unique cases that are especially informative. Since many teachers do not as yet have formal qualification in Technology due to its relative newness compared to other traditional subjects, the purposiveness of the study was based on selecting those teachers who have studied Technology as a major subject at the higher education institutions. The desire was for them to have acquired sound subject matter knowledge in Technology. Four participants were interviewed in order to establish their beliefs and views on the role that the CRT can play in teaching design skills. All the participants were also observed in practice. They were requested to use the CRT in teaching design skills. A brief discussion was held with them.
after the interviews to clarify teaching through CRP. Relevant guidance during the planning of the lessons was offered by the researchers where there was a need.

Fossey, Harvey, McDermott and Davidson (2002) posit that participant observation is used to learn about the naturally occurring routines, interactions and practices of a particular group of people in their social environments. According to Gay, Geofrey, Mills and Airasian (2011), in participant observation the researcher participates in the situation while observing and collecting data on the activities, people and physical aspects of the setting. The researchers actively participated in using IK to generate ideas for producing a technological product. The researchers’ participation helped them to understand how IK can assist learners to develop design skills in Technology classrooms.

**Trustworthiness**

The researchers used triangulation and member checks to ensure the trustworthiness of this study. For Snape and Spencer (2003), triangulation involves the use of different methods and sources to check the integrity of the collected data. This can be done by using different sources of data or research instruments (Anney, 2014), in this case interviews and observation. Triangulating the data sources and methods permits the comparison and convergence of perspectives to identify corroborating and dissenting aspects of the research issue (Fossey et al., 2002). The participants were requested to verify if the collected data indeed represented their views. Billups (2014) agrees that at the end of an interview, the researcher can summarise what has been said and ask participants if the notes accurately reflect their position. This was done by consultation with participants to see if the analysis resonated with their views (Given, Winkler, and Willson, 2014).

**Ethical matters**

The two overriding rules of ethics are that participants should not be harmed in any way physically, mentally, or socially as Wiersma and Jurs (2009) advise that the researcher is obligated to protect participants from risk. The participants in this study were protected from any physical, social and psychological harm. Strict adherence to asking the participants questions which they were comfortable with was ensured. During observation the classroom space was not altered to avoid any possible physical harm. According to Welman, Kruger and Mitchell (2010), the respondents should be given the assurance that they would be indemnified against any emotional harm. Neuman (2011) advises that a sensitive researcher should be aware of harm to a person’s self-esteem. The disclosure of the purpose of the study, confidentiality, anonymity, etc. helped to set the participants at ease. Welman et al (2010) state that the researcher should obtain the necessary permission from the participants after they were thoroughly informed about the purpose of the interview and the investigation. All the participants were informed about the purpose of this study and signed a consent form about data collection. The consent form included the purpose of the study, a statement of voluntary participation, information about the confidentiality of the study and the option to withdraw their participation from the study at any time without penalty. All the participants
volunteered to take part in this study, were duly informed from the outset about the voluntary participation and withdrawal at any point and were assured anonymity and confidentiality (Hancock & Algozzine, 2011). They were thus coded as G7TP1, G8TP1, G9TP1 and G9TP2. GTP stands for Grade teacher participant.

FINDINGS AND DISCUSSION

The researchers used field notes to collect data from the interviews and observations. The field notes were transcribed verbatim. Themes were decided by the researchers guided by what the data were showing them and in response to the research question. The findings are presented under such themes subsequently.

CRP as a teaching strategy to integrate IK in teaching design skills

The researchers asked participants to give their views about the CRP in an attempt to gain insight about their understanding of the relationship between the CRP and the teaching of design skills. They described the CRP as a teaching strategy which can be used to accommodate different cultures in learning. In their own words, the participants stated: “CRP can be used to include African knowledge in teaching design skills” (G9TP1), “It is the teaching that does not discriminate other existing knowledge” (G7TP1), “It is the teaching that can treat all knowledges as equal in classrooms” (G9TP2). By way of describing the CRP, the participants’ views show that the CRP can be used as a vehicle to integrate IK, thus transforming the teachers’ teaching to acknowledge other knowledge systems in the teaching of design skills. These views support the work of Rosa and Orey (2010), who claim that the CRP is a teaching style that validates and incorporates students’ cultural background, ethnic history, and current societal interests into teachers’ daily instruction.

