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Theme: Pursuing sustainable and inclusive quality education through research informed practice in Mathematics. Science and Technology

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Message from the SAARMSTE President 2018

A conference does not just ‘happen’… Thank you to the University of Botswana LoC under the chairpersonship of Alex Nkhwalume – and all those unsung heroes who have quietly gone the extra mile to make SAARMSTE 2018 a memorable experience. Thank you to the SAARMSTE Executive Committee for a year of dedicated hard work and friendship.

We are privileged to welcome to Botswana plenary speakers of international renown:

- Celia Hoyles; UCL Knowledge Lab, University College London;
- Kgomotso Garegae, University of Botswana;
- Merrilyn Goos, University of Limerick, Ireland;
- Fred Lubben, University of York

I am sure that we will be enriched by their wisdom and wealth of research experience.

In order to maintain an institutional memory, the SAARMSTE Proceedings for the last 20 years have been saved on to the CASIO memory sticks which have been given to each delegate at the 2018 conference.

This year the Executive has sponsored three emerging researchers to attend the conference in Botswana and Taylor & Francis has provided funds for an award for the best article published in AJRMSTE during 2017 by an early career researcher.

Although this conference is the culmination of months of planning and hard work, the Executive Committee has reached many milestones:

Ken Ngcoza has been a strength, inspiration and support as President Elect this year.

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.

Hamsa Venkat and her Research Capacity Building Committee worked with Washington Dudu and Percy Sepeng from North-West University to arrange another inspiring Research School in North West Province mid-year. Merrilyn Goos and Frackson Mumba participated as expert international facilitators. Doctoral researchers continue to offer very positive evaluations of the Research School, with many returning as graduate alumni – a fitting tribute to the developmental and collegial environment that has been built and sustained over time.
Tulsi Morar has kept SAARMSTE finances in check, so that we can celebrate achieving the milestone we set ourselves two years ago. SAARMSTE is becoming self-sustaining...

Mike Mhlolo and Audrey Msimanga keep the Chapters up to date with events and activities. Chapter activities included two well-presented and attended colloquia – Eastern Cape; Annual conference in collaboration with the DBE – North West Province; Involvement in National Assessment Report and Current Trends Research – Mozambique.

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.

The theme of this year’s conference: “Pursuing sustainable and inclusive quality education through research informed practice in Mathematics, Science and Technology” underlines the importance of research intertwined with practice. We look forward to discussing, debating and sharing ideas and experiences in the warm and nurturing environment of the SAARMSTE family.

Welcome to beautiful Botswana!

Lyn

Hamsa  Audrey  Ken
Venkat  Msimanga  Ngoza

Mike  Tulsi  Carolyn  Fred
Mhlolo  Morar  Stevenson-Milln  Lubben
Reviewing Process for Long Papers 2018:

All 6 000 – word long papers were reviewed by at least two external reviewers. Reviewers were selected from the list of reviewers for the African Journal for Research in Mathematics, Science and Technology Education (AJRMSTE) published by Taylor & Francis. Other recognized researchers in the field of Mathematics, Science and Technology Education were also approached to be reviewers.

The reviewers’ suggestions were considered by the members of the Review Panel. Where there was consensus, the reviewers’ recommendations were accepted by the Review 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 provide a compelling argument for no further revision.

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

L. Webb

Lyn Webb
SAARMSTE President
Saarmste Long Paper Reviewers 2018:

The SAARMSTE Executive thanks the following long paper reviewers for their time and expertise:

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Guidelines for paper submission for SAARMSTE 2018

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 1 500 word short paper, authors may elect to develop their research further into a 3 600 word paper which will NOT be reviewed but, after consultation with the editor, could be published in the Book of Short Papers.

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 the 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.
CODE SWITCHING AS A TEACHING STRATEGY: WHAT ARE THE IMPLICATIONS FOR MATHEMATICS TEACHING IN MULTILINGUAL CLASSROOMS?

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ABSTRACT
The teaching of mathematics in many South Africa’s classrooms is affected by the language teachers use during teaching because the majority of learners in these classes are taught in neither their first nor second language. As a result, teachers use the learners’ first language through code switching to enhance communication and understanding of mathematical concepts during teaching. This paper explores current mathematics teacher code switching practices exhibited in three Eastern Cape grade 11 multilingual classes in South Africa. Data were collected through observations and interviews while these teachers were teaching trigonometry. Quantitative and qualitative methods were used to analyse data. This paper found that observed teachers borrowed terms significantly during code switching. Results also indicate that teacher code switching for explaining concepts was consistent and precise in some cases, and in some situations, it was not. Deliberate steps will need to be taken to orient teachers to develop and understand a mathematics register in languages other than English and Afrikaans in South Africa. This paper concludes that research and discussions centering code switching should shift into seeking ways in which teachers can be trained and assisted with how, when, why, and where to use code switching more strategically. This will foster more informed teacher code switching practices in mathematics education that will help to ensure the sustainability of quality teaching and inclusivity of marginalized township and rural schools.

Key Words: Code Switching; Multilingual; Consistency; Precision

INTRODUCTION
The language used to teach mathematics remains an important component in the development of mathematical understanding and proficiency. The teaching of mathematics in many South Africa’s classrooms is affected by the language teachers use during teaching. This is because the majority of learners in South Africa’s classrooms are taught in neither their first nor second language. The Language of Teaching and Learning (LOLT) chosen by the majority of township and rural schools is one in which learners are not adequately proficient. As a result, teachers use the learners’ first language as a resource for enhancing communication and understanding during teaching. One of the goals of mathematics teaching is to promote successful communication and grasp of mathematical concepts by students. The use of languages
other than the LOLT in the teaching and learning of mathematics to provide learners with access to mathematical concepts has gained much attention in research over the last three decades. This phenomenon is much more prevalent in countries like South Africa where teachers are teaching in a language that is not their first language nor is it the students’ native language. Studies have shown that a lack of adequate proficiency in the LOLT is a primary obstacle for successful learning of science subjects (Halai, 2009) such as mathematics. Teachers in multilingual classrooms have come up with language innovations and strategies to aid conceptual understanding and access to mathematics.

One of the strategies is code switching, defined by Adler (2001) as “the use of more than one language in the same conversation” (p. 73). It is argued that code switching occurs naturally and spontaneously in settings where the speakers share two languages (Sánchez-Martín, 2013; Coronel-Molina & Samuelson, 2017). In the school settings, code switching exists in classrooms where the LOLT is not the learners’ first language. Cook (2001) contends that teaching methods that enable the teacher to use learners’ first language and the LOLT concurrently (for example, incorporating code switching) create particularly authentic learning environments. With code switching being a natural way bilinguals communicate (Coronel-Molina & Samuelson, 2017), and most of the world becoming multilingual (Halai, 2009), coupled with factors associated with globalization and migration of people within countries and beyond countries and continents, the use of more than one language in speech in daily lives has become a common phenomenon. However, use of two or more languages through code switching during teaching of mathematics needs further investigation especially considering that the mathematics register is not formally developed in indigenous languages such as isiXhosa in South Africa. This paper (a subset of a bigger study) focusses specifically on the concept of code switching as it is practiced in situations where the mathematics register is not developed in the learners’ first language. We answer the following questions: How do teachers code switch into a language whose mathematics register is not developed and formalized? How precise and consistent is their chosen vocabulary in code switched forms? What are the implications of legitimizing language strategies like code switching to the teaching and learning of mathematics?

FUNCTIONS OF TEACHER CODE SWITCHING IN THE MATHEMATICS CLASSROOM

Teachers code switch in their classrooms consciously or unconsciously in the interest of conveying concepts in a meaningful way. Research has shown that there are legitimate reasons, advantages and disadvantages to teacher code switching (Coronel-Molina & Samuelson, 2016; Modupeola, 2013; Sánchez-Martín, 2013). Baker (1993) and Ferguson (2003) acknowledge that the functions of code switching are infinite hence, it is not possible to compile an exhaustive list of these functions. However, such functions may be broadly classified in various ways due to a significant degree of similarity of these functions in various studies. One way is to use five categories suggested by Baker (1993). These are code switching for pedagogic and curriculum access reasons, communicative functions of code switching, code switching for social
reasons, code switching for classroom management purposes and code switching for identity purposes. In this paper, our focus is on the first two functions.

**CODE SWITCHING FOR PEDAGOGIC AND CURRICULUM ACCESS REASONS**

The key role of code switching is to provide access to mathematical content through scaffolding mathematical knowledge construction for learners whose first language is not LOLT (English). Üstünel and Seedhouse (2005, p. 308) observed that “teachers code-switched from English to Turkish in order to deal with procedural trouble, clarify meaning by providing the Turkish equivalent, encourage and elicit learner participation, elicit Turkish translation, check learner comprehension, and give meta-language information.” Thus, teachers’ main reason was to provide learners with access to mathematical concepts during teaching.

According to Baker (1993), teachers use the learners’ first language in the second language classroom for three macro-functional categories of code switching. These are firstly for pedagogical access purposes, secondly to maintain social interaction with the students, and thirdly to manage the classroom. Code switching can be used to explain content and check that students have understood that content under discussion (Ferguson, 2003). Nzwanga (2000, p. 85) in her analysis of three teachers’ use of learners’ first language in the college classroom, code switching was found to advance the following functions: “translate, practice discovery and rote learning, explain/expand a teaching point, bridge communication gaps, and enhance students’ reflection”. Cook (2001) suggests that because the first language is always present in the learners’ mind, its role in the classroom might have positive effects on learning and teaching as a way of conveying meaning in the second language. Nzwanga (2000) suggested that enacted teaching methods should incorporate the learners’ first language to encourage meaningful teaching and learning in those classes where teachers and their students regularly employ the first language.

Many researchers especially in mathematics teaching and learning advocate providing access, inclusiveness and equity in education. Teacher code switching in many mathematics classes is and has been found to be motivated by the need to provide curriculum access to learners. Researchers have identified different purposes for code switching. Probyn (2006), Ferguson (2003), and Metila (2009) for example, noted that teachers would code switch for explaining and clarifying lesson content. Mafela (2009) found that Botswana teachers in a History class would code switch to clarify particular points on a matter they thought could be better explained and understood in Setswana. Probyn (2006) also found teachers code switching to negotiate lesson content and to provide students with examples from their familiar day to day environments. Setati et al. (2002) in her study noted code switching for building up learners’ understanding of content matter. Mafela (2009) also observed that teachers used code switching “to make understanding easy, to facilitate understanding of concepts and terms of the subject” (p. 68). This reiterates with what Gulzar (2010) found, that teachers would code switch to assist their learners in interpreting subject matter and confirming that they had
understood what was explained. In all the above examples code switching is intended to assist learners access to the teacher’s input and thereby promoting learning with comprehension. What is however not so evident in these studies is analyzing access to content in situations where learners’ first language does not have an officially developed mathematics register.

COMMUNICATIVE FUNCTIONS OF CODE SWITCHING

Teachers’ ability to communicate in a way that students understand increases effective learning of intended concepts. Some researchers (Moschkovich, 2013; Üstünel & Seedhouse, 2005) regard use of two languages through code switching in content subjects such as mathematics and science as an interactional resource that teachers and students use to understand each other. Code switching as purported by Genesee et al. (2004), is a communicative resource available to all multilinguals. Üstünel and Seedhouse (2005) explain that code-switching is routinely used as an additional meaning-making resource within the ongoing flow of classroom talk. Metila (2009) noted that teachers and students would code switch from English to Filipino for various communicative functions. These include code switching for easier self-expression, for communication that is more effective and the ability of code switching to provide an idea’s equivalent term in the other language during problem solving.

In much research on code switching functions, researchers focused mainly on the communicative functions of teacher code switching in the classroom. Halai and Karuku (2013) identified communicative strategies that teachers in Tanzanian multilingual mathematics classrooms used during teaching. They noted that teachers’ code switching was used for various reasons such as explaining concepts, asking questions, managing classroom behavior of students and for qualifying key components of a phrase or sentence in a mathematics problem.

Gardner-Chloros (2009) presents five communicative functions of code switching as for translation, for we code, for procedures and directions, for clarification and for checking understanding. Gulzar (2010) noted that of the eleven functions of code switching that he examined in Pakistan, teachers code switched most for clarification, ease of expression, giving instructions effectively, creating a sense of belonging, checking understanding and translation among others. One major conclusion of Gulzar’s (2010) study was that “… the teachers do not know about the limits of the use of code switching and for which functions they can/should code switch to cater for the needs of the students” (p. 38). Gulzar (2010) encourages well planned and systematic use of code switching because insensible use of teacher code switching can have long-lasting harmful ramifications on the students’ learning in a multilingual classroom.

Probyn (2006, p. 403) found Grade 8 teachers “switching to IsiXhosa if they saw the learners were not understanding a concept or a word.” These teachers also used code switching for question tags such as ‘neh’ [okay] and ‘andithi’ [Isn’t it so] among others, as attention checks and for confirmation purposes. According to Modupeola (2013), the learners’ first language was used for checking comprehension, finding out whether or not students understand a word, phrase or sentence used either by the teacher or in a
given activity. Thus, teachers used first language of learners to elicit knowledge from the students. A study by Then and Ting (2011) in which Malaysian English and Science teachers were interviewed, found that the teachers viewed code switching as helping their students to understand terminology and concepts as well as the instructions pertaining to classroom instructions.

In these cases, the teacher’s goal in classroom communication is to make sure pupils have understood what the teacher intended to put across. Setati et al. (2002) adds that code switching by the teacher is used to support classroom communication and exploratory talk. To this Mafela (2009) concluded that code switching has the potential to add value to the quality of classroom talk enabling content knowledge dialogue and transmission.

**CONSISTENCY AND PRECISION**

Mathematics employ **consistent** words and symbols to ensure precision of expression as loss of precision is always risky and might lead to difficulties of adjustments later. **Consistency** in this study means invariability in frequency of code switching into the vernacular (IsiXhosa), uniformity of repeated use of terms, accuracy of translation into the vernacular and lack of ambiguities and contradictions in translated terms. **Precision** means the use of terms and symbols, consistent with mathematical definitions, in ways appropriate for students at particular grade levels (Ball et al., 2005).

**THEORETICAL FRAMEWORK**

This study is informed by aspects of socio-cultural theory as envisaged by Vygotsky especially the critical role of language in communication and cognitive development. Vygotsky’s (1978) theory emphasizes the social environment as a facilitator of development and learning. Socio-cultural perspectives enable viewing language backgrounds of teachers and pupils as a resource for teaching and learning Mathematics (Moschkovich, 2013). The socio-cultural aspects of Vygotsky’s theory illuminate the point that learning and development cannot be dissociated from their context. The social environment influences cognition through its “tools”, that is, cultural objects, language, and social institutions. According to Vygotsky (1978), people use psychological tools—signs, symbols and conventions that have been socially negotiated- to engage and understand their environments. People think and perceive things in a way made possible by the vocabulary and phraseology of their language, hence, concepts that cannot be encoded in their language will not be accessible to them, or at least will prove very difficult (Bodrova & Leong, 2007). Learning then is seen as internalization which is the transformation of communicative language into inner speech and further into verbal thinking (Vygotsky, 1978).

Orton (2004) emphasizes that language used for thinking is almost certainly the first language. Thus mathematics communicated in one language might need to be translated into another to allow thinking and then translated back in order to converse with the teacher. Vygotsky thus, perceptively observed that language forms do not replace one another but coexist in the human mind (Bodrova & Leong, 2007). Vygotsky’s theory
enables exploring issues of learners’ first languages as used to teach trigonometry through code switching in the mathematics multilingual classroom.

SAMPLE AND RESEARCH PROCESS

This study used a case study approach, which enabled us to gain a detailed view of teacher code switching practices manifested during teaching trigonometry in multilingual classrooms. Data were obtained through observing and interviewing three grade 11 mathematics teachers purposively selected from three schools in the Eastern Cape Province. Each teacher was observed for five consecutive lessons in a week teaching trigonometry. The lessons were video recorded. At the end of each lesson, each teacher was interviewed.

The videos were transcribed and analysed first, quantitatively for consistency in the frequency of code switching into IsiXhosa across teachers, using lesson categories developed from the works of Gumperz (1982) and Mercer (1995). The lesson categories were: response to student contribution (RC), questioning (TQ), teacher explanation (TE), classroom assessment techniques (CA), evaluative remarks (ER), and class management talk (CM).

Two overall teacher code switching practises emerged. These were referred to as borrowed code switching (BCS) and transparent code switching (TCS). Data was further analysed for consistency in these two practices.

**Borrowed Code Switching Strategies (BCS)**

BCS is where a teacher borrows from the English language either by retaining the English spelling or by adapting the phonology of the borrowing language (Baker, 2011) in this case IsiXhosa. Two forms of borrowing code switching were noted:

Transliteration (TLT) where nativisation of existing English language mathematical terms was done that involved giving an IsiXhosa spelling and pronunciation to English terms (Barton, Fairhall and Trinick, 1995). For example *drawisha* (draw) and *mascalculateni* (let’s calculate).

Loan word borrowing (LWB) when teachers borrowed from the English language retaining the spelling, meaning and pronunciation of the word (Baker, 2011). For example, *i-period ye-Tan graph* (period of Tan graph).

**Transparent Code Switching Strategies (TCS)**

TCS is where the meaning of the term was not concealed but noticeable, self-evident and transparent to students (Meaney et al., 2012). Four forms of TCS as adapted from Gauton, Taljard and De Schryve (2003) emerged in this study.

Semantic Transfer (SST)-Code switching where a new meaning, and/or additional more technical meaning, was attached to existing words by modifying their semantic content. An example is *sombulula* that has more than one meaning but here it means ‘solve’.
Paraphrase (PAR) - Code switching that was a short description or explanation of the word derived by putting together related words or unrelated words (Baker, 2011). For example *amacala mane* (quadrilateral).

Compounding (COM) - Code switching where a term was coined by combining existing words to form one word (Meaney at el., 2012). An example is *umgca engeko goso* (straight line).

Ready Translated Equivalent (RTE)- this refers to all situations where there was no problem of non-equivalence at word and/or phrase level between source (English) and target language (IsiXhosa) because IsiXhosa already possessed ready equivalent of the English term (Gauton et al., 2003). Example include *bala* (calculate), *lingana* (equal), *ubude* (height).

Data was further analysed qualitatively for consistency and precision of IsiXhosa terms that teachers used during teaching.