The participants indicated that allowing other knowledge systems can help learners in acquiring design skills. The participants criticised the use of the teaching strategies which do not promote the use of IK in teaching design skills, “Technology teachers should find some other ways of teaching which will enable them to use IK” (G8TP1). G9TP2 concurred by stating, “Technology teachers should try to use learners’ knowledge from their communities for teaching design skills.” It can be noticed from these views that the participants regarded CRP as a catalyst for integrating other knowledge systems such as IK. This finding is in support of Young’s (2010) claim that in general, the students’ cultural capital is the means to build learning on their personal experiences and to make the curriculum meaningful to them. The CRP is accommodative of this as it can provide space for the expression of the knowledge, skills and values that Technology learners bring to the classroom. This makes the CRP a necessity in the teaching of design skills.
The role of culturally relevant pedagogy in teaching design skills

The data were also analysed to establish the role of the CRP in teaching design skills. Three sub-themes emerged from the interviews: (1) CRP motivates learners to learn, (2) CRP promotes creativity and (3) CRP ensures relevant education through using the appropriate teaching strategies.

**CRP motivates learners to learn**

The participants were requested to explain the role of the CRP in motivating learners to learn and acquire design skills. The participants believed that the CRP can indeed motivate learners to learn in Technology classrooms in the sense that it can boost the learners’ concentration and interest during teaching and learning. The participants believed that the integration of IK through using the CRP can also help to maintain learners’ attention during teaching. G8TP1 said in this regard: “I think this culturally relevant pedagogy can help these learners to listen when we are teaching. Sometimes our learners do not pay attention even though we always try our best to motivate them to learn.” G7TP1 concurred with G8TP1 in claiming that learners do not listen because they are bored, unlike when one talks about the knowledge that they know. G8TP1 stated, “When I teach them about design skills which are related to the indigenous skills they will be captivated to listen”.

The views of the participants seem to support Brown-Jeffy and Cooper (2012) who state that teachers’ recognition of learners’ desires to learn about things beyond the classroom can have tremendous power to motivate and invite learning. Only G9TP2 held an opposing view about the role of the CRP informed by the thinking that the learners of this age are much interested in learning about western knowledge. This participant indicated further that the only way that can make IK to be accepted as western knowledge is to change the mind-sets of learners through its inclusion in the Television programs. G9TP2 said: “IK will not be accepted by learners due to its status in learners’ minds. The negative attitudes toward IK will demotivate learners to concentrate in learning. The learners will think that they are being taught the knowledge which is not important.” However, this participant advised that Technology teachers should start by explaining to learners that IK is also equivalent to western knowledge in order to change their negative attitude towards IK. The observations seemed to confirm the idea that that the CRP can motivate learners to learn as it turned out that Technology learners were eager to learn as they listened with keenness to know and were even asking their teachers questions to when the CRP was used.

**CRP promotes creativity during the teaching of design skills**

The participants’ views revealed that the CRP can promote curiosity in Technology learners to learn and encourage them to creatively solve the technological problems from their prior knowledge – being comfortable in using the knowledge from their contexts can nurture creativity. TP1 stated that: “When learners are allowed to use different knowledge systems to solve a technological problem, ultimately these learners will generate different ideas without any limitation”. According to G9TP2,
allowing learners to use their prior knowledge can enhance creative thinking skills. The participants’ views are consistent with the work of Rosa and Orey (2010) who reveal that the CRP builds on and values cultural experiences and knowledge of all learners and empowers them intellectually by using cultural referents to impart knowledge, skills and attitudes. The participants’ views were congruent with the conducted observations during which the researchers noticed that Technology learners were more active in generating new ideas to solve the given problem scenarios when teachers were using the CRP. The learners were responsive and willing to solve the existing technological problem together.

Promotion of relevant education through using appropriate teaching and learning methods

The findings revealed that the CRP can enhance relevant education through the usage of appropriate teaching methods. The relevant teaching and learning methods can help Technology learners to acquire design skills. The participants indicated that Technology teachers should use relevant learning methods such as discussion and experiential learning. According to the participants, the CRP can allow learners to discuss about different skills which can help to solve technological problems, e.g. time management, design, evaluation, cutting, etc skills. From the interviews it emerged that when learners discuss ideas they will be able to use their prior knowledge as they seek new ways to solve the existing technological problem. For example, G9TP1 stated that: “The discussion method will allow learners to compare different ideas, compare existing knowledge, indigenous skills and knowledge in order to invent new products.” The observations confirmed that the discussion teaching method can enhance the acquisition of design skills. Almost all the learners were very active in discussion when they were allowed to discuss ideas for solving the technological problems using all knowledge systems at their disposal. The responses are consistent with Beagle (2015:54) who found that discussing issues is an authentic learning experience because the skills used and practised in the classroom are directly applicable to real life situations.