**DATA ANALYSIS AND DISCUSSION**

**Teacher code switching across lesson categories**

The three participating teachers’ code-switching frequency across lesson categories was examined to determine their language use patterns. As indicated in Figure 1, during the teaching of Trigonometry, all teachers used isiXhosa predominantly to ask questions: TQ – (A-31%, B- 40%, C-37%); and for the purpose of explaining concepts: TE – (A-45%, B-39%, C-42%).

![Figure 1: Comparison of Teacher Code Switching Across Lesson Categories](image)

It is apparent that the consistency of the frequency of code switching into isiXhosa across the teachers for TQ and TE respectively varies. The teachers’ explanations were mostly done in two languages as indicated in Figure 1. This warranted further analysis of teacher explanation as indicated in the sections below.

During this quantitative phase, data was further analysed for consistency in BCS and TCS.
As indicated in Table 1 and Figure 2 teachers predominantly used the LWB (A-65.3%; B-67.2%; C-67.9%) strategy throughout the five lessons. The greater part of the mathematical talk in IsiXhosa was through borrowing (LWB). This was where teachers would attach prefixes to already existing English mathematical terms, for example, *le-parallelogram, i-quadrilateral*. All teachers consistently used the borrowing strategy (A-69.8%; B-75.9%; C-88.7%) throughout the teaching of trigonometry more than using the transparent code-switching strategy (A-20.2%; B-24.1%; C-11.3%). Most of the borrowing was for explaining trigonometric concepts and posing questions.

The classroom use of RTE strategies suggests that there are mathematical words that exist in IsiXhosa. Moreover, because the teacher is using such terms in the classroom, means they are of the students’ IsiXhosa dialect or they are familiar to these students. Examples of such terms used by the teachers included *fumana* (find), *bala* (calculate), *kuqala* (first), *zoba* (draw), *Krwela umgca* (draw a straight line), *dibanisa* (add), *cala* (side), *lingana* (equal to). In the interviews, Teacher A explained that the students and
the teacher use these terms in daily life. These same terms/phrases have a technical or mathematical meaning. On checking the meaning of these terms, it was noted that they retain their mathematical meaning of their English equivalents.

Very little transparent code switching, which according to Meaney et al. (2012), supports students’ understanding and thinking in mathematics, was evident in the observed teachers’ language practices. The quantitative results suggest that, because most of the observed code-switching practices are not transparent, the intended outcome of quality learning is compromised. Prevalent borrowed code switching, which apart from the added prefixes, are words in English does not provide learners with clues, hints or access to mathematics concepts. As shown in Figure 1, most of the code switching was for explaining concepts. We examine teacher explanation further to determine whether these explanations were consistent and precise.

TEACHER EXPLANATION

During teaching, all teachers used explanation more often as compared to other lesson categories (see Figure 1). Most of the teachers’ code switching was done when teachers were explaining concepts to their students. In this section, we focus on instances when teacher code switching for explaining concepts was consistent and precise, and those situations when it was not. We focus only on a few examples of each of the four situations identified.

Consistent and precise teacher explanations in isiXhosa

Though not widely practiced, we noted instances across all teachers where the use of isiXhosa was consistent and the corresponding translation precisely done. In the extract below, we consider Teacher B’s use of the term ‘identity’:

Teacher B: Ikhona (is there an) i-identity eniyibonayo pha (that you can see) heee heee /yes/ yeyiphi le (which one is it) identity eniyibonayo pha (that you can see), okanye aniyazi kwa eza, zintoni ezi kuthwa (or you don’t know what identities are) zi-identities /yes/ yes yes any identity there, ikhona i-identity oyibonayo pha (Lesson 4).

The key word in this part of the teacher’s explanation, ‘identity’, is being used consistently in English except for the prefix. This word has a different meaning in daily life from its mathematical use. In everyday life ‘identity’ means personality, character, singularity or distinctiveness. In mathematics, it means identicalness, congruence, sameness, interchangeability or parallelism. This was considered as the teacher’s way to minimize the risk of losing the meaning of this key word. The teacher maintained the borrowing strategy instead of finding its Xhosa equivalent.

There were some instances when teachers maintained precision and consistency in isiXhosa translations during their explanations. While these were not frequent, they were evident. In the explanations below, Teacher A and Teacher B consistently and precisely used the word fumana (find) across lessons for example.
In the discussion above, teachers used two strategies to maintain precision and consistency in their language. Firstly, by borrowing, which was commonly practiced by all the teachers in all their lessons. Borrowing was practiced with symbols (for example $u-AD$, $ku-AD$) and words such as $i$-focus, $i$-triangle, singam-calculator. Two forms of borrowing were evident, loan word borrowing (LWB) and transliteration (TLT). These teachers frequently used LWB as opposed to TLT. This involved adding a prefix to an English word.

Secondly, consistency and precision were maintained by isiXhosa terms that had ready translation equivalent (RTE). These everyday words used for mathematical purposes were however not commonly used during teaching.

**Consistent and imprecise teacher explanations during code switching**

The focus in this section was on those situations where the teacher would consistently use his or her own imprecise translation during explanation. The use of the esoteric language of mathematics during explanations of key concepts is crucial for modelling the correct language that pupils are required to use. In the extract below for example, Teacher B is emphasizing the need to make AC the subject of the formula. He uses the word ‘isolate’ which he translates to abeyedwa.

**Teacher B:** You need to isolate $u-C$ nhe, la-$AC$ funeka abeyedwa (we want to isolate AC) (Lesson 1).

**Teacher B:** Sifuma ashiyeka yedwa (we want to isolate AC) $u-AC$ apha akunjalo (here isn’t that so) (Lesson 1).

**Teacher B:** You solve for AD, what is AD? How do you solve, besithe senza njani kanene, apha sifuma $u-AD$ abe yedwa nhe (what did we say we do, here we want AD to be on its own) (Lesson 1).

While the English term ‘isolate’ was not precise, it was translated consistently. Isolation is separation, distancing, set apart, keep in solitude. ‘Isolate’ does not fully express the equality or identity form that needs to be maintained. The term ‘isolate’ leaves out the idea of two sides of an equation that must be kept equal and only focuses on separating or distancing. The result is an incomplete concept being emphasized to students. Teacher B was consistent with the use of an imprecise term. This was so in three of his
lessons. In the last extract above, Teacher B repeats the question in isiXhosa and adds an explanation too in an effort to make it clearer.

**Inconsistent and precise teacher explanations in isiXhosa**

There are terms that teachers translated and used precisely but inconsistently when they were explaining concepts. Teachers in this study used precise translations of a given concept once or twice and resorted back to the English form of the word or concept. The translated form was not used again throughout the lessons or across lessons. Some cited examples are shown in the extracts below.

Teacher C used the word *uzizobela* (draw for us) which is in a RTE form. It is used in daily life of the teacher and the pupils but not for scientific or mathematical purposes. But in this case the translation was precisely done. It was only used in one lesson.

**Teacher C:** *So one full Tan graph nantsi* (here is the) *i-shape yayo, xa uzigobela yona yiponge* (when you draw it) *(Lesson 5).*

In other lessons, the teacher used the English word ‘draw’ and not the word’s isiXhosa equivalent. For this same activity, Teachers A and B used different terms, for example, *krwela mgca* (draw a line), *masiploteni* (let us plot) and *drawisha* (draw). This then implies that there was no consistent use within and across teachers.

**Teacher C:** *afuna bani apha, masithi ufumene* (what are you looking for, let’s say you got) *u-Sin x is equal to 0.8222 whatever stuff it is nhe wafuna* (then you solved for the) *i-arch angle le ka Sin* *(Lesson 4).*

The word *wafuna* here is used to depict solving as the focus was in finding the arch angle. ‘*Funa*’ is an everyday word used for scientific purposes in this particular case. This is the only instance it was used to imply solving. In other occasions ‘*funa*’ was used to mean want, look for and need. While the translation in this case was precise, the teacher exhibited inconsistent use of the term.

**Inconsistencies and imprecise teacher explanations in isiXhosa**

In this section, our interest was on those cases when the terms used were both imprecise and used irregularly during teaching. In the extract below for example, calculate and solve were in some cases used inconsistently and inaccurately by the teachers:

**Teacher A:** *Kuthwa masi calculate-e u-x phayana, bendithe izolo* (we are asked to solve for x, I told you yesterday) *(Lesson 4).*

Teacher A is saying we are asked to calculate x, which has been translated to mean ‘solve for x’. The teacher uses ‘solve’ and ‘calculate’ interchangeably. While this was common with Teacher A, the word ‘solve’ which she later gave during interviews as ‘*sombulula*’ in isiXhosa was more appropriate. In other lessons, *bala* was used for calculate and in other instances, ‘borrowing’ was used. This was also evident in Teacher C and Teacher B’s lessons. Thus, there was no consistency nor precision in the choice of isiXhosa words for these concepts.
Teacher C: *Isiphinto ethi kengoku uba sifunu* (this gives us the direction that if we
are looking for) “h” as the subject of the formula *siza cross multiplya akunjalo* (we
will cross-multiply isn’t it)? (*Lesson 1*).

Teacher C is using the phrase ‘subject of the formula’ which is more precise. Teacher
B used ‘isolate’ which is not very precise mathematically and Teacher A used
‘transpose’. There is no consistency amongst teachers in the use of the term make
subject of formula.

Teacher C: *Ekuqhibeleni u* (in the end) “h” will be $H = c \cdot \sin A$. Can you see now?
That represents *kanye le value ka* (precisely the value of) “h”. *Apha ngoku
asisabhali “h” si za bhala bani, ngubani u “h” wethu ngoku?* Ng (in this slot we no
longer write “h” what do we write, what is our “h” now? It is) C. Sin A (*Lesson 1*).

The teacher is explaining that ‘h’ is now replaced with its calculated value. Instead of
saying *asisabhali* (we will no longer write), the teacher would have used ‘substitute’ to
make this more mathematical. The language used by Teacher C is in everyday form.
Substitution concept is one of the major concepts that is a prerequisite at upper
secondary school. Thus, if teachers are cautious in their explanations to make such
concepts explicit, understanding during teaching and learning would be enhanced.

Teacher C imprecisely and inconstantly used the code-switched forms of the term
‘calculate’ (*bala*):

Teacher C: *Masiiye 3minutes, 3minutes. Ndiyabala ke mna ukuqala ngoku. Nina
nenzu number 2, nenzu number 2 kuyo yonke le exercise. So, nina nenza anything
engu number 2* (So you, let me make this easy, we need to hurry up, hurry up, hurry
up, 3 minutes. Let’s move, 3 minutes, 3 minutes. I am counting the minutes starting
now. This group you work on number 2 in each exercise. There are three questions;
your responsibility is to work on number 2 in each). (*Lesson 1*).

Teacher C: *Xa u bala u zayibalela apha lento* (when you calculate, you will calculate)
using your calculator, isn’t it? Using your calculator. (*Lesson 1*).

Teacher C: who is sharing the same problem Qhayi is calculating, over to you
Qhayi, bala ithini i-answer yakho (calculate, what is your answer)? (*Lesson 4*).

The word *bala* in the first extract is used to refer to ‘counting’. In the second extract
*bala* is used to mean ‘calculate using a calculator’. This is not a precise translation and
hence inconsistent use of the word. ‘Using a calculator’ was referred to as ‘cofa’ by
Teacher B and this is more precise. In the third extract *bala* is used to mean ‘calculate’.
There is an inconsistent use of *bala* by Teacher C in his explanations. These extracts
were taken from three different lessons hence such an inconsistent use was across
lessons. While *bala* was also used by other teachers, its use was varied.

Code switching during teacher explanation was extensively practiced (see Figures 1 &
2 above). Some terms were consistently used and precisely borrowed while some were
not. Even some everyday terms adopted for mathematical purposes were used
consistently and in some cases inconsistently. In some cases where code switching was
precise, its use was inconsistent. Results demonstrate lack of uniformly principled use
of code switching during teacher explanation.
IMPLICATIONS OF CODE SWITCHING FOR MATHEMATICS TEACHING

In South Africa’s classrooms where both the teacher and the learners share a common language, code switching is used as a linguistic feature, which potentially aids teaching and learning. Code switching practices that are now common practices by teachers are no longer considered as ‘smuggling the vernacular into the classrooms’ (Probyn, 2009, p. 123). Thus, with code switching practices now wide spread and enjoying official sanction and legitimacy in South Africa (Adler, 2001), and teachers using it more frequently, South African multilingual mathematics classrooms need to find rigorous and practical ways of carefully incorporating this resource in the teaching and learning process. Adler (2001, p. 85) concludes that “it is not a matter of whether or not to code switch, nor whether or not to model mathematical language, but rather when, how and for what purposes.” Discussions centering on code switching should shift into seeking ways in which teachers can be assisted with the how, when, why and where of this strategy.

The training of teachers for multilingual classes is considered here as one factor that needs careful review. Currently, the implementation of multilingualism in the classroom, through code switching, is left entirely up to the teacher. It is the teacher’s decision to ascertain when, how and where to code switch. Essien (2013) argues that the current state of affairs in teacher training institutions assumes that teachers trained in English will recontextualise what they have learnt into a different linguistic context at the end of their qualification. With the teacher language practices we have observed in this study, and what other research studies (Essien, 2013; Probyn, 2015; Wildsmith-Cromarty, 2012) have found, such an assumption does not suffice.

We advocate for structured pre- and in-service teacher code-switching courses for teachers of learners who are not yet proficient in the language of instruction. Probyn (2015) concurs with lack of proper teacher training and a clear official position on code switching:

In South Africa, although there has been an unofficial drift towards recognizing code switching as a valid classroom strategy, there is little training that guides teachers towards a coherent systematic approach to using both languages in classroom in ways designed to enhance opportunities to learn (p. 220).

Understanding the mathematics register in one language does not necessarily mean that one understands mathematics in another language. The inconsistent and often imprecise use of code switched terms cited in this paper illustrates the need for the development of a mathematical register in isiXhosa to enable teachers to code switch appropriately to the learners’ first language. Deliberate steps will need to be taken to train teachers to use and understand the mathematics register in languages other than English and Afrikaans in South Africa. Wildsmith-Cromarty (2012) recommends that teacher training needs to be conducted in a bilingual institutional context to enable teachers to use indigenous languages for instructional purposes. Accepting and legitimising code switching practices as a teaching resource should be accompanied by training teachers on the appropriate use of these practices.
CONCLUSION

In this paper, we have noted that while most researchers have argued that multilingualism and the occurrence of code switching in multilingual classrooms is potentially a resource and an advantage for teaching and learning mathematics, more is still required for this to realize its intended benefits. Current code-switching practices, that are characterized by predominantly borrowing and less transparent code switching, have less benefit to the teaching of specialized subjects like mathematics. Informed teacher code switching practices in mathematics education is required in an endeavor to pursue sustainability of quality teaching and inclusivity of marginalized township and rural schools.

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ABSTRACT

A key challenge for task design in mathematics education and in STEM education more generally, is to design to enhance engagement with mathematics for all. One way to achieve this is to exploit digital technology to reveal more of what mathematics actually is; first, by offering a glimpse of the mathematical models underlying a given (and carefully chosen) phenomenon; and second, by fostering an approach to mathematical tasks that transcends the purely procedural. We describe in this paper how we have attempted to address these challenges in two research projects.

BACKGROUND

A key challenge for researchers in mathematics education and in STEM education more generally is to design schoolwork to enhance engagement with core knowledge for all learners and to widen access to these key disciplines. For mathematics the overarching and enduring challenge is the invisibility of the subject. Most people just do not understand what the subject is about and why they are studying it for so many hours over so many years. So we would argue that to increase engagement with mathematics, we need to design tasks that tackle this invisibility, and one way to do this is to embed digital technologies which allow dynamic and symbolic manipulation of the key variables, thus opening new windows on the knowledge at stake.

A common theme for research in task design with digital technologies is that learning evolves in ways that are contingent on design. We follow a programme of design research (Cobb et al., 2003) with a theoretical framework underpinning the design of the activities presented to the students, and the fine-grain HCI of the software. Our designs were driven by the theoretical framework of constructionism, which argues for learning by building and sharing with computer tools (Harel, 1991). But as we shall see, there is much to elaborate about the complexities of the design process. In Noss and Hoyles (1996), we argued that there is a complex relationship and mutual influence of tool and knowledge. We argued that digital tools – particularly those symbolically represented - shape mathematical learning as students ‘think with and through the tool’, constructing what we termed “situated abstractions”. Reciprocally, the tools are themselves shaped by the context of mindful use (for a related discussion of the idea of mindful engagement with technologies, see Salomon et al., 1991). It is not only that digital technologies add new representations or link old ones; research is increasingly coming to recognise that digital representations change the epistemological map of what
it is intended to teach and learn, so open up disciplines to more learners Kaput & Roschelle, 1998). In a complementary strand of research, this process has been described as one of “instrumental genesis”, whereby artefacts are transformed into “instruments” - systems with which the user gains fluency and expressive competence (see Verillon & Rabardel, 1995). Our common vision is that computational tools are a means by which new mathematical meanings can be developed but in so doing, the role of the tools in shaping meanings must be acknowledged. Building on this framework, Olive & Makar (2010) propose technology as a fourth vertex for Steinbring’s “didactic triangle” (Steinbring, 2005), in order to illustrate how the interactions among student, teacher, task and technology form the ‘space within which new mathematical knowledge and practices may emerge’ (ibid. p.169).

Significant progress has been made in designing sets of digital tools (DTs) or “microworlds” embedded in activities through which to pursue mathematical learning goals, taking on board the framework of DR, where the iterative development of the microworld is considered as a piece of DR in itself (Drivers & Trouche, 2008). In this sense, microworld design is an incubator for developing and researching radical approaches to innovative mathematical learning that enhances motivation and engagement. As Hoyles & Noss (2003) put it, a powerful way to think about the microworld idea is a vision in which “software tools and knowledge would grow together interactively in the pursuit of epistemologically rich goals” (ibid. p. 3).

As well as the evolution of design research there has been a parallel evolution of task design research. In her editorial for the recent ICMI book, Watson & Ohtani, (2015) make the point that few studies justify task choice or identify what features of a task are essential and what features are irrelevant to the study. We agree. This is what, we presume, Papert had in mind when he criticised the more general field of mathematics education research for not allocating sufficient energy to consider the ‘what’ rather than merely the ‘how’ of teaching, where all participants were encouraged to reflect on the 10% of knowledge that would need to be rethought given the use of new tools. This was later abbreviated to ‘Papert’s 10%’. Many of us have continued to struggle with this challenge.

Thus, we note that in the domain of mathematics and DT, the task, its design and the software are all at the forefront of the collective design research effort, and highly visible. This is hardly surprising, as the enterprise of the design of digital tools focuses closely on identifying and expressing mathematical concepts in novel ways, e.g. dynamically rather than statically. In this paper, we present some theoretical and practical exemplars arising from two design research projects that have scaled out to hundreds of schools, which together illustrate our approach. Both projects iteratively designed a network of tasks (rather than just one of two tasks) that embed digital technology. For the purposes of evaluation of the classroom implementation, we designated some tasks as “landmark activities” to be used as a “framework for action” in the DR and as a focus for our data collection in the implementation phases of the DR.
The first example derives from the *Cornerstone* project\(^1\), which seeks to exploit the dynamic and visual nature of DT to stimulate engagement with mathematical ways of thinking about core mathematics topics among students aged 11-14 years. The second example, the *ScratchMaths* \(^2\) project explores the role of programming in mathematical learning among younger students (age 9-12), with an emphasis on promoting mathematical reasoning for all by making the process more visible and tangible.

We provide a brief outline to the idea of landmark activity, and how it plays out in the context of design in terms of the anticipated learning goals, and how the task design is planned to exploit the affordances of the digital tools embedded in the activity and iteratively tested with teachers as co-designers;

Some preliminary observations on the degree of fidelity of resulting classroom implementations.

THE RATIONALE FOR LANDMARK ACTIVITIES

We define landmark activities as those designed to trigger a rethinking of mathematical ideas or an extension of previously held ideas – the ‘aha’ moments that indicate surprise. They can provide evidence of particular mathematical understandings of the concept, the anticipated learning goal. We surmise that disruptive but carefully designed technologies can lead to a ‘situation of non-obviousness’ (Winograd & Flores, 1988), where established routines are ‘replaced by conflict, disagreement or doubt’. These moments, we conjecture, are particularly conducive to learning. Others have studied how underlying theories on how unanticipated classroom events can be instrumental in developing teachers’ epistemology and some have elaborated the underlying role of technology in such ‘disrupted’ processes, (or example, the notions of ‘hiccups’, (Clarke-Wilson & Noss, 2015), and of ‘critical incidents’ (Aldon, 2011).

Our landmark activities by contrast, are planned for optimal engagement with the concepts at stake by means of the mediational affordances of the embedded DT. Thus we take as read that in technology-enhanced mathematics classrooms, the use of DT can disrupt routine practices in a transformative sense, and ensuing breakdowns\(^3\) can promote further reflection and thinking again, extending previously held ideas by reflective inquiry, and crucially in this process make thinking more visible.

The challenge is that the use of dynamic mathematical technology can change the way mathematical ideas are expressed and communicated, so the design is to achieve

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\(^2\) *ScratchMaths* is a 3-year research project funded by Education Endowment Foundation from Sep 2014: researchers Laura Benton, Ivan Kalas, Piers Saunders.

\(^3\) We have used the approach of making thinking more visible through DT in communication ‘across boundaries’ between different communities.
learning gains. But among various new elements of complexity, the learning gains may not reflect the whole situation: it is unlikely that, for example, there would be – or should be – learning gains on measurements derived from old curricula.

The next stage is one of implementation of the landmark activities in classrooms, with observations of teacher moves and student responses along with ‘post-lesson’ teacher and student interviews, with analyses of these data feeding into the next phase of the design in an iterative way.

**EXEMPLAR 1: THE CORNERSTONE PROJECT**

The design foci of the *Cornerstone* Project are several core mathematical concepts to be explored by middle school students (11-14 years) in ways that exploit the affordances of dynamic digital tools that can make links between key representations. The project began in 2010. It initially adopted a “design-based research approach to investigate how student use of bespoke dynamic mathematical technology in lower secondary English mathematics classrooms could enhance engagements and attainment (see Hoyles et al., 2013; Clark-Wilson et al., 2015). Following consistently positive quantitative and qualitative evaluations the innovation has been scaled to over 100 classrooms across England. *Cornerstone* comprises web-based software, student materials, teacher support materials and mandatory professional development with a focus on topics known to be hard to teach and where the DT can clearly offer new ways to explore the mathematics and engage the students: linear functions, geometric similarity and algebraic patterns and expressions. In this project we used the construct landmark activity to provide a focus not only for task design, but also to tease out the extent to which classroom practice aligns with the epistemic and learning goals of the *Cornerstone* materials and sheds light on learning (of teachers as well as students) that follows engagement with the activity.

In *Cornerstone*, the process of identification of landmark activities went through several stages. First, the research team made their own selections from the student workbook based on past experience and theoretical concerns. Then they discussed their selections and agreed a list of activities that were highly aligned to the design principles of the *Cornerstone* curriculum unit under discussion, and which could reasonably function as landmarks, in relation to the three criteria outlined earlier. This process was repeated face-to-face with a focus group of three teachers, selected as they had provided thoughtful reflections to online surveys, and who provided their rationale for their choices.

The following activity was selected as one landmark activity in the unit around linear functions. Fig 2 shows the software environment (the software was derived from Simcalc): it comprises a simulation (top right) performed by Shakey, a timer, play and editing (top left) and three ‘standard’ mathematical representations of how distance varies with time; a graph, a table of values and an algebraic function. Rethinking was provoked given the novelty of dynamic links, and the need to discover and explain what

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There are many points that we are unable to pursue on these and similar aspects of methodology.
could be changed and why, as well as what were the controls that allowed these changes
to be made. The anticipated learning goals were to identify speed as the gradient of the
graph and link that to the coefficient of the function, and also to identify the starting
point of Shakey with the intercept of the graph on the ‘distance’ axis and with the
constant in the function.

The aim of this activity was to explore the software, play the simulation, and watch the
effects on the graph, the table of values and the function. Then Shakey’s ‘journey’
could be edited, either by changing the graph (making it steeper or adjusting its starting
point.), by changing the function, or by manipulating the simulation itself or any
combination of these, and then reflecting on the effects on the journey, while trying to
 tease out and explain how the different representations were linked. Note that the graph
and the narrative – but not the table – can ‘drive’ the simulation in contrast to the usual
situation in which a graph is a read-only representation of it.

![Figure 1: Landmark for Cornerstone: different representations of Shakey’s journey](image)

We anticipated that the focus on the dynamic representations and the links between them
would be sufficiently novel to engage the students and teachers in rethinking what they
knew about linear functions: all our prior work gave support to this, hence its selection
as a landmark activity. Our early analyses indicated that the dynamic approach was
successful in provoking a rethinking of the meaning of the graph and its relationship
with the algebra although there was considerable variation in implementation. Here we
report what might be a common mutation of the innovation in some classrooms.

The teacher had fully bought in to the idea of establishing the link between the equation
and the graph. But we noticed the generic manner of his approach, with little or no
exploitation of the dynamic affordances of the digital tools. For example, the task was
presented on the interactive whiteboard and the teacher simply talked about it and
described the different ‘windows’, reminding the class of their functionality, but only
verbally – not by demonstrating. We noticed when students worked on the activity themselves (mainly in pairs), the teacher circulated giving advice, but again general advice: such as ‘try different things’ ‘you should be exploring’, and even ‘you need to establish the link between graph and equation’. He did not play with the simulation at any point. The researcher asked him if he would kindly do this and demonstrate, say, how to edit the graph. He was resistant as ‘he wanted them to explore’, but eventually agreed to do this and changed the steepness of the graph asking what “would happen to Shakey?” Many could not find the words to describe their ideas – some made vague references to going faster, many did not know what to refer to. But again, what was notable was the teacher still did not play the simulation to illustrate what happened after editing or point to the key changes and the links between them. Unsurprisingly, rather few of the students could articulate the connections between the representations.

We draw similarities with early research with computers, in which it was reported that teachers often felt they had no role: they wanted pupils to explore and sought to restrain themselves from telling answers (or funnelling towards them), but this was interpreted as an injunction against telling pupils anything at all!

**EXEMPLAR 2: THE SCRATCHMATHS PROJECT**

Computer programming is undergoing a renaissance in English schools. Recent policy and curriculum initiatives have resulted in Information and Communication Technology (ICT) being replaced by computing across all ages from 6 to 16 years (see DfE, 2013). These changes have been motivated by a concern about students leaving school with little or any understanding of computer science or the creative side of computing (Furber, 2013). From September 2014, all schools in England have to teach computing, with a curriculum that requires students to learn about how computational systems work, to use technology safely and to design and build their own programs. At least at the policy level, computing is recognised as not just about programming per se, but programming as a modeling tool: a key component of thinking that allows ideas to be brought to life and explored in different subject areas and contexts. How far this is happening in practice is of course a complex matter shaped by schools, teachers and the resources (material and people) available to support their work.

Since much of the research in the field of programming within schools was conducted in the latter part of 20th century, many new blocks-based programming environment specifically aimed at children have been developed (see Weintrop & Wilensky, 2015). One of these is Scratch, which is used by a huge number of young children in and out of school. The popularity of this style of programming for use with novice programmers is in part due to its ease of readability, composition and browsability alongside its interactivity, and visual and dynamic outcomes (ibid). *ScratchMaths* is a 3-year research project that seeks to exploit the opportunity of universal programming for learning mathematics. We also knew from past research in programming and mathematics (see, for example, Hoyles & Noss, 1992) that it was important to focus on the design of tasks and curricula and to take seriously the role of the teacher in classroom implementation.
The ScratchMaths project comprises a one-year iterative design phase followed by a 2-year implementation phase with students aged 9-11 years. The ScratchMaths intervention is intended to comprise approximately 20 hours teaching time across each of the two school years, with the first year focusing on computational thinking (see, Wing, 2008) with an implicit mathematical component, and the second year foregrounding explicit investigations of key mathematical concepts using the programming tools. Thus the ambitious vision of ScratchMaths is to introduce students and teachers in the first year to a new representational infrastructure with which to express mathematical concepts and procedures, with the intention that these skills will be exploited the following year to explore key concepts through mathematical reasoning and problem solving. The intervention has been subject to cycles of iterative design research with the final quantitative outcome measure being the national standardised mathematics test scores, taken by all students in England at the end of primary school. Here we focus on the early phases of design research.

We designed tasks with clear learning outcomes and explicit guidance for implementation in written form and as part of professional development support for the teachers (face-to-face and online). One early outcome of the design research was the emergence of the need for an explicit framework of pedagogy to help successful implementation of the different aspects of the ScratchMaths intervention. We devised a framework consisting of five constructs, the 5Es, clearly based on a host of research into good practice in teaching and learning, but also framed by findings emerging from early design workshops. The 5Es are: Explore: Investigate ideas, try things out for yourself and debug in response to feedback. Envisage: Have a goal in mind and predict what the outcome might be before trying out. Explain: Reflect on what you have done, articulate and explain the reasons behind your approach and the feedback received to yourself, to peers and to the teacher. Exchange: Share different approaches and collaborate with peers to learn from each other; try to see a problem from another’s perspective as well as defend your own approach in comparison with others. bridgE: Make links between the ScratchMaths work and the ‘standard’ mathematics curriculum and the language of ‘official’ mathematics and explore commonalities and differences. This final E is fundamental to ensure the effective exploitation of programming in modelling knowledge in all other disciplines, not just mathematics.

The ScratchMaths intervention comprises a host of investigations and exercises on and off the computer, to be undertaken individually or in pairs. We now turn to describe one landmark activity. The learning objectives were to explore how to move a sprite without dragging it, snap blocks together to create a script, and explain the script, debugging if necessary. In addition, the mathematical goals included reasoning in steps, abstracting from immediate action, exploring angle as turn, and a total turn of 360 degrees.

As preliminary work, students were given five existing individual Scratch blocks, (see Fig. 1), thus constraining activity merely to turning a given number of degrees, to ‘stamping’ the original tile, and ‘moving’ the tile in a straight line. The students could click them together to build a simple script, a sequence of actions, and observe the
outcome. This simple scenario hides a number of deep mathematical as well as computational concepts. From a computational point of view, the key concept is that a single block can have a repeatable outcome: and that putting blocks together leads to predictable results. This latter point, we found was surprisingly difficult for some students, and its mathematical corollary was a major stumbling block for many. The idea that mathematics is a game played with constrained rules, that algorithms have a rationale, that little pieces of knowledge can be brought together to represent larger ones, and that mathematical statements have consequences are all in some sense, deep. Furthermore, there is a major conceptual challenge that involves recognising the structure of the intended outcome, and predicting running the script in the future – in mathematics an analogy would be to envisage the output of a function for different values of the input.

The chosen landmark activity had two learning goals: the notion of algorithm and 360 degrees as total turn. The students were required to compare and predict the outcome the two algorithms shown in Figure 2.

![Algorithm 1](Algorithm_1.png)

**Algorithm 1**

![Algorithm 2](Algorithm_2.png)

**Algorithm 2**

**Figure 2. Landmark for ScratchMaths: comparing two algorithms**

It was clear from the implementation that a tension had to be resolved between the use of the tool and learning. We noted students were familiar with the tool, it was observed that the ease of building scripts tended to encourage students to build extremely long scripts, by simply clicking blocks together: without, first envisaging the outcome. Super-long scripts appeared to have status as demonstrating a lot of ‘work’! In fact, in some classes, pupils went to great lengths to ensure that their scripts were longer than others’. The challenge was to establish a norm in which the aesthetic and pragmatic value of short scripts is recognised along with the appreciation that long scripts are hard to explain and to predict what they would do. Thus, a key ‘rethinking’ promoted in SM...
classrooms entailed using definitions instantiated in ‘build your own block’, BYOB, in order to reduce complexity and aid readability. One point highlights the relationship between learning outcomes and the affordances of the digital tools available. An earlier version of Scratch (1.4) did not allow the ‘user’ to build your own block (BYOB), and it is perhaps here that we find the reason for the ubiquity of the ‘longer is better’ preferences on the part of the pupils. At the very least, the advent of BYOB in version 2.0 gave us as researchers a different and more powerful tool with which to promote mathematical description: write a program, give it a name, and reuse it.

Similarly, introducing the repeat block into the landmark activity alongside the constraint in the activity of ‘no overlaps’, provoked the need for further reflection while opening the opportunity to build connections between the computational and mathematical ideas. Again, progress was varied in implementation with some students ‘seeing’ no connections, while others were observed calculating the value of the repeat block by dividing 360 by any chosen value in the turn block and iterating. Sometimes this resulted in a decimal number, e.g. 5.5, which they then inputted into the repeat block. It was also noteworthy that there were differences in classroom implementation of the landmark activities and in their effectiveness for learning, which we think might be related to how far are the representations and links were explored by the teacher as well as the students using the Scratch tools and, how far the teachers used the 5E pedagogical framework along with “unplugged” activities (away from the computer) to promote and consolidate the notion of algorithm.

While one of our 5Es (Exchange) highlights the pedagogical advantages of collaboration, it proved (perhaps unsurprisingly) to be challenging in classrooms. It seemed to operate most effectively when teachers encouraged the ‘more able’ students to support the ‘less able’ by ‘teaching’ them what they had already discovered for themselves. In this way individual discoveries spread around the whole class with rather little explicit teacher intervention beyond encouragement, as students collectively monitored what their peers were working on. Apart from sharing mathematics this process would seem central to supporting the key skill in life and in work of being able to share ideas and work collaboratively. This is an interesting example of fidelity achieved in tandem with the evolution of the intervention; the intervention aligning itself with the ‘natural’ ecology of the classroom.

CONCLUDING REMARKS

In this paper, we have presented research from two large-scale projects designed to exploit the affordances of digital tools to achieve specific learning goals and widen access to challenging mathematical ideas. We have described the background and rationale for landmark activities, and sketched some observations from classroom implementation of these landmark activities. We note here that in both projects the teachers involved were either positive or highly positive about the intervention, the materials and the professional development, with comments such as:

“Great insight into a different approach to maths and ICT”
“I really look forward to implementing this at school and seeing the results. I can see the benefits and I hope they come to fruition. Cheers!”

“Best CPD ever!”

We also note some ongoing issues derived from our observations and interviews that include:

teachers being adequately prepared for the lesson: although the materials produced reduce much of the planning and preparatory work, it is helpful if teachers try out some of the activities for themselves before teaching. Some teachers do this and some don’t. Those who do are more likely to be more confident with the intervention; those who do not are more likely to find it challenging to debug issues on the fly.

differentiating an approach to the materials so as to be accessible to all pupils

being able to monitor progress across all pupils and support collaborative work on and off the computer

All these factors worked together to suggest ways by which the implementation of the innovation was shaped by the teachers’ appreciation of the new affordances for learning mathematics. It is not simply a matter of expertise in the use of the software but rather the conscious exploitation of the tools to promote a new window on mathematical ideas and how these might be appropriated by the students.

While it is too early to draw generalised conclusions from these data, we might simply note the fragility of innovation fidelity, (especially as it is a computationally based innovation), which we conjecture arises for the following reasons. First the close tie between affordance – what the system invites the learner to do – and the relationship between this and what the teacher feels inclined to focus on. Second, the landmark construct gives teachers the opportunity to operationalise the notion of a window through which to gain insight into student meanings, but this may not be exploited. Third, and perhaps most significantly, the idea of landmarks brings some systematicity to the difficult and enduring methodological challenge of identifying what matters to teachers and students in the context of classrooms. By focusing on task design, we acknowledge the role of a learning ecology which depends centrally on “the tasks or problems that students are asked to solve”, as well as the tools and materials in use. From a methodological point of view, the landmark idea may help to tame the complexity of inter-relationships between the different elements that shape an intervention, all the more complex, of course, where digital technologies are involved. One possible new strand of the design research methodology might be to strengthen the ’mixed-methods’ research framework by building an even stronger complementarity between qualitative and quantitative data analyses that harness emerging techniques of big data and learning analytics.

The projects reported here are the last two of many we have pursued with an underlying conviction that the technology-based ‘information society’ needs model-based reasoners who use mathematical thinking as a way of making sense of the world and of their world. Appreciating the existence of models that underpin so much of daily life
(financial transactions, connectivity, climate changes) is crucial for all and has been a key facet in our collective work to achieve high quality inclusive education, which opens opportunities for all learners. The projects reported above represent the next steps in researching learning processes in mathematics and devising robust and scaleable technology-based applications that develop learners’ ability to construct, describe, and explain how things work. Computer programing has been one important tool in this work, but so too has visual and dynamic mathematics software designed with a focus on developing specific mathematical concepts with appropriate activities, teachers guidance and professional development. Clearly we have more work to do to continue to try to navigate between deep questions of how people learn, and how to leverage digital technologies to help them learn and in the process blend high quality research and innovation with actionable and sustainable practice.

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INVESTIGATING PROCEDURAL AND CONCEPTUAL KNOWLEDGE OF GRADE 7-9 STUDENTS: A FOCUS ON FRACTION OPERATIONS

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ABSTRACT

Procedural knowledge and conceptual knowledge of fractions are essential in performing fraction operations. Procedural knowledge enables students to identify appropriate procedures, techniques and rules and use them accurately to compute fractions while conceptual knowledge is concerned with connections between aspects of knowledge through which a student knows why procedures, techniques and rules are appropriate for carrying out a particular fraction operation. This study used a diagnostic test to determine a group of grades 7 - 9 students’ level of procedural knowledge and conceptual knowledge on fractions operations. The data showed a higher level of procedural knowledge as compared to conceptual knowledge through the grades.

Key words: Fractions operations; conceptual knowledge; and procedural knowledge.

INTRODUCTION

The need for fraction knowledge, both procedurally and conceptually, is crucial in mathematical patterns, differentiation, solving algebraic equations etc. Teaching fractions conceptually tends to pose difficulties to many educators (Cooper, Susan, Wilkerson, Montgomery, Mechell, Arterbury & Moore, 2012). In addition, strong evidence shows that research into procedural and conceptual knowledge of fractions has drawn enormous interest (see, for example, Rittle-Johnson & Siegler, 2001; Charalambous & Pitta-Pantazi, 2007; Hallet, Nunes & Bryant, 2010; Hallet, Nunes, Bryant & Thorpe, 2012). Charalambous and Pitta-Pantazi (2007) report that fractions are one of the most complex mathematical concepts taught to primary school students. Unlike with ordinary numbers, computations of fractions tend to follow different procedures and processes. For example, when adding or subtracting fractions, one has to first convert all fractions to their equivalent fractions forms with same denominators and then only add or subtract the numerators. When multiplying fractions, numerators are multiplied together and similarly with denominators. The process for multiplication is different from adding and subtracting fractions. The product of fractions is smaller than the multiplicand and multiplier, and this contradicts the notion that multiplication is repeated addition and that multiplication is always generates a bigger answer. For
division the process is even more laborious and demanding because the numerator and denominator of the divisor have to be transposed while changing a division sign into a multiplication. Students tend to master all these procedures and processes after considerable practice, in most cases, without being able to account for them conceptually. For example, determining the product of $\frac{1}{2} \times \frac{1}{4}$, according to the afore-explained process, procedurally denominators and numerators would be multiplied separately. The difficulty comes when there are attempts to consider the real/actual meaning of the process. That is, for example, when explaining conceptually dividing $\frac{1}{4}$ into two equal parts, or taking $\frac{1}{2}$ of a quarter which is $\frac{1}{8}$. This study therefore investigates the procedural and conceptual knowledge of grades 7 to 9 students in fraction operations. The study’s guiding question is ‘What is the level of grades 7 – 9 students’ procedural and conceptual knowledge of fraction operations?’

**PROCEDURAL AND CONCEPTUAL KNOWLEDGE**

Procedural knowledge is seen as the “knowing how” to do something (Hallet, Nunes & Bryant, 2010). In mathematics, procedural knowledge involves following the correct technique, algorithm or sequence of defined actions to reach a correct answer to a problem. According to Huang, Liu and Lin (2009) procedural knowledge in mathematics is formed by the formal language of symbols and rules used in a mathematical task. It also involves knowing when and how to use a particular procedure appropriately. The benefit of procedural knowledge is that the procedures are linearly executed and independent of meaning (Hallet et al., 2010). Another benefit as noted by Schneider and Stein (2005) is that procedural knowledge allows students to solve problems quickly and efficiently, and through practice, the procedures can be mechanised. Mechanisation allows quick activation and execution of procedural knowledge; involves fewer cognitive resources and puts less demand on working memory and this contrasts conceptual knowledge. Hallet et al. (2012) consider procedural knowledge to be a “goal directed action sequence” or an algorithm that can be used to solve mathematical tasks. The downside to procedural knowledge is that it is tied to a specific problem type and if the problem type cannot be identified the problem cannot be solved or becomes difficult to solve.

When working with fractions, procedural knowledge is about the procedures needed to perform operations on them. The focus is not explaining ‘why’ a procedure or rule is used or tell what a procedure, rule or symbol actually mean. According to Star (2005), Hiebert and Lefevre (1986) created a perception that procedural knowledge is only in one form, which is superficial, is fraught with algorithms and is devoid of connections or relationships in nature. Refuting the notion, Star argues that this form of procedural knowledge is actually deep and is associated with flexibility, comprehension and critical judgement. That is, when a student masters systematic procedures he/she can identify appropriate rules needed to solve a particular mathematical task. Thus, a student who is able to perform operations of fractions with accuracy and flexibility displays deep procedural knowledge whereas a student who only displays knowledge of procedures,
algorithms and rules used to compute fractions solve is set to have superficial procedural knowledge.

Schneider and Stein (2005) formally defined conceptual knowledge as the knowledge of the core concepts and principles plus how they are interlinked in a certain domain, which is stored in a form of relational representation referred to as schemas. Hallet, Nunes, Bryant and Thorpe (2012) define conceptual knowledge as relationally linked knowledge, which is structured in such a way that the relationship between the different knowledge structures is explicit. Drawing on Hiebert and Lefevre (1986), conceptual knowledge is defined as knowledge rich in relationships that have permeated students’ facts and propositions in order to have all units of knowledge linked to a network. Therefore, conceptual knowledge does not entail memorisation of separate pieces of information of procedures to follow, but the ability to see the interconnection between the aspects of knowledge (Hallet et al., 2010). In addition, conceptual knowledge is not linked to one particular problem type and can be used to generalise a variety of problem types in a given domain. Lin, Becker, Byun, Yang and Huang (2013) consider conceptual knowledge as the underlying structure of mathematics. Thus, conceptual knowledge is defined as the knowledge of “knowing why” use certain methods or procedures when solving fractions. Students with conceptual knowledge of the procedures used when performing operations on fractions tend to understand the logic, thinking and reasoning behind those procedures.

Conceptual knowledge is characterised by a wealth of relationships (Star, 2005). In essence, it is a knowledge developed by linking a concept being learned with what is already known. This suggests that a unit of conceptual knowledge cannot be treated as discrete piece of knowledge, rather it should be perceived as a continuous knowledge web. A student learning about fractions should not only know what a denominator is and what a numerator is, but should also know the meanings of the two terms and how that meaning relates to the fraction and concepts as well. For example, in ¼ what do 1 and 4, respectively mean and how is each one of them relates with the meaning of the quarter? That is, there is 1 part that has been divided into 4 equal parts, and ¼ would mean 1 out 4 parts is being considered. In terms of ¼ + ½, for example, it is important that a student knows the actual meaning of the addition of the two fractions and is able to relate this operation with real situation or represent and illustrate it with a diagram.

**RESEARCH INTO PROCEDURAL AND CONCEPTUAL KNOWLEDGE**

Research into procedural and conceptual knowledge in mathematical cognition has focused on the relation between them (Schneider & Stern, 2005; Hallet et al., 2010; Hallet et al., 2012). Earlier studies have produced contradicting results from which three different theories were produced (see, for example, Rittle-Johnson & Siegler, 2001; Schneider & Stern, 2005; Hallet et al., 2010). *Procedure-first* theory has shown that many students can solve fraction problems procedurally without any conceptual knowledge of the method employed (Hallet et al., 2010). *Concept-first* theory entails students deriving conceptual knowledge from verbal instructions, for example (Schneider & Stern, 2005). This will then through practice lead to a procedural
knowledge of the mathematical concept. Rittle-Johnson and Siegler (2001) distinguish between these two contradicting theories and went on to propose a third model called the Iterative-model. The model suggests that the link between the two knowledge concepts is iterative, that is, an increase in one kind of knowledge will lead to an increase in the other and vice versa. In the debate on the importance of conceptual knowledge and procedural knowledge in problem solving particularly when chances of success have to be optimised, it is imperative to note that without conceptual knowledge procedures, techniques and skills will be used without any idea of what is being or needs to be done. Based on the debate on the significance of the two forms of knowledge and their roles in problem solving, it is worthwhile to gain more insight into students’ procedural and conceptual knowledge of grades 7 to 9 students in fraction operations.

According to Pantziara and Phillippou (2012) for students to understand a mathematical concept, they need to have both the procedural and conceptual knowledge of that concept. Research has shown that either poor procedural or conceptual knowledge of fractions or even both can adversely affect students’ ability to solve problems involving fraction manipulation (see, for example, Rittle-Johnson & Siegler, 2001; Hallett et al., 2010; Hallett et al., 2012). Research by Rayner, Pitsolantis and Osana (2009) and Pantziara and Phillipou (2012) show that students with only procedural knowledge may find it difficult to handle complex conceptual concepts and students with a high degree of conceptual knowledge tend to have sophisticated mathematical thinking. It is also evident from the study by Hallet et al. (2010) that students developing conceptual knowledge first, tend to perform better than those who develop procedural knowledge first. Nevertheless, there is a view that generally students experience difficulties when they construct conceptual knowledge (Charalambous & Pitta-Pantazi, 2007; Prediger, 2008; Rayner, Pitsolantis & Osana, 2009; Cooper, Wilkerson, Montgomery, Mechell, Arterbury & Moore, 2012; Pantziara & Phillipou, 2012). Drawing on Mogari’s (2004) claim on how conceptual and procedural knowledge is developed, it is argued the difficulties students experience might be eliminated, among others, by actively involving them in the learning activity.

**THEORETICAL MODEL OF FRACTIONS**

It has been noted that fractions consist of multifaceted construct instead of single concept (see Charalambous & Pitta-Pantazi, 2005; 2007). It is reported that

- the constituent constructs of a fraction (viz. part-whole, ratio, operator, quotient and measure) are interrelated;

- knowledge of fractions depends largely on knowledge each of the constructs and their confluence;

- part-whole is perceived as the seedbed from which the other constructs were developed; and
the theoretical model of fractions was further developed to enable linking the various interpretations of fractions to basic operations of fractions, problem solving and fraction equivalence (Charalambous & Pitta-Pantazi, 2007).

It is also worthwhile to note that teachers immensely use the part-whole construct to introduce the fraction concept in early grades in school. The theoretical model of fractions is as follows:

```
Part Whole
   /\  \\
/     \\
Ratio Operator Quotient Measure
   |    |       |        |
/     \\
Equivalence Multiplication Problem Solving Addition
```

Figure 1: Theoretical model of fractions developed by Behr et al (1983).

According to Charalambous and Pitta-Pantazi (2005), Figure 1, first shows that part-whole is essential in knowledge of ratio, operator, quotient and measure. Second, knowledge of equivalence and equivalent fractions hinges on knowledge concept of ratio, knowledge notion of operator promotes ability to multiply, and knowledge of measure sub-construct is helpful in learning how to add. Lastly, successful problem solving in fractions is a function of knowledge of the five sub-constructs of fractions. It is therefore argued that students will successfully conceptualise fractions and have sound problem solving skills within the fraction domain if they can develop procedural knowledge and conceptual knowledge in all the five sub-constructs of fractions.

**SOUTH AFRICAN MATHEMATICS CURRICULUM**

Charalambous and Pitta-Pantazi (2005) speculate that part-whole concept dominates school curricula across various countries because it is fundamental in knowledge of the four subordinate constructs of fractions. South Africa is not absolved from this view. In that, by the end of grade 9, its curriculum known as the Curriculum and Assessment Policy Statement (CAPS) requires a mathematics student to be proficient in the following when it comes to common fractions (Department of Education, 2013, p. 16).

- Be able to describe and order fraction by comparing and ordering common fractions, including tenths and hundredths.
- Addition and subtraction of common fractions in which one fraction is a multiple of another.
Calculate a fraction of a whole number.
Recognise and use equivalent forms of common fractions with 1-digit or 2-digit denominators.
(denominators to be multiples of each other)
Solve problems in context involving common fractions.

The extract shows that at least procedural knowledge of calculations involving addition and subtractions of fractions is intended to be developed by students by the end of grade 6. The CAPS also places emphasis on the use of common fractions in different contexts and this should lead to development of some conceptual knowledge of common fractions as suggested by (Charalambous & Pitta-Pantazi, 2007). Students in grades 7 – 9 are to build on their prior knowledge and Table 1 details the progression required from students in the topic Common Fractions over the three years.

Table 1: CAPS SP extract from Topic 1.4 Common Fractions (Department of Education, 2013, p.17)

<table>
<thead>
<tr>
<th>Grade 7</th>
<th>Grade 8</th>
<th>Grade 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ordering and comparing of common fractions extended to thousands</td>
<td>Addition and subtraction of common fractions, where the denominators are not multiples of each other.</td>
<td>Addition and subtraction of common fractions, Do calculations with all four operations with common fractions and mixed numbers.</td>
</tr>
<tr>
<td>Multiplication of common fractions.</td>
<td>Multiplication of common fractions.</td>
<td></td>
</tr>
<tr>
<td>Use knowledge of equivalent fractions to add and subtract common fractions</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Divide whole numbers and common fractions by common fractions, using knowledge of reciprocal relationships to divide common fractions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Solving problems in context involving common fractions.</td>
<td></td>
</tr>
</tbody>
</table>

From the CAPS document, it is clear that procedural knowledge of the sub-constructs of factions is developed, except division of fractions, as a formal procedure. In addition, much emphasis is placed on using fractions in different context and that should lead to conceptual growth of fractions. This study is focused on the operations done only on common fractions (i.e. fractions with a numerator and denominator both being integers). Therefore, the current study focuses on the four basic operations of fractions. Division is also included because by the end of grade seven students will have had formal teaching of the concept.
FRAMING THE STUDY

The study is underpinned by Skemp’s Theory of Knowledge where relational and instrumental knowledge (see Skemp, 1978) are used as equivalent terms for conceptual and procedural knowledge. Success in mathematics depends highly on successful problem solving where concepts, rules and procedures have to be appropriately and proficiently used to generate solutions to given problems. Of fundamental importance in this regard is for students to apply mathematical knowledge to real and non-routine problem solving situations and not to recall and religiously follow routine procedures and rules to obtain an answer. In numerous occasions, students do not understand the procedures, rules and symbols they use. Drawing on the nature of procedural knowledge, regardless of whether it is superficial or deep, an assertion is made that procedural knowledge is restricting and limiting because it enables students to perfect their skills and knowledge in order to solve only routine problems and it is not always adaptable to unfamiliar problems or problems in context. With such knowledge, only, a student cannot establish connections among integral concepts of fractions and flounders when fractions are presented differently from the ones seen before.

Furthermore, the significant value and use of mathematics in society necessitates that students have requisite ability to solve non-routine real word problems involving fractions. As implied in the posting on ‘the blog’ by Yeap Ban Har after he taught a grade 3 class fractions. In this lesson Har gave students the following problem to solve:

‘Here is a cake. Nohair got 2-ninths. Spiky and Curly got the rest. How much of the cake did each of them get? Find as many ways as you can. (Students received a bar model cut-out to represent the cake)’.

(see Mathematics Educator Education: Singapore Approach, March 03, 2015)

From this problem, it is evident that students are not expected to compute fractions using routine procedures, instead they have to cut the bar model into various possible ways to find the solution. Through this activity students are exposed to interrelated (sub)concepts such as the whole can be divided into separable parts; the whole can be divided into separable parts in various ways; there exists a strong link between the number of separable parts and the number of divisions (cf. Hierbert & Tonnessen, 1978); and the operations of fractions are interrelated and also can be interdependent. An argument is therefore advanced that through such an instructional approach students develop new knowledge using their prior related knowledge and the given learning resource (i.e. bar model) to model possible solutions to the problem, and thus develop conceptual knowledge of fractions.

In sum, conceptual knowledge and procedural knowledge present distinct advantages to a student. The former focuses on relationships among concepts while the latter deals with step-by-step procedures, rules and techniques essential in solving a mathematical task. Thus, a contention is made that success in learning and computing fractions hinges on sound development of both conceptual and procedural knowledge. Also, as students progress in their schooling these forms of knowledge should equally develop as well. Hence, the focus of the current study is on the level of students’ conceptual knowledge and procedural knowledge relating to fraction computations.
METHODOLOGY

Participants and procedure

An explanatory research was conducted to gain insight into the levels of procedural and conceptual knowledge of a convenient sample of grade 7 - 9 students of a South African private school. The grade 7 group with age range of 12 – 13 years consisted of 57 students; the grade 8 group had 57 students with age range of 13 – 14 years; and the grade 9 group consisted of 49 students with age range of 14 – 15 years.

The school teaches CAPS and promotion to a senior grade only happens when students have beyond any doubt, shown the required level of proficiency in working with and applying mathematical concepts, rules and procedures as set out in the CAPS document. After the school had sanctioned the study, the second author met with the mathematics educators of the three grades to brief them about the study and implore them for their assistance. The educators agreed to participate in the study and invigilate the test sessions. All the grades 7 - 9 students wrote a diagnostic test, which they were not alerted about to prevent any special preparations because the test did not only measure the procedural and conceptual knowledge, but how students’ abilities changed through the grades. Time allowed to complete the test was 30 minutes and each student was given a unique code to use instead of his/her name.

INSTRUMENTATION

A test used in this study was adapted from studies by (Charalambous & Pitta-Pantazi, 2007); (Pantziara & Philippou, 2012); (Lin, Becker, Byun, Yang, & Huang, 2013) and (Prediger, 2008), and was modified according to stipulations set out in the CAPS Mathematics document. The nine educators that assisted in the testing verified the validity and suitability of the test items for the purpose of the study. The Cronbach’s alpha yielded 0.71 as the test’s reliability coefficient.

The test consists of four sections containing the four fraction operations: addition, subtraction, multiplication and division. Each section was split into two parts, one part procedural knowledge (PK) type questions and the second part conceptual knowledge (CK) type questions. The addition section consisted of one PK item and two CK items. The subtraction section had one PK item and two CK items. The multiplication section had three PK items and four CK items. While CAPS does not require the teaching of division of fractions in grade 7, a section on division was however included in the test, since this is taught formally at a South African private school. In total, the test had 15 questions (6 on procedural knowledge and 9 on conceptual knowledge).

As in the study by Charalambous and Pitta-Pantazi (2007) all grades wrote same test. The following is an extract from addition section in the test and illustrates how procedural and conceptual knowledge was measured:

1.a. How do you solve the following problem? \( \frac{2}{3} + \frac{1}{2} \) (PK)

1.b. Make a drawing to show how you solved the problem, \( \frac{2}{3} + \frac{1}{2} \) (CK)
Each item was given a mark out of 2 where 0 was given for a wrong answer, 1 for partially correct answer and 2 for correct answer. Similar scoring was done by Huang, Liu and Lin (2009). In the PK questions full marks were given even if the fractions were not simplified because the focus was on procedure of the operation and not simplification of fractions into equivalent forms. Partial marks were given if the student made a clear calculation error but showed knowledge of the procedural method, for example:

In the CK questions full marks were given if drawings of the fractions were clear and the wording of the word problems where logical and the concept was correctly expressed. For example:
Partial marks for conceptual items were awarded if the drawing and the wording of the word-problems was unclear but the basic concept was correct, for example.

For scoring reliability, the tests were moderated, and the test scores were captured by an educator and an assistant (second year university mathematics student).

RESULTS

Cross-Grade Comparison of Procedural and Conceptual knowledge

The data was entered into an MS Office Excel spreadsheet and Data Analysis Tools were used to determine the mean and standard deviation of the scores per grade. Table 2 presents the % means over the four operations per grade.

<table>
<thead>
<tr>
<th>Table 2:</th>
<th>Grade 7(n=57)</th>
<th>Grade 8(n=57)</th>
<th>Grade 9(n=49)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Addition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK</td>
<td>84.21%</td>
<td>33.97%</td>
<td>68.42%</td>
</tr>
<tr>
<td>CK</td>
<td>47.81%</td>
<td>34.50%</td>
<td>35.09%</td>
</tr>
<tr>
<td>Subtraction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK</td>
<td>81.23%</td>
<td>30.03%</td>
<td>60.03%</td>
</tr>
<tr>
<td>CK</td>
<td>47.81%</td>
<td>34.50%</td>
<td>35.09%</td>
</tr>
<tr>
<td>Multiplication</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK</td>
<td>76.32%</td>
<td>31.03%</td>
<td>57.89%</td>
</tr>
<tr>
<td>CK</td>
<td>35.09%</td>
<td>18.50%</td>
<td>32.68%</td>
</tr>
<tr>
<td>Division</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK</td>
<td>65.79%</td>
<td>45.07%</td>
<td>34.21%</td>
</tr>
<tr>
<td>CK</td>
<td>0.00%</td>
<td>0.00%</td>
<td>1.75%</td>
</tr>
</tbody>
</table>

In the table, the procedural knowledge mean scores are high over all operations and in all the grades. The procedure for the division operation of fractions is only taught late in grade 6 and early in grade 7. The grade 8 mean values are considerably lower respectively to all the other means.
Cross-Grade Comparison of the Operations under Procedural Knowledge

Table 3 shows that various PK questions have higher % mean scores with addition = 79.63%; subtraction = 82.41%; multiplication = 71.5% and division = 62.35%.

| Table 3: Descriptives Procedural Knowledge over all grades |
|---|---|---|---|---|---|---|
| Addition | 2 | 100% | Subtraction | 2 | 100% | Multiplication | 2 | 100% | Division | 2 | 100% |
| Mean | 1.59 | 79.63% | Mean | 1.65 | 82.41% | Mean | 4.29 | 73.50% | Mean | 1.25 | 62.35% |
| Standard Error | 0.06 | 3.08% | Standard Error | 0.06 | 2.92% | Standard Error | 0.17 | 2.79% | Standard Error | 0.07 | 3.74% |
| Median | 2.00 | 100.00% | Median | 2.00 | 100.00% | Median | 6.00 | 100.00% | Median | 2.00 | 100.00% |
| Mode | 2.00 | 100.00% | Mode | 2.00 | 100.00% | Mode | 6.00 | 100.00% | Mode | 2.00 | 100.00% |
| Standard Deviation | 0.78 | 39.23% | Standard Deviation | 0.74 | 37.16% | Standard Deviation | 2.13 | 35.47% | Standard Deviation | 0.95 | 47.63% |
| Sample Variance | 0.62 | 30.76% | Sample Variance | 0.55 | 27.62% | Sample Variance | 4.53 | 75.50% | Sample Variance | 0.91 | 45.38% |
| Kurtosis | 0.30 | Kurtosis | 1.06 | Kurtosis | -0.58 | Kurtosis | -1.71 |
| Skewness | -1.48 | Skewness | -1.72 | Skewness | -0.91 | Skewness | -0.51 |
| Range | 2.00 | Range | 2.00 | Range | 6.00 | Range | 2.00 |
| Minimum | 0.00 | Minimum | 0.00 | Minimum | 0.00 | Minimum | 0.00 |
| Maximum | 2.00 | Maximum | 2.00 | Maximum | 6.00 | Maximum | 2.00 |
| Sum | 258.00 | Sum | 267.00 | Sum | 695.00 | Sum | 202.00 |
| Count | 162.00 | Count | 162.00 | Count | 162.00 | Count | 162.00 |
| Sample Variance | 0.12 | 41.82% | Sample Variance | 0.02 | 46.30% | Sample Variance | 0.12 | 36.19% |

Cross-Grade Comparison of the Operations under Conceptual Knowledge

In Table 4, the percentage mean score for the addition = 41.82%; the subtraction = 46.30%; multiplication = 36.19% and division = 1.54%. Thus, all low average scores.

| Table 4: Descriptives Conceptual Knowledge over all grades |
|---|---|---|---|---|---|---|
| Addition | 4 | 100% | Subtraction | 4 | 100% | Multiplication | 4 | 100% | Division | 4 | 100% |
| Mean | 1.67 | 41.82% | Mean | 1.85 | 46.30% | Mean | 2.90 | 36.19% | Mean | 0.03 | 1.54% |
| Standard Error | 0.11 | 2.78% | Standard Error | 0.11 | 2.81% | Standard Error | 0.12 | 1.50% | Standard Error | 0.02 | 0.92% |
| Median | 2.00 | 50.00% | Median | 2.00 | 50.00% | Median | 3.00 | 37.50% | Median | 0.00 | 0.00%
| Mode | 2.00 | 50.00% | Mode | 2.00 | 50.00% | Mode | 2.00 | 25.00% | Mode | 0.00 | 0.00% |
| Standard Deviation | 1.41 | 35.34% | Standard Deviation | 1.43 | 35.82% | Standard Deviation | 1.53 | 19.08% | Standard Deviation | 0.23 | 11.72% |
| Sample Variance | 2.00 | 49.95% | Sample Variance | 2.05 | 51.31% | Sample Variance | 2.33 | 29.13% | Sample Variance | 0.05 | 2.75% |
| Kurtosis | -1.11 | Kurtosis | -1.15 | Kurtosis | 0.24 | Kurtosis | 63.06% |
| Skewness | 0.28 | Skewness | 0.12 | Skewness | 0.15 | Skewness | 7.90% |
| Range | 4.00 | Range | 4.00 | Range | 8.00 | Range | 2.00 |
| Minimum | 0.00 | Minimum | 0.00 | Minimum | 0.00 | Minimum | 0.00 |
| Maximum | 4.00 | Maximum | 4.00 | Maximum | 8.00 | Maximum | 2.00 |
| Sum | 271.00 | Sum | 300.00 | Sum | 469.00 | Sum | 5.00 |
| Count | 162.00 | Count | 162.00 | Count | 162.00 | Count | 162.00 |
| Sample Variance | 0.22 | 41.82% | Sample Variance | 0.22 | 46.30% | Sample Variance | 0.24 | 36.19% |

DISCUSSION

The study investigated the level of grade 7 – 9 students’ conceptual knowledge and procedural knowledge. Table 3 shows relatively fairly better scores than those in Table 4. It means the students display better procedural knowledge than conceptual knowledge and this is consistent with findings by Rayner, Pitsolantis and Osana (2009) and Pantziara and Phillipou (2012). Better procedural knowledge suggests that the procedural methods of all the grades are better developed. This supports the view that teaching in mathematics classes generally puts emphasis on mastering techniques, accurate use of procedures and rules as well as mechanical thinking. Students can compute fractions with minimal challenges because the solution strategies and techniques they use are routine, mechanical and have been rehearsed and perfected with continual practice (cf. Schneider & Stein, 2005). Educators have tendency to make

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students believe that success in mathematics is a function of habitually practicing algorithms, procedures, techniques and application of rules rather than on reasoning, thinking and problem solving. With conceptual knowledge, the students were to demonstrate their understanding of fractions by representing them verbally or graphically. In addition, Table 4 shows that conceptual knowledge levels are the lowest under multiplication and division. This may be because multiplication of fractions works differently from those of whole numbers. Multiplication essentially means ‘OF’ for fractions and repeated addition for whole numbers. The same goes for division. As noted earlier, multiplication of fractions yields a product that is smaller than the multiplier and the multiplicand and for division the quotient can be smaller or bigger depending on the respective sizes of the divisor and dividend. Generally, educators do not bother to explain this ‘anomaly’ largely because the lessons tend to mainly focus on students knowing what to do (i.e. mechanical systematic process followed) when multiplying fractions and not on what multiplication of fractions essentially mean (cf. Hallet, Nunes & Bryant, 2010). The same goes for division of fractions. Perhaps, it is this inconsistency in procedures and meaning between multiplication and division of fractions and whole numbers that poses challenges to students (see Charalambous & Pitta-Pantazi, 2007).

Another point to note is that there was a slight improvement in conceptual knowledge under multiplication but none such for division from grade 7 to 9. It is clear that the conceptual knowledge of division of fractions is lacking in most students. The convenient way to display conceptual knowledge of division of fractions involves the use of number line. The process works better when the dividend and divisor have same denominator and this implies the invocation of the concept of equivalent fractions when the denominators of the dividend and divisor are different. Students should also know how to partition the number line accordingly and how to plug the divisor onto the partitions on the number line. This is a much more complex, complicated and cognitively demanding process and perhaps it is on this basis that the students battle to illustrate division conceptually.

Table 2 also shows that there is a concomitant change in both procedural knowledge and conceptual knowledge levels between the grades 7 to 9 but there is a drop in the means in all fraction operations under procedural knowledge and conceptual knowledge in grade 8. This can be because fractions are not taught in grade 8. Mathematics is a hierarchal and utility subject by its nature whereby what a student has learned in lower classes will be developed further and used, possibly to learn other concepts, in higher classes (see Department of Education, 2013). Grade 8 students are therefore expected to apply their knowledge of fractions in other aspects of the mathematics syllabus and not to have forgotten what they were taught about fractions in lower classes if they had learned content conceptually. Arguably, this is an indictment on the ways mathematics is generally taught in schools. Emphasis tends to be put on the mastery of algorithms, procedures and rules to speedily and accurately solve problems, and not on establishing relationships or making efforts to recognise relationships between what is learned and what is already known (Hallet et al., 2010). Given that conceptual learning espouses
understanding, it is argued that if students had learned fractions conceptually in lower classes there would be a relevant knowledge structure in their minds that ensures the knowledge of fractions never wanes (cf. Sweller, 1994). Educators tend to be obsessed with students acquiring and mastering mechanistic procedures, strategies and techniques at the expense of developing connections between what is known and what is being learned; engaging in critically thinking and reasoning as well as verbalising and attaching meaning to what they learn.

In conclusion, the study shows that

i. The levels of procedural knowledge and conceptual knowledge of grade 7 – 9 students are not the same with procedural knowledge being better developed.

ii. The students’ conceptual knowledge of multiplication and division is low as compared to addition and subtraction.

LIMITATIONS AND FURTHER CONSIDERATIONS

It is possible that the results will be different if a larger sample in the diverse South African schooling environment is used. The test had a limited number of items.

Including more procedural knowledge questions and scaffolding the questions in each fraction operation section would give a better diagnostic result and allow the researcher to pinpoint the level of procedural knowledge per fraction operation sections.

Some guidance could be given with the conceptual knowledge items. The general feedback from the educator/invigilator was that the students found the type of question foreign and had difficulty knowledge what was required. The division section was answered most poorly and only one student gave an acceptable answer, shown below:

Setting up an action research study within the school to develop a programme to further conceptual knowledge of fractions and fraction operations and thereby enhance knowledge with a clear view of problem solving. The sample could be expanded to include students from grade 10, 11 and 12. Again this would provide a better knowledge on the procedural and conceptual knowledge of fraction operations in higher grades.

The study could also be expanded to include percentage, ratios and decimal fractions within a problem solving framework.
Another study could investigate the correlation between fraction knowledge and later mathematical achievement.

REFERENCES


Mathematics Educator Education: Singapore Approach (March 03, 2015). Grade 3 Lesson on Fractions by Yeap Ban Har. (Downloaded from http://banhar.blogspot.com on 03/03/2015).


ABSTRACT

The use of Mathematics’ principles like algebra, arithmetic in almost all subjects and daily activities have made it the “heart” of every subject learnt in the science field. It is for that reason that students need to understand most of the concepts of the subject with less challenges and hindrances. As a result, the on-going difficulties of BSc students to attain a pass mark at the University of Swaziland (UNISWA) in a First year Mathematics course; Algebra, Trigonometry and Analytic Geometry (MAT111) is a cause for concern.

This paper reports on a study conducted to identify the different types of beliefs that first year MAT111 students at the UNISWA have and further find out how these beliefs compare with their performance. In this study, qualitative research design was used for purposes of collecting data. From a total of 82 BSc students in first year, 74 students were randomly selected making a sample of 37 males and 37 females. From the 74 students, the researchers ensured that none of them were repeating Mathematics in first year by cross-checking from the University’s system with their students’ identification numbers.

An open-ended questionnaire adopted from Adams (2014) and Schoenfeld (1985) was used. Analysis of the data showed that the students have both negative and positive beliefs about Mathematics as well as about self. The analysis also found that negative beliefs on Mathematics result in the students performing lower than those with positive beliefs on the subject. The data also showed that the belief on the nature of relevance of Mathematics did not show any differences in the student’s performances, as students with either belief concerning Mathematics relevance had their average marks equal.

INTRODUCTION

It is recommended that Mathematics instructors employ approaches and strategies that can help in minimizing or uproot the negative beliefs that students have on Mathematics. One of them includes evolving the classroom and applying teaching strategies that will make Mathematics relevant to the students’ daily life experiences, so they can view it
as an important subject, not just a discipline that is irrelevant, and is there to confuse them.

A learning institution be it a school or a college is built mainly for purposes of impartation of knowledge to the students (Op’t Eynde, De Corte & Verschaffel, 2002). During the process of knowledge impartation, there are a lot of factors that tend to influence the students’ construction and storing of the knowledge. Factors like the teacher’s personality, learning environment, teaching methods, size of class, availability of teaching resources, social factors and mental factors including beliefs and attitudes of the students tend to affect the learning process (Mason, 2010).

Most theories reflect that among students in school, there are different set of beliefs that exist ranking from teacher’s beliefs down to beliefs about the subject. Schoenfeld, (1985) States that ‘much research has been conducted on the essential role of beliefs in learning and teaching Mathematics and found that, beliefs, indeed affect the process of learning and teaching Mathematics’. Research have shown that during the teaching and learning process, students tend to develop certain feelings, attitudes and beliefs, and in turn these affect the student’s construction of knowledge, and hence the performance (Steele & Ambady, 2006)

**BACKGROUND OF THE STUDY**

First semester results statistics for 2016/2017 indicate that 48% of students in the BSc programme failed to attain a passing mark in the course MAT111. Moreover 71% of these students entered the BSc programme with a Mathematics grade of B or better in the SGCSE Mathematics. This indicates that some candidates with a B grade or better in SGCSE fail to pass MAT111. This is a cause for concern.

In every Mathematics classroom, students are taught valuable concepts which enable them to be successful in their Mathematical careers throughout their lives. Such concepts permit the students to have success in their current classes as well as when they are outside the context of schooling, that is in their everyday life situations. Teachers, hope that if the students have mastered and understood the concepts very well, they can as well apply such in future situations, such as problem solving and investigations. It is believed and assumed that, if a student has mastered a concept very well, then there are fewer chances that the student can struggle in using the concept to solve other related problems. So, for students to be successful academically in Mathematics, concepts mastering is one of the key things they need to have (Schonfeld, 1989). However, students have problems conceptualizing and seeing importance of concepts they consider irrelevant to their everyday life (Tarmizi, 2010).

To master a concept in Mathematics involves a lot of things, more than the teacher teaching and student learning. Kloosterman, Raymond, and Emenaker, (1996) pointed out, that a number of factors can influence a student in his or her learning of Mathematics, factors like teachers pedagogical and content knowledge, learning environment, teaching method, class size, teacher’s beliefs and student’s beliefs about
teachers and Mathematics as a subject. All these factors can influence the learning of Mathematics. The researchers believe that, such drastic decrease in the performance of the First Year Mathematics students at UNISWA are due to some of these factors, and randomly chose to study student’s beliefs about Mathematics. In this respect we mean we could have studied any of the factors but chose to study beliefs arbitrarily.

Some researchers have found that indeed Students beliefs influence their performance in Mathematics (McLeod, 1994; Viholainen, Asikainen & Hirvonen, 2014; Smith, 2014). Furthermore Adams, (2014, p.5) says:

...some students assume that if they cannot solve a problem within the first 5 minutes they work on it, then they will never be able to solve it. Such a belief could keep students from persevering on Mathematics problems, which often require longer than 5 minutes to solve.

The researchers therefore believe that there are a lot of other beliefs and attitudes that learners might have which could affect their performance in Mathematics.

Other factors that affect students’ performance include family influences such as working-class parents or siblings (Downey, 2008). Also linked to Mathematics achievement is students’ academic motivation, which is created by the cultural, family and societal context in which students live (Wang, 2012). This study therefore focused on attitudinal factors that might affect learners’ conceptualization of Mathematical knowledge. This study seeks to identify the types of beliefs that exist among the students and further examine how they compare with the Students’ performance in a first year Mathematics course at UNISWA.

CONCEPTUAL FRAMEWORK

Beliefs

Op’t Eynde, et al., (2002) divided students’ mathematical beliefs into three classes: “beliefs about Mathematics education, beliefs about self, and beliefs about the social context.” The first category includes beliefs about Mathematics as a subject, beliefs about mathematical learning and problem-solving, and beliefs about Mathematics teaching (Viholainen, Asikainen & Hirvonen, 2014, p 161.). McGregor (2014, p 453-454.) on the other hand categorised beliefs into four main types: the nature of Mathematics in general; self-efficacy for solving mathematical problems; how Mathematics should be taught; and the way society views Mathematics. The aspect he has added is the belief on the nature of Mathematics in general. The third category, belief about the social context include beliefs about social norms in the students’ own class and beliefs about socio-mathematical norms in their own class (Op’t Eynede, et al., 2002). Beliefs about social norms include the role and the functioning of the instructor plus the role and functioning of the students (Op’t Eynede, et al., 2002). McGregor (2014)’s “the way society views Mathematics” seems to include more than “beliefs about social context” as described by Op’t Eynede, et al., (2002). However, in this paper our interest is beliefs about Mathematics education and beliefs about self.
In the next two paragraphs we describe each of the two categories in line with (Op’t Eynde, et al., 2002).

Mathematics Education:
These are the beliefs that students have about the nature of Mathematics (Op’t Eynde, et al. 2002). For example, many students believe that Mathematics is very difficult and is based on a set of rules and only bright learners succeed in it.

Self:
These include mainly Self efficacy beliefs. Consist of the students perceived level of success and failure in learning Mathematics. For example, the student’s confidence on his or her understanding of a certain chapter, say trigonometry within the Mathematics syllabus (Op’t Eynde et al. 2002).

Student’s beliefs and performance:
Literature point out that student’s performance in Mathematics is mostly aligned with the kinds of beliefs the students have about Mathematics (Kislenko, Grevholm & Lepik, 2008; McGregor, 2014). Student’s beliefs about Mathematics play an important role in Mathematics education (McLeod, 1994). It is highly believed that the learning outcomes of students are strongly related to their beliefs about Mathematics (Furinghetti, 2000). Lester, Garofalo, and Lambdin Kroll, (1989) as cited in Kislenko, Grevholm and Lepik (2008) point out that;

Any good Mathematics teacher would be quick to point out that students’ success or failure in solving a problem often is as much a matter of self-confidence, motivation, perseverance, and many other non-cognitive traits, as the Mathematical knowledge they possess. (p.75)

This shows directly the effect of students’ beliefs on their performance in Mathematics. Students’ beliefs about Mathematics and their attitudes towards learning the subject have been related to their results in Mathematics (McGregor, 2014). Additionally, Burstein (1992) in Mensah, Okyere and Kuranchie, (2013) reports that there exists a direct link between students’ beliefs and attitudes towards Mathematics and their outcomes. Moreover, Schloglmann (2009) also states that some beliefs about Mathematics education develop amongst the students based on their performance in the subject. Mensah et al, (2013) also state that, the more positive the belief, the more positive is the outcome. This means the student’ beliefs about Mathematics, affect their performance in the subject.

PURPOSE OF STUDY
The purpose of the study was to determine the types of beliefs about Mathematics that First year BSc students at the UNISWA have and further find out how they compare with their performance in MAT111.

The study addressed the following questions;

What types of beliefs about Mathematics exist among First year BSc students at the University of Swaziland?
How do the students’ performance compare with their beliefs about Mathematics?

RESEARCH METHOD

Research Design
The study followed a survey design using questionnaires. They were chosen because they are a quick method for collecting data. The study is descriptive and explanatory; therefore amenable to the survey design (Barbie 2007). Additionally, the survey design was appropriate as the results were used to generalize first year BSc students (Creswell, 2003).

Sampling Procedures and Population
To get a representative of the whole population, simple random sampling was done. This is a technique where by each member of the population have an equal chance of being selected as a subject (Blakstad, 2009). It was employed because it gave every member of the population a fair chance to be selected thus reducing biasness. Also, simple random sampling results into having a representative sample that is unbiased, hence it becomes reasonable to make generalizations from the results of the sample back to the population (Blakstad, 2009). The participants were selected randomly among the First year BSc students, assuming that they had fewer differences in terms of presumed academic capabilities as they were admitted for the same program.

In the department of Mathematics, they had 119 first year students who are taking the course MAT111. Out of this, 82 are from the Faculty of Science and Engineering, which is the area of interest.

The Sample
The study used seventy-four (74) First year students taking the Mathematics course. There were 34 males and 34 females. The participants averaged between eighteen (18) and nineteen (19) years of age, since they were from high school and normally seventeen (17) is the leaving age for high school in Swaziland.

Instrument
For purposes of collecting data, an open-ended questionnaire was used. The questionnaire items that the researchers used were adapted from (Adams, 2014) and (Schoenfield, 1985). The reason for using a questionnaire as a data collection tool was to get more detailed insights in the different beliefs the students may have. The questionnaire was divided into 3 sections, section A containing demographic information and 3 general questions which were later used to evaluate some responses given in the section B. Section B contained 7 questions on beliefs the students have on Mathematics education and the last part, section C contained 3 questions on self-beliefs on Mathematics the students’ might have.
DATA ANALYSIS

The data were analysed qualitatively. The responses were grouped into two groups as in the questionnaire, those with beliefs about Mathematics education and those with beliefs about self. Then, for each category, the responses given were used to formulate belief statements, which were then used to come up with the types of beliefs the students have. From the section of beliefs on Mathematics education, ten (10) belief statements were formulated, in a way that five were positive beliefs on Mathematics education and the other five were contrary to the positive ones. The formulated positive belief statements were mainly: Mathematics is not hard, Mathematics is important, Mathematics is not selective, Mathematics is relevant and I like Mathematics. Those contrary to these ones were mainly: Mathematics is hard, Mathematics is not important, Mathematics is selective, Mathematics is not relevant and I do not like Mathematics. In formulating the belief statements, those who responded to the question on Mathematics level of difficulty as; Mathematics is hard were given the belief statement that Mathematics is hard. Those who responded to the question on Mathematics selectivity, that is if everyone can be good in Mathematics with a No, were given the belief statement that Mathematics is selective, meaning one needs certain features and attributions like be very smart, to pass Mathematics, and those given the contrary belief statement were those who responded that they believe, everybody is capable to excel in Mathematics. The belief statement that Mathematics is relevant was given to those who responded to the question of relevance with a Yes, and the contrary belief statement given to those who responded with a No. On the question of importance of Mathematics, the belief statement that Mathematics is important was given to those who responded positively, and said that it is important, and the contrary belief statement was given to those who responded with a No. Their explanations were used to determine if the belief was genuine or not. It was easy to formulate the belief statements because; the questions were asked in a way that, the response was positive or contrary to the positive.

When analysing the self-beliefs shown by the students, the following belief statements were formulated; I am good in Mathematics, I am an average student and I am not good in Mathematics. Again here, students who responded to the question on the part which asked if they think they were good in Mathematics with a No were given the belief statement that they are not good in Mathematics. Also, students who, when responding to the question on where can they rank themselves in the classroom, ranked themselves, at most at the top 20%, were again given the belief statement that they believe they are good in Mathematics. Students who ranked themselves between the top 21%- 69% were given the belief statement that they believe they are average in Mathematics. Those who ranked themselves above the top 70% were given the belief statement that they believe they are not good in Mathematics. Also, those who said they like Mathematics were given the belief statement that they like Mathematics and the contrary statement was given to those who responded negative. The formulation of
belief statements is in accordance with the study done by (Adams, 2014), as each response he got from the students, he named it as a belief statement.

Having found the types of beliefs, the students were then grouped according to their beliefs and their performances compared with the beliefs. This was done by grouping the students in groups of the shown beliefs, and then finding an average of their marks obtained in MAT111. The MAT111 is given to the student as a letter grade, so to find a mark representing a particular grade, we found the average mark of all marks in that range as shown in Table 3. In that way, we were able to see, how each group with each type of beliefs compared with its performance.

When it comes to the comparing part, the researchers coded each belief statement so it can be easily represented in tables and graphs as shown in tables 1 and 2.

Table 1: Coding of belief statements on Mathematics education

<table>
<thead>
<tr>
<th>Belief Statement</th>
<th>Special Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematics is not hard</td>
<td>MNH</td>
</tr>
<tr>
<td>Mathematics is hard</td>
<td>MH</td>
</tr>
<tr>
<td>Mathematics is not important</td>
<td>MNI</td>
</tr>
<tr>
<td>Mathematics is important</td>
<td>MI</td>
</tr>
<tr>
<td>Mathematics is not relevant</td>
<td>MNR</td>
</tr>
<tr>
<td>Mathematics is relevant</td>
<td>MR</td>
</tr>
<tr>
<td>Mathematics is not selective</td>
<td>MNS</td>
</tr>
<tr>
<td>Mathematics is selective</td>
<td>MS</td>
</tr>
<tr>
<td>I do not like Mathematics</td>
<td>IDL</td>
</tr>
<tr>
<td>I like Mathematics</td>
<td>IL</td>
</tr>
</tbody>
</table>

Also, self-beliefs about Mathematics were coded as shown in Table 2.

Table 2: Coding of Belief statements

<table>
<thead>
<tr>
<th>Belief Statement</th>
<th>Special Coding</th>
</tr>
</thead>
<tbody>
<tr>
<td>I am good in Mathematics</td>
<td>IG</td>
</tr>
<tr>
<td>I am average in Mathematics</td>
<td>IA</td>
</tr>
<tr>
<td>I am not good in Mathematics</td>
<td>ING</td>
</tr>
</tbody>
</table>

For purposes of getting the average mark, the marks recorded in the questionnaire were verified from the University results, and were ranked as shown in Table 3.
Table 3: Ranking of marks in MAT111 in Percentages

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Average mark (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A+</td>
<td>95</td>
</tr>
<tr>
<td>A</td>
<td>84.5</td>
</tr>
<tr>
<td>B+</td>
<td>77</td>
</tr>
<tr>
<td>B-</td>
<td>72</td>
</tr>
<tr>
<td>C+</td>
<td>67</td>
</tr>
<tr>
<td>C-</td>
<td>62</td>
</tr>
<tr>
<td>D+</td>
<td>57</td>
</tr>
<tr>
<td>D-</td>
<td>52</td>
</tr>
<tr>
<td>E</td>
<td>40-47</td>
</tr>
<tr>
<td>F</td>
<td>19.5</td>
</tr>
</tbody>
</table>

Apart from tables, bar graphs were also used to display the data.

RESULTS

The following tables summarise the number of students per belief statement.

Table 4 Number of students per belief statement on Mathematics education

<table>
<thead>
<tr>
<th>Belief Statement</th>
<th>Number of Students</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>MNH</td>
<td>6 (17.6%)</td>
<td>34</td>
</tr>
<tr>
<td>MH</td>
<td>28 (82.4%)</td>
<td>34</td>
</tr>
<tr>
<td>MNR</td>
<td>5 (14.7%)</td>
<td></td>
</tr>
<tr>
<td>MR</td>
<td>29 (85.3%)</td>
<td>34</td>
</tr>
<tr>
<td>MNI</td>
<td>8 (23.5%)</td>
<td></td>
</tr>
<tr>
<td>MI</td>
<td>26 (76.5%)</td>
<td>34</td>
</tr>
<tr>
<td>MNS</td>
<td>15 (44.1%)</td>
<td></td>
</tr>
<tr>
<td>MS</td>
<td>19 (55.9%)</td>
<td>34</td>
</tr>
<tr>
<td>IDL</td>
<td>15 (44.1%)</td>
<td></td>
</tr>
<tr>
<td>IL</td>
<td>19 (55.9%)</td>
<td>34</td>
</tr>
</tbody>
</table>

Table 5 Number of students per belief statement on self
<table>
<thead>
<tr>
<th>Belief statement</th>
<th>Number of Students</th>
<th>Percentage Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>IG</td>
<td>8</td>
<td>23.5</td>
</tr>
<tr>
<td>IA</td>
<td>6</td>
<td>17.6</td>
</tr>
<tr>
<td>ING</td>
<td>20</td>
<td>58.8</td>
</tr>
</tbody>
</table>

After classifying the types of beliefs, they were then compared with the performance of the students. Results upon comparing are shown on the figures below.

Figure 1 Comparison of student’s Mathematics beliefs with their performance

Figure 2 Comparison of student’s self-beliefs with their performance in Mathematics
DISCUSSION

From the results, we see that the students have both positive and negative beliefs on Mathematics education as shown in table 4. We see that out of 34 respondents we got, 6 students believe that Mathematics is not hard, about 17.6%. However, 82.4% of the students believe that Mathematics is a hard subject, as shown in table 5. This shows that, a lot of students in the MAT111 class believe that Mathematics is a hard subject. There are many reasons why students believe that Mathematics is hard. One of them is the fact that, some students tend to not master the concept when it is taught to them, but only be interested in getting the answer, such that when another problem in different format but asking same concept is brought to them, they fail to solve it, in the process they then think it is a hard subject (Steele and Ambady 2006)

Also from Table 4, 29 (85.3%) students have the belief that Mathematics is relevant to life situations. This means the majority of the students believe Mathematics is relevant to life situations. This is contrary to what Schoenfield (1992) in Op’t Eynde, et al.(2002) says about students. He says students tend to believe that Mathematics is irrelevant and has got nothing to do with real life situations and explains this as a result of the way students actually perceive and experience specific Mathematical concepts. However, in this study, we found that a majority of students believe that Mathematics is relevant, and has something to do with real life situations. The class level, country and period of Schoenfield’s study sample is different from the study reported on in this paper. The participants in his study were students in Grades 9-12 which are levels lower than the ones on the present study. Those in Grade 12 are almost on the same level with those reported in this study but the full semester of university Mathematics could have given them other views about the relevance of Mathematics.

Form Table 4, we see that, 26 students, about 76.5% have the belief that Mathematics is an important subject. Literature cites many reasons on the existence of such beliefs among students, and one of them being the one cited by Op’t Eynde et al.(2002) above. When students are taught a concept or a subject that they see irrelevant to their daily life situations, they will, in turn, have difficulties in conceptualizing it, and therefore see it as less important (Tarmizi, 2010). Results also showed that 44.1% of the students believe that Mathematics is not selective while 55.9% believes it is selective. Mason (2010) argues that statistics reporting that boys are good performers in the subject than girls is one factor that leads to people believing Mathematics is selective.

On the part whether they like or do not like Mathematics, Results show that a larger percentage do like Mathematics, 19 students, which is about 55.9% compared to the 15 students that do not like Mathematics, which is 44.1% as shown in table 4. The percentage of those that like Mathematics is not pleasing when one considers the high Mathematics grades these students had attained in Form5. Moreover Adams (2014) says whatever attitude or feeling a student develops towards a particular subject is influenced by how they perform in the subject. Basically, what Adams is saying is that when students perform well, they tend to have positive beliefs towards the subject. On the other hand,
Mensah et al, (2013) also reported that student’s attitude and beliefs about Mathematics are also based on the performance, and stated that, the more positive the belief, the higher the level of achieving in Mathematics. One can argue that, the liking and not liking Mathematics of the students comes from their performance, looking closely at how the differences of the two groups compared. There are other factors that lead to students developing hate or like attitudes towards a particular subject, as reported in literature.

Op’t Eynde, et al. (2002) defined four categories of self-beliefs, namely; self-efficacy, control, task value and goal oriented beliefs. In this research, our main focus were the self-efficacy beliefs, as they are the ones that play a major role in how one approaches goals, tasks, and challenges (Adams, 2014). Data from table 5 shows that 20(58.8%) students believe they are not good in Mathematics, 6(17.6%) believe that they are average in Mathematics and only 8(23.5%) believes that they are good in Mathematics. Such beliefs develop during the teaching and learning process, such as students’ continuous performance in Mathematics (Schloglmann, 2009). It is believed that, the students’ performance in Mathematics as they go from class to class is responsible for creation of such beliefs (Adams, 2014). He says if students perform poorly in Mathematics from class to class, they will conclude that they are not good in Mathematics. However, the students in the study reported here have been performing well in school Mathematics. This means that, our sample have some positive beliefs about Mathematics, basing this on the claims made by Mensah et al, (2013), that, the more positive the belief, the higher the level of achieving in the subject. It would seem the majority of the students entered with positive beliefs about themselves and Mathematics but maybe due to their performance in MAT111 they then developed negative beliefs about themselves and Mathematics.

From Figures 1 and 2, we see how the different beliefs compare with the student’s performance in MAT111. The results show that students who believe Mathematics is selective have a much higher average than those that said it is not selective. A student who says Mathematics is selective is one who is saying only a few people can do it with less challenges or not everyone can do Mathematics. On the other hand, when one says Mathematics is not selective, they are saying anyone can do Mathematics. Is it possible that the students that said Mathematics is selective are students that see themselves as belonging to the people that can do Mathematics? Considering that these students came from high school with high grades, it is possible that the ones that said Mathematics is not selective were speaking from their previous achievement in Mathematics and are seeing themselves as belonging to the selective group that can do Mathematics. This is where a follow up interview would have benefitted the study. Also, students who believe that Mathematics is not hard and important had their average marks higher than those who believed that it is hard and not important. Students who like Mathematics and also believe they are good in it had their average mark, again higher than those who do not like Mathematics and those who believed they were not good in it. However, the study found that, students who believe that Mathematics is relevant to life situations or irrelevant had their average marks equal, as shown in figure 1.
CONCLUSION

Based on the above findings from the study, the following conclusions were made:

Strong negative beliefs about Mathematics among MAT111 students include Mathematics is hard and Mathematics is selective.

Strong positive beliefs include: Mathematics is important and Mathematics is relevant.

Students with Positive beliefs perform better in Mathematics than those with negative beliefs.

From the above points it is concluded that students come to the university aware of the importance and relevance of Mathematics but they become discouraged by their performance in MAT111. Consequently, they develop negative attitudes and become indecisive about other beliefs, such as the relevancy and irrelevancy of Mathematics. We also conclude that positive beliefs results in good performance and negative beliefs yield poor results in Mathematics.

IMPLICATIONS

The results show that students who had positive beliefs about Mathematics education and about self, performed better than those that had negative beliefs. Since literature shows that performance impacts on beliefs university lecturers should sustain the high level of Mathematics performance that students bring from high school and work hard to develop students’ positive beliefs about themselves in relation to university Mathematics.

Additionally, Mathematics lecturers at UNISWA should liaise with school Mathematics teachers on the teaching and learning of Mathematics so that there is continuity in the students’ success in Mathematics. In this respect, first year Mathematics lecturers should be informed of the content of school Mathematics so that they are aware of concepts to build on.

FUTURE STUDIES

For future research, the following studies can be conducted;

- Explore beliefs students have about Mathematics at the beginning of MAT111
- Probe some possible causes of these types of beliefs among the Students.
- Investigate ways of promoting positive beliefs among first year Mathematics students

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ANALYSING THE ROLE AND USE OF VISUALIZATION OBJECTS IN TEXTBOOKS IN NAMIBIA

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selmanghifimule@gmail.com; m.schafer@ru.ac.za

ABSTRACT

This paper reports on a study that analysed the nature and role of visualisation objects (VOs) used in three approved grade 9 Namibian mathematics textbooks namely y=mx+c to success, Maths for Life 9 and Discover Mathematics 9. To achieve this, 266 VOs from the Algebra and Geometry chapters were analysed in terms of the type of VOs, the roles of VOs, the relation of VOs to mathematical content and the relation of VOs to reality. Other data was also collected through survey questionnaires which sought 50 selected mathematics teachers’ views and perceptions on the use of the identified VOs. The findings revealed that most of the VOs used in the selected textbooks align well with the mathematical content and make abstract ideas concrete, stimulate learning, and simplify and clarify written texts. This implies that VOs in textbooks can be used as a tool for reasoning and an instrument for problem solving. In contrast, however, the findings also revealed that some learners found it difficult to interpret some VOs on their own without the help of the teacher because some VOs are vague and confusing, leading to misinterpretations by some learners.

Key words: Visualisation; Visualisation Objects

INTRODUCTION

Textbooks are a universal and central element of teaching and learning mathematics (Namibia. Ministry of Education [MoE], 2008). In many developing countries where there is often a shortage of reading materials, the textbook is often the only resource text that teachers and learners can draw on for subject-specific content and information (Namibia. MoE, 2008) and thus their quality assumes special importance. Furthermore, the national and school examinations are often largely based on an ability to reproduce what is to be found in prescribed textbooks (ibid.). Researchers indicate that diagrams in mathematics texts, such as textbooks, are often used as visualisation objects to enhance the learning of mathematical concepts (Konyalioglu, 2003; Steenpaß & Steinbring, 2014). Such visual objects can illustrate an abstract idea in a concrete way and they can reinforce a mathematical procedure diagrammatically. VOs also help learners to explore mathematical structures and enhance their meaning (Gellert & Steinbring, 2014).
As a procedure in Namibia, “all textbooks in education require the evaluation and approval of the Namibia National Institute for Educational Development (NIED)’s curriculum panels” (Namibia. MoE, 2008, p. 4). Textbook evaluators mostly base their selection on four criteria, namely the conformity to the subject syllabus; the appropriate coverage of the prescribed content; the language and editorial quality; the design, presentation and ease of use of the textbook (Namibia. Ministry of Education Arts and Culture [MoEAC], 2015). Although the use of visualisation is not specifically mentioned, it is partly incorporated in the last criterion, which looks at the usefulness, relevance and accuracy of graphics and illustrations, and the quality and attractiveness of illustrations. In 2008, NIED’s (Namibia. MoE, 2008) curriculum panel approved three mathematics textbooks for Grade 9 learners. These are \( y = mx + c \) to *Success 8-10* (D'Emiljo, 2009)*, ‘Mathematics for Life Grade 9’* (Courtney-Clarke & Coulson, 2009)* and ‘Discover Mathematics Grade 9’* (Fourie & Marchant, 2008). It is these books that are central to this study.

In 2007, a survey of schools in Namibia for Grades 5-12 revealed that a shortage of books and other instructional materials was prevalent in Namibian primary and secondary schools (Namibia. MoE, 2008). In July 2008, the government of the Republic of Namibia and that of the United States of America (USA) reached an agreement whereby the USA government provided grant funding for public investment in Education through the Millennium Challenge Account (MCA) for five years. In the education sector, the MCA’s overall objective of this sub-activity in education was to achieve a textbook to learner ratio of 1:1 by 2013 for the three core subjects – Mathematics, English and Science (Namibia. MOE, 2008). At the end of this project, the report (Namibia. Millennium Challenge Account [MCA], 2015) indicated the achievement of the goal of 1:1 was reached. Thus, it is incumbent on the teachers to take advantage of the availability of textbooks and get the best out them, particularly in relation to the use of VOs evident in mathematics textbooks.

- To gather sufficient and meaningful data, three research questions formed the core of the study:
  - What is the nature of different visualisation objects evident in the Namibian Grade 9 mathematics textbooks
  - How are these visualisation objects viewed in terms of their use by selected teachers in their teaching?
  - What were the authors’ rationales for using the identified visualisation objects in their textbooks?

**MATHEMATICAL VISUALISATION**

Visualisation is vital in the teaching and learning of mathematics (Pape & Tchoshanov, 2001; Zimmerman & Cunningham, 1991). In his discussion on the roles of visualisation, Arcavi (2003) defines visualisation as: “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 understandings**. This definitions resonates well with this study, for it focuses on VOs which can be interpreted specifically as products of visualisation.

**Visualisation objects**

A VO refers to any configuration of characters, images, concrete objects etc., that can symbolize or ‘represent’ something else (Kim, 2012). Similarly, Diezmann and English (2001) define a diagram as a “visual representation that displays information in a spatial layout” (p. 77). Similarly, in his study representations such as numerals, algebraic equations, graphs, tables, diagrams, and charts are external manifestations of mathematical concepts that “act as stimuli on the senses” and help us understand these concepts (Janvier, Girardon, & Morand, 1993, p. 81).

**Roles and uses of Visualisation objects**

Many researchers recorded that the use of visualisation objects are central elements to the effective teaching and learning of mathematics (Gellert & Steinbring, 2014; Dimmel & Herbest, 2015) because they often help us to ‘see the unseen’ (Arcavi, 2003). Likewise, Soebbeke (2005) proposed that in mathematics classrooms, visual diagrams help the learners to better see mathematical concepts and ideas. In essence, visualisation representations can be used as epistemological tools to explore mathematics structures and bring about new meaning (Gellert & Steinbring, 2014). As for textbooks, which form the basis of this study, Fotakopoulou and Spiliotopoulou (2008) posit that, VOs are important for them because they assist ‘non-expert readers’ to understand the esoteric domain of a scientific field.

Similarly, Duval (1999) suggested what he terms as ‘Invisible mathematical tools’ that assist in making representations to become communicable (p.3). Those tools include drawings, pictorial illustrations/pictures, diagrams, charts and graphs (Fotakopoulou & Spiliotopoulou, 2008). It is against that background that, “more pictures, illustrations, and diagrams have been used in recent textbooks than in the past” (Kim, 2012, p.175). In his views, visual representations in mathematics textbooks can serve not only as informative agents but also as “tools for thinking” which students manipulate (Kim, 2012, p.178).

Many researchers deem the use of visualisation objects to be a powerful tool in learning and understanding mathematical concepts (Kim, 2012; Gellert & Steinbring, 2014). As Levin and Mayer (1993), as cited in Kim (2012) suggested, “Since visual representations provide students with concrete and concise images of related concepts, they help improve students’ understanding of the contents” (p. 177).

In contrast, Steenpaß and Steinbring (2014) warned that mathematical visual images could be ambiguous elements that do not necessarily convey the concept effectively to students, and can thus lead to misunderstanding. Gellert and Steinbring (2014) added that “interpreting mathematical visual diagrams is a challenge faced by mathematicians as well as students” (p.16). Therefore, students require appropriate assistance and
guidance from teachers and knowledgeable peers as they select, interpret, and create visual models of mathematics (Moyer & Jones, as cited in Moyer, 2014, p.3). For these reasons, it is important to understand how representations are used and their roles in mathematics textbooks because “representation is more than a process; it is a way of teaching and learning mathematics” (Fennell & Rowan, as quoted by Kim, 2012, p.1). It is this challenge that inspired this study.

In order to better understand and analyse the roles of VOs evident in Grade 9 mathematics textbooks in the Namibian context, a framework illustrated in Figure 1 was used. This framework was adopted and modified from a study conducted on the analysis of visualisation representations found in Greek’s secondary school textbooks of Economics. For our study, this framework was suitable because it provided room for analyzing and classifying of mathematical VOs both structurally (shapes) and functionally (roles). VOs can be categorized into many sub-groups. For the purpose of this study they were categorized according to their type, relation to the content, relation to reality, function and dimension (Fotakopoulou & Spiliotopolou, 2008), as in Figure 1 below shows.

![Analytic tool to analyse visualization objects](image)

(Figure 1: Analytic tool to analyse visualization objects
(Adapted from Fotakopoulou & Spiliotopolou, 2008.)
SOCIAL CONSTRUCTIVISM AND VISUALISATION

From a constructivist point of view, “all knowledge is constructed” (Noddings, 1990, p.7). A constructivist perspective maintains that individuals’ views and understanding of the world around them are based on an ongoing lifelong process of building and constructing knowledge (Watkins et al., 2004). Yackel (2001), a constructivist, indicates, “Students construct their own meaning from the words or visual images they see or hear” (p. 41). Hence, students need various resources, such as books, technological devices and media with VOs to construct knowledge. From a Namibian perspective, where textbooks are traditionally a key resource for teaching and learning mathematics, one may assert that textbooks are a necessary and critical means for knowledge construction. Other than that, they are also the most readily available and accessible resource for teachers and learners in the classroom. It is against this backdrop that this study took place.

METHODOLOGY

This research was underpinned by an interpretive paradigm using a mixed method approach, utilizing qualitative and quantitative methods (Bertram & Christiansen, 2014). The choice of this paradigm is well aligned with the purpose of this study, which is to understand how teachers make sense of VOs and how textbook authors made their choices in using these VOs in their mathematics textbooks. Data was generated through survey questionnaires and interviews respectively.

Sources of data

The selection of the sources of data for this study was done by using a ‘purposive sampling strategy’ (Bertram & Christiansen, 2014, p.60). In purposive sampling, the researcher makes specific choices about the objects or people to be included in the sampling process for validity.

As indicated earlier, the sources of data in this study were textbooks, teachers and authors. As the grade 8 - 10 mathematics teacher, we opted to use the textbooks within our own field of specialization. The three Grade 9 Namibian mathematics textbooks that were analysed were *y=mx+c to success; Maths for Life Grade 9* and *Discover Mathematics Grade 9*. These textbooks are approved by the Ministry of Education for the use in the junior secondary phase in Namibian schools. Furthermore, all the three textbooks were written based on the 2010 revised national curriculum (Namibia. MoE, 2010). Due to the scope of this study only two chapters from each book were analyzed, namely the algebra and geometry chapters. From our teaching experience, as well as the mathematics congresses that we have attended, these two chapters are not well understood by teachers and learners. As a result, they are perceived to be particularly challenging and are poorly performed. In addition, the participating teachers in this study are Grade 9 mathematics teachers from different regions of Namibia who assembled for the National Mathematics Congress in Swakopmund, Namibia May 2016. The two selected authors both reside in Namibia and were thus easily reachable.
PURPOSE OF THE STUDY

This study aimed to analyse the nature and roles of visualisation objects used in three grade 9 Namibian mathematics textbooks and to understand selected teachers’ views and perspectives on the use of these VOs. It was hoped that this study would contribute towards improving the quality of textbook evaluations, and design of suitable and more comprehensive assessment procedures in Namibia. It was also hoped that it created a critical awareness of the roles of VOs in textbooks amongst teachers, and inspires them to help their learners interpret VOs effectively. The importance of VOs should inspire potential authors to use suitable and appropriate VOs that enhance conceptual teaching and learning of mathematics.

DATA ANALYSIS

Our research study involved both quantitative and qualitative analysis, as described below.

Quantitative analysis

In this study, the quantitative analysis consisted of statistically analyzing VOs by using the analytical framework illustrated in Table 2. This analytical tool is divided into five categories, which enabled us to analyse each VO, according to the type of VOs, the roles of the visualisation objects (this is the special focus of this paper), reality, properties and content. We coded each category and sub-category using table 2.

<table>
<thead>
<tr>
<th>Score</th>
<th>Description of evidence of the indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>n/a</td>
<td>Not applicable</td>
</tr>
<tr>
<td>0</td>
<td>Weak evidence</td>
</tr>
<tr>
<td>1</td>
<td>Average evidence</td>
</tr>
<tr>
<td>2</td>
<td>Strong evidence</td>
</tr>
</tbody>
</table>

The scores in the fourth column were then counted and analysed using descriptive statistics.
Table 2. Coding template to analyse each visualisation object

<table>
<thead>
<tr>
<th>Category</th>
<th>Subtype</th>
<th>Definition</th>
<th>Score A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Picture, Sketch/</td>
<td>A simple drawing/shape which does not have many details</td>
<td></td>
</tr>
<tr>
<td></td>
<td>drawing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Distribution</td>
<td>Histogram; Point Graph; Stem-and-Leaf Plot; Tally Graph</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Photograph</td>
<td>A picture produced using a camera</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Table, matrix, text</td>
<td>A table of different sizes and forms</td>
<td></td>
</tr>
<tr>
<td></td>
<td>chart</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Graph</td>
<td>A graphical representation of data, relations and processes in bar, column,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>pie, spider graphs, graphic timetable form</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Schematic</td>
<td>A representation of an idea or theory for easy understanding.</td>
<td></td>
</tr>
<tr>
<td>Function</td>
<td>Decorative</td>
<td>Made to look more attractive or ornamental – a decoration</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Exemplifying</td>
<td>- They are examples or ideas that the text refers to.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- It exemplifies the problem or idea.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Explanatory</td>
<td>They are notes accompanying the diagram, which assist the text and provide</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>new aspects of information necessary to make the idea under consideration</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>clearer.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complementary</td>
<td>- They provide information not included in the text nor described explicitly</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>in the written form.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Adds to or reinforcement of the written text</td>
<td></td>
</tr>
<tr>
<td>Reality</td>
<td>Realistic</td>
<td>Realistically represents the concept true to real life situation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Metaphorical</td>
<td>Not having real existence</td>
<td></td>
</tr>
<tr>
<td>Properties</td>
<td>3D</td>
<td>It is three dimensional</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2D</td>
<td>It is two dimensional</td>
<td></td>
</tr>
<tr>
<td>Content</td>
<td>Absent/weak</td>
<td>It has a weak connection to the content</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Meaningful to the</td>
<td>In line with the content</td>
<td></td>
</tr>
<tr>
<td></td>
<td>content</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Qualitative analysis**

During our research analysis, the responses to the survey questionnaires and the transcribed interviews of the authors were analysed using inductive analysis. During this analysis process, similarities were coded and categorized to bring about our five major themes. The themes that emerged from the collected data are the interpretation of VOs by learners, the choices on the type of VOs by authors, the roles of VOs by authors and teachers, the relation of VOs to mathematical content, and the VOs relation to reality. In the survey questionnaires, key words were identified, their frequency counted and an average for each keyword was calculated.

**DATA PRESENTATION**

The section begins with the data presentation on the role of the VOs that were evident in the three selected grade 9 mathematics textbooks. Secondly, the research results from the survey questionnaires are presented, followed by the presentation of research results.
from the interviews with the authors. The discussion on the role of VOs as understood by the authors and teachers is also presented.

**Data presentation from three selected mathematics textbooks for grade 9**

The number of VOs from each of the three Namibian mathematics grade 9 textbooks is illustrated in Figure 2.

VOs were counted based on their frequencies. Figure 2 below specifically illustrates the topics under scrutiny in the three textbooks and the number of VOs used in each topic.

As anticipated, Figure 2 shows that there were more VOs used in Geometry in comparison to Algebra in all the three grade 9 textbooks selected for this study.

**Roles of VOs**

Roles of VOs were divided into four subcategories viz:

Decorative - when the VO was made to look more attractive or ornamental – a decoration;

exemplifying - this refers to VOs that make the text and the mathematical idea clearer;

explanatory - this refers to VOs with accompanying notes which clarify the text and provide new aspects of information necessary to make the idea under consideration clearer;

complementary - this refers to VOs that provide information not included in the text nor described explicitly in the written form.

The number of VOs used for these roles in both Algebra and Geometry in the three textbooks are presented in the graphs (Fig 3 and Fig 5) below.
Algebra

Figure 3 shows the number of VOs used for different roles in the three textbooks.

![Figure 3 Number of VOs used in their roles in Algebra](image)

It is clear that VOs used for explanatory purposes were more commonly used in Algebra than the other categories in all three textbooks. It was noted that VOs used for complementing were seldom used in all the textbooks.

Figure 4 below is a specific example of a VO used as an explanatory visual - the notes attached explain what the diagram is illustrating, making the idea clearer.

![Figure 4: VO from y=mx+c p.100, topic: Algebra, solving linear equations](image)

Geometry

Figure 5 below shows the number of VOs evident in the Geometry chapters of the textbooks in relation to their roles.

The graph indicates that more than 50% of VOs in Geometry in all the textbooks were used for the purpose of explanation. It further shows that the decorative and complementary VOs were hardly used in all three textbooks.
Figure 5 Number of VOs used in Geometry and their roles

Figure 6 is a specific example of a VO used to exemplify. The diagram makes the written text clearer, by showing the mirror line, the distance from the mirror line to the object and to the reflected image.

Nonetheless, a third of the VOs only partially illustrated or made clear the idea given. They do not really exemplify the text. For example, the VO in Figure 7 below was used to illustrate Pythagoras’ theorem, which states that “In a right-angled triangle, the square on the hypotenuse equals the sum of the squares on the other two sides”.

This VO only partially illustrates or makes clearer the idea given in the text above. It does not fully exemplify the text, i.e. Pythagoras’ theorem, because it does not fully show in a visual sense what the text has stated, as it does not illustrate that the square on the hypotenuse is the sum of the squares on the other two sides. If, for example, the diagram had included 5:4:3 ratios on the sides then it would exemplify the text statement more fully.
In conclusion, it was observed that, VOs in the Geometry chapters were mostly used for the purpose of explanation in comparison to exemplifying, decorating and complementing.

**BRIEF SUMMARY OF THE RESEARCH RESULTS FROM THE SURVEY QUESTIONNAIRES**

All teachers noted that VOs are central and imperative to the teaching and learning of mathematics as a subject. Therefore, the roles of VOs used in mathematics textbooks cannot be overemphasized. The majority, 95% of the teachers’ responses stated clearly that VOs make abstract concepts concrete and clarify mathematical ideas whose meanings are difficult to comprehend. In addition, all the teachers further asserted that VOs attract learners’ attention and stimulate learners’ interest to learn mathematics. They further argued that VOs also makes mathematics fun and practical. VOs enhance deep conceptual understanding.

85% further highlighted that VOs help learners to grasp mathematical concepts without difficulty as they learn better by seeing visuals rather than texts. VOs play a significant role in learning mathematics as they aid learners to recall the concept discussed during the lesson. It was noted that 40% of the teachers’ responses collected emphasized that VOs can also be used as a tool for reasoning. The majority (90%) of teachers indicated that VOs are central to problem solving in mathematics. VOs also help learners to solve real life problems by relating them to mathematical problems, thus enabling learners to link and connect the mathematical concepts learnt in class to real life situations.

The majority of teachers (90%) stated that most of the VOs which are evident in all the three textbooks align well with the curriculum content, despite arguing that some VOs used were inappropriate, unsuitable, and did not align well with the content. In addition, some teachers claimed that several VOs used in textbooks are not familiar to the learners. This makes it challenging for learners to comprehend them and understand the message they display without the assistance of the teacher.

Most teachers 75% revealed that although they find VOs to be essential to teaching and learning mathematics, there are some challenges coupled with the use of VOs, especially in their interpretation. Some of the VOs lack information; they are ambiguous and are not self-explanatory. The teachers noted that most of the learners could not visualise on their own without the help of the teacher. They further reported that the language used
on some of the notes accompanying the diagrams in some instances, were not at the level of the learners, that is, the level of English was too high for the learners.

Because of these points, they requested authors to use VOs that are familiar to learners and straightforward. On the same note, authors should use diagrams that respond to real life mathematical approaches and methodologies. In addition, the VOs should also align well with the curriculum content. Since the teachers also experienced challenges with the interpretation, they suggested that teachers’ induction and in-service training would be helpful in making full use of the VOs in the prescribed textbooks.

RESEARCH RESULTS FROM INTERVIEWS WITH AUTHORS

The two authors that were interviewed had broad and vast experiences in mathematics and mathematics education. The two provided in-depth and detailed responses to the questions posed to them.

Both authors strongly believed that the VOs serve various purposes in mathematics textbooks.

Both authors agreed that the textbooks are central to teaching and learning of mathematics, and that VOs in textbooks are important elements of what they were trying to achieve in their books. They pointed out that though there are no criteria or conditions on the type of VOs to be included in textbooks, the choice of VOs is entirely their own. They both said that it was important for them to consider the entire spectrum of learner ability – example they had to consider both the weak and the strong learner when choosing VOs. They also said that they needed to ensure that their VOs aligned with the curriculum content. They also commented that the VOs needed to be relevant to learners’ contexts – i.e. the learners needed to be able to identify with the VOs. The authors also had to be careful to select VOs that were not misleading and ambiguous.

Interestingly, both authors said that VOs needed to be easily interpreted by learners alone without the help from the teacher or peers. Both authors acknowledged that it is vital for the VOs to be accompanied by supporting notes. They explained that at times, when the VOs are not self-explanatory they require additional notes to explain what the figure entails. The authors further emphasized that notes help learners to understand what mathematical ideas the VOs are trying to portray and promote. Additionally, the two authors expressed that they both used VOs for decoration purposes in their textbooks. They further acknowledged that VOs used for decoration purposes help to stimulate learners’ interest in learning mathematics, as they are attracted to colourful and interesting drawings and sketches.

Nevertheless, one of the authors did admit to not having the experience to fully utilize the available computer technology to draw diagrams that would capture the attention of young learners. It is thus important that authors have the necessary skills to capitalize on the drawing capacity of the technologies at their disposal, or are able to employ the necessary expertise to do so. There is a need for them to do research and acquaint
themselves with what learners know and what is trending so that they can use familiar VOs to attract learners’ interest in mathematics.

Both authors strongly believed that VOs serve various purposes in mathematics textbooks. The two authors revealed that the VOs could be used as a tool to stimulate the learners’ interest in learning mathematics. The authors agreed that VOs help to simplify and clarify the written text making it easier for the learners to grasp mathematical concepts. Both authors believe that VOs help learners recall the mathematical concepts as the visual information is more easily remembered than text information. Both authors affirmed that VOs could be used as an instrument to solve mathematical problems. VOs simplify the problem as they clearly portray what the written texts signify and provide extra information that allows learners to understand the problem better.

Both authors indicated that it is worthwhile to use VOs that represent the concept true to a real life situation. They explained that this helps learners recognize that mathematics is not confined to the classroom; rather it is practical and has a place in real life, thus inspiring learners to study mathematics. Both authors argued that the VOs used in textbooks need to explain the content explicitly. They further claimed that VOs are entirely dependent on the content, thus the content pre-exists the VOs. They further clarified that content is one of the aspects they consider when selecting the VOs, therefore one cannot choose the VOs before studying the content. This implies that VOs should always be in line with the curriculum content.

Both authors acknowledged that it is significant to use VOs that are familiar to learners and connected to their background and experiences. In spite of that, they argued that it is challenging to use VOs that are suitable and familiar to learners from all 14 regions in Namibia since they come from different backgrounds: rural, urban and different ethnic groups. In addition, the two revealed that they select VOs on an assumption that most of the learners are exposed to different pictures via social media, TV and newspapers.

**DISCUSSION OF THE FINDINGS**

During this analysis process, similarities were coded and categorized to bring about five major themes. Because of the scope of this paper, this particular discussion is only focused on the nature roles of VOs by authors and teachers.

Both the teachers and the authors corroborated Gellert & Steinbrings (2014) assertion that the use of VOs are central elements to the effective teaching and learning of mathematics.

Both authors and 70% of the teachers specified that VOs attract learners’ attention and stimulate learners’ interest in learning mathematics. They further argued that VOs also make mathematics fun, enjoyable and practical. One author confidently explained, “For the learners who do not like mathematics, using diagrams is one way of getting them to like the subject as you get their attention through pictures”. She further denoted,
“learners do not like reading but when you bring in a picture they will get attracted and tempted to find out what the picture is all about”. In accordance with this teacher, Levie & Lentz (1982) recorded that illustrations help motivate students’ reading and stimulate class discussion.

Levie & Lentz (1982) highlighted that text information is remembered well when pictures illustrate it, rather than when there are no illustrations. In agreement, the findings from both authors and teachers indicated that VOs play a significant role in mathematics as they aid learners to remember the concept discussed during the lesson for a longer period. Similarly, visual information is recognized and remembered for longer durations than verbal information alone (Mayer, 1989).

Sobbëke (2005) proposes that in mathematics classrooms, visual diagrams help the learners to better see mathematical concepts and ideas. In agreement, the findings from a number of the teachers and both the authors suggested that VOs help to simplify and clarify the written text, making it easier for the learners to grasp the abstract mathematical concepts easily. A picture gives a meaning better than the written text (Bosch et al., 2006). One teacher explicated, “through the use of visualisation objects, it gives learners a clear picture of what is meant by a certain mathematical concept, e.g. a cube, showing them a drawing of a net of a cube helps them understand better, the faces, the vertex, and make it easier to calculate the total surface area”. Mathematical representations are designed to represent explicitly and concretely mathematical ideas that are abstract (Moyer, 2001).

Some teachers indicated that VOs could also be used as a tool for reasoning. “Pictures, graphs and signs, and other spatial representations play an important role in reasoning, in part because we are able to interpret or infer meanings from these representations without specific instruction in how to do so” (Monoyiou et al., 2007, p. 2).

Ho (2010) in his study reflects that visualisation is at the heart of mathematical problem solving and “it can be a powerful cognitive tool in problem solving” (p. 1). The outcomes from 90% of teachers and both authors pointed out that VOs are significant to solving problems in mathematics. VOs simplify the problem as they clearly portray what the written texts signifies and provides extra information that allows learners to understand the problem better. In addition, Lohse et al. (1994) says, “visualisation objects can facilitate problem-solving and discovery by providing an efficient structure for expressing the data” (p.37). In agreement Diezmann & English (2001) suggest, “In problem solving a diagram can serve to unpack the structure of a problem and lay that foundation for its solution and it can serve as a tool of mathematical learning” (p. 77).

CONCLUSIONS

From this study, it is clear that textbooks are key resources for the teaching and learning of mathematics. They can make important contributions to improving the quality of education in all stages of educational development (Verspoor, 1989). Besides that, we argue that a good quality textbook with appropriate and exciting VOs could have a positive impact on the teaching and learning of mathematics, particularly in Namibia.
From our experience, teachers are continuously looking out for new practices on how to help their learners learn mathematics better and improve performance. We believe that the strategic use of VOs by teachers and learners could enhance the teaching and learning experience of any mathematics classroom. Teachers should be aware of the roles that VOs can play and then integrate these into their teaching repertoire. It is thus important that VO and diagram literacy be developed and encouraged at all teacher-training levels in order for VOs to be used appropriately so that learners are able to read and interpret VOs in such a way that it enhances and enriches their mathematics learning in all phases of their schooling.

REFERENCES


THE LINGUISTIC COMPONENT IN MATHEMATICS ASSESSMENT AND ATTENDANT TENSIONS AND DILEMMAS: THE TEACHERS’ EXPERIENCES.

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ABSTRACT
This paper reflects on the experiences, tensions and dilemmas of two South African Grade 4 mathematics teachers as they taught mathematics and administered annual national assessments to Grade 4 English Second language learners. The paper emerges from a broader PhD study which investigated the linguistic challenges experienced by three classes of 106 Grade 4 learners and their two teachers in the 2013 mathematics national assessments. The paper specifically explores the teachers’ perceptions and experiences of the national assessments. Semi-structured interviews elicited, among other things, teachers’ perceptions of the Grade 4 learners’ assessment experiences, the language of the mathematics assessments and the learners’ reading skills. Findings indicated that teachers felt that the language of the assessments was too difficult for English second language learners, considering their limited linguistic proficiency and exposure. Teachers also experienced dilemmas and tensions about whether or not to assist learners during the assessment, and whether or not to code switch during mathematics teaching, among others. The study recommends consideration of learners’ language proficiency in learners’ assessment, and a provision for teachers’ mediation of the linguistic component to ensure accessibility of test items and guarantee that mathematics assessments assess mathematics rather than language.

Key words: assessment; language proficiency; linguistic mediation; teacher mediation

INTRODUCTION
Of the myriad problems the South African education system faces, a large amount of research attests to the persistence of learners’ poor performance in literacy and mathematics (Department of Education, 2013, 2014; Reddy, Zuze, Visser, Winnaar, Juan, Prinsloo, Arends & Rogers, 2015; Spaull, 2016, Pretorius & Spaull, 2015). In 2015, Grade 12 mathematics results were quite disturbing, with only 20% learners achieving a 50% and above (DBE, 2016). This means the majority of the learners who were learning mathematics at Grade 12 were not able to apply mathematical skills, yet Kilpatrick, Swafford and Findell (2014) argue that at this level, learners are expected to apply their knowledge, to demonstrate different mathematical skills and to apply mathematical reasoning to daily problems so as to compete in the future world. The 2014 DoE results of the Annual National Assessments revealed that in 2014, the average
performance of learners in mathematics declined from 68% in Grade 1 to 37% in grade 4 and 11% for Grades 9. Learners’ poor performance was more marked from Grade 2 to Grade 3, where teachers are not allowed to assist their learners with reading during assessment (as was done in Grade 1 and 2). The decline in performance was also evident in Grade 4 (in 2012, 2013 and 2014) where the language of teaching and learning changed from the learners’ mother-tongue to English.

This study focused on Grade 4 learners who experienced unique transitions which include moving from ‘learning to read’ in Grade 3 to ‘reading to learn’ in Grade 4 (Chall, Jacobs & Baldwin 1990). The DoE (2007) expectation of Grade 4 learners reading fluently at independent level is based on learners whose home language is English, when in actual fact most of the learners are English Second language speakers. This is tantamount to linguistic marginalisation of the bulk of the learners who have to learn in, and read expository texts in, a language they have neither adequate proficiency nor exposure. The expository texts are dense with vocabulary specific to content subjects and are very unlike narrative texts which consist of simple everyday language and which they would have had greater exposure to.

In South Africa, the majority of learners at Grade 4 would only have had scant exposure to English as a subject, for a few hours a day. With that limited exposure and proficiency, they are catapulted into Grade 4 where they use English as a language of learning and teaching without even having acquired the basic vocabulary in English to communicate and learn in, let alone using English in writing assessments at the end of that year (Sibanda, 2017).

In 1979 Cummins proposed the Threshold Hypothesis which explains the cognitive effects of bilingualism in children. The hypothesis postulates that English second language learners, for instance, need to cross a certain threshold in English language proficiency for any competences developed in their home language to transfer to the second or target language (Cummins, 1979). Hence, the learners should be competent in both first and additional languages for transfer to happen. However, considering the limited exposure to English language in most of the South African young learners, it is doubtful that these learners attain the threshold in the additional language, English, for the transfer of linguistic skills to take place. A case can therefore, be made in this paper that, by Grade 4, most South African learners are not proficient in English language. Furthermore, using English for learning, teaching and assessment poses challenges for learners, especially in mathematics which has its own complex language. By Grade 4, learners’ competence in English is not yet well developed and they are also not well-developed in their mother-tongue, as Spaull (2016) notes. Grade 4 therefore, becomes a critical stage with significant transitions and requiring much learner support.

Within this background, this paper seeks to explore the Grade 4 teachers’ experiences of the linguistic experiences of Grade 4 mathematics assessments some Grade 4 learners wrote in 2013 mathematics annual assessments. The study also illuminates the tensions and dilemmas teachers face in relation to the teaching and learning of mathematics.
LITERATURE REVIEW

Assessing English Second Language learners’ mathematical competence in English is problematic because whatever method of assessment is used, it assesses the learners’ English proficiency to some extent (Kopriva, Gabel, & Cameron, 2011). Abedi (2010) argues that assessments which do not take into consideration the learners’ language proficiency are not reliable because they cannot tell what learners really know. Abedi (2006) and Abedi, Hofstetter and Lord (2004) found that much of the underachievement by English language learners in the U.S. context is caused by the linguistic challenges presented by the assessments. Similarly, in South Africa, Graven and Venkat (2013) have questioned the fairness of annual assessments in terms of the inaccessibility of the language of several annual national test items.

The language challenge in mathematics

Mathematics has words, symbols, sentences and grammatical structures which are essentially part of the language (Bergqvist, Dyrvold & Osterholm (2012). It also has highly specialized mathematical terms which have a variety of meanings from those used in everyday language (Bell, 2003). In addition, the technical vocabulary and grammatical structuring associated with it make the oral and written language challenging in its own right (Schleppegrell, 2007, p. 145). Hammil (2010, p. 1) describes mathematics as “informationally dense and structurally complex” and also observes that the ideas are expressed in dense noun phrases and relationships described by verbs and extensive use of logical connectives. Hence, Halliday’s (1989) assertion that it is not only English additional language learners who struggle with mathematical English, but also English home language (HL) learners. If English HL speakers are also challenged by reading despite their oral fluency in the language and their tacit knowledge of the language, the challenge can only be greater for those learning in English as an additional language with little exposure to the language. Cummins (1980) observes that it takes five to eight years for a child to master the linguistic skills necessary for academic language in a second language, like English. The assumption then was that the few hours a day exposure to English as a subject in the three years of schooling which the Grade 4 learners had, would hardly have prepared them for the challenges of assessment in English which they needed between five to eight years to master. Abedi (2010) notes that if learners are to perform well in mathematics, they should possess competence in both everyday language and mathematics specific language. This calls for the teacher to mediate mathematical texts and assessments considering the manifest disadvantage limited linguistic exposure placed on the learners.

NAVIGATING THE LINGUISTIC CHALLENGES IN MATHEMATICS INSTRUCTION AND ASSESSMENT

The application of ZPD and scaffolding

In his theory of the zone of proximal development (ZPD), Vygotsky (1978) argues that a child learns through the best use of potential as well as through assistance, support, or
ZPD is what the learner can do independently and what they need assistance in order to be able to do. When learners are in this zone, they can be successful with instructional help. If ZPD is that which a learner can do alone at a particular time, then that which cannot be performed even with assistance of more knowledgeable one is out of the ZPD and should be avoided. Thus, what children can accomplish with the help of an adult tells more about their mental ability to learn in the future than tests they undertake without any assistance (Denhere et al., 2013). Adults assist children by cuing, showing them how to do something, explaining, or exemplifying in order to make concepts understandable. Barbu (2014, p. 139) suggested “an increased comprehensibility of mathematical presentation, a focus on vocabulary and a scaffolding approach in presenting new facts.

Code switching may also be used as a way of scaffolding the learners en route to independent comprehension in the language. Moschkovich (2010) and Webb and Webb (2013) found code switching to be useful in enhancing learners’ comprehension and discussions that were done in home language, as well as in arithmetic computations, and it is therefore, recommended. It allows learners to express themselves in their home language. Adler (1998, p. 30) however, views code switching as a dilemma in which on one hand teachers feel that explaining the mathematical concepts in the native language of the English Second Language Learners might help them to better understand the material. On the other hand, since all the official testing as well as the future mathematical applications are written in English, the students will have to relearn the same concepts in this language.

Adler then suggested that it is important for mathematics teachers to know why they are doing code switching and how and when to do it. Brock-Utne (2005) observed that although the language of instruction is English in most schools, it has been found that in many South African schools, the mother tongue is the best way to communicate with learners. The same author also observes that code switching in classrooms where the language of instruction is supposed to be English is critical because if teachers speak in English only, it is like teaching dead stones (Brock-Utne, 2007). Barbu (2014, p. 140) then concludes that “code switching is an efficient use of English Language Learners’ language skills and should be encouraged.”

**The issue about oversimplification and the balance that is needed**

In this study, and in other studies before, teachers were concerned with assessments whose language was too complex for Grade for learners and they suggested the simplification of mathematics, as well as science texts so that they can be accessible to English Second language learners. Rollnick (2004, p. 117) however, disagrees with this and points out that, “Oversimplification can lead to loss of meaning and even accusations that the texts no longer reflect the discipline