The participants also indicated that the CRP can allow Technology teachers to use experiential learning for promoting the acquisition of design skills. They indicated that experiential teaching will allow teachers to give learners the technological problems from their own context. The participants believed that learning new things in context can simplify learning for Technology learners. G7TP1 said: “Technology teachers should be taught design skills in real context.” G9TP2 shared his views about teaching abstractly: “When you teach Technology in an abstract context which learners are not familiar with you are confusing learners. Only few learners can be able to grasp your lesson; Technology is practical.” The practicality of Technology also found mentioning by G8TP1, “design skills are practical, they should be acquired by practice in a real context”.

The findings reveal that Technology learners should be given problems which are related to real problems experienced by indigenous people in their communities. This finding is consistent with Taylor (2018, p. 61) who states that the CRP has the potential to bridge the cultural and experiential divide. Young (2010) agrees that teachers who practice the CRP engage learners in critical thinking.
and utilize real-life examples to help learners understand the difficult concepts. The current study found that acquiring design skills in different contexts, particularly the context which learners are conversant with, can promote the smooth acquisition of design skills.

The barriers to teaching through CRP

Teachers’ inadequate knowledge of CRP

The participants were requested to explain the barriers for teaching design skills through the CRP. The participants expressed their concern about their inadequate knowledge in the CRP. They stated that they were not well conversant with the use of the CRP in practice. They claimed that they had never been trained to use the CRP. G8TP1 said in this regard: “I have not received any training about CRP. I am just learning to implement it on my own.” G8TP1 raised a concern, “when we attend district meetings we are told to integrate IK, but we are not told how and which method to use.” The findings show that that Technology teachers are not trained to integrate IK in teaching design skills, consequently they are not able to implement the CRP in teaching design skills. These findings support the study by Maluleke (2013) which revealed that Technology teachers who are conversant with different teaching methods can challenge their learners to use higher order thinking skills. The researchers opinionated that being conversant with the varied teaching methods helps teachers to accommodate other knowledge forms and learners’ diverse learning cultures.

Lack of indigenous artefacts in schools

The participants expressed a concern that there is lack of indigenous artefacts in their schools. According to them, lack of indigenous artefacts hampers the use of the CRP in Technology classes. TP4 substantiated this view by stating that “even if you want to show learners any indigenous artefact in order to motivate them to see how indigenous people use their skills to make products, you are limited as you will never get a single indigenous artefact here.” G9TP2 stated: “...You know in our school we do not even have a single indigenous object. We have got a lot of western objects that we can use to teach Technology, but I have never seen indigenous objects here”. The participants complained that lack of indigenous artefacts in schools has a negative impact on learners thereby making them develop the attitudes towards the CRP. They suggested that indigenous artefacts should be provided in schools in order to promote teaching through the CRP in Technology classes. G8TP1 said: “I believe that the use of indigenous artefacts can help learners to value IK in schools.”

CONCLUSION AND RECOMMENDATIONS

The findings of this study have shown that CRP can play a significant role in teaching design skills in the Technology subject. The CRP can be used to promote the use of different knowledge systems in teaching design skills. Technology learners can also be allowed to use their IK in solving technological problems. This study found that the knowledge and skills that learners bring into their classrooms
can be used to simplify learning. Technology teachers are advised to consider other knowledge systems than western knowledge because if these other forms are used correctly, they can facilitate meaningful learning. This study found that the CRP can play a role in motivating learners to concentrate and learn in their classroom. As inclusion of the CRP can simplify learning, all learners will be motivated to learn ultimately. The use of the CRP can also promote creativity. This study found that Technology learners who are allowed to use their background knowledge which includes IK in acquiring design skills can generate many ideas for solving technological problems. The findings have shown that many teachers are not conversant with the use of the CRP, and are not able to integrate IK in their teaching of design skills consequently. When teachers taught through the CRP they realised the desired interest, active participation, creativity and passion to learn in learners. Learners were interested in Technology lessons which integrated IK. The researchers recommend that the Department of Basic Education should make effort to train Technology teachers in CRP. Technology teachers’ workshops should also train them on IK and its integration in teaching Technology and be offered a continuous support. Further research is recommended which looks tracking the performance of learners who are taught through the CRP and lessons which integrate IK.

REFERENCES


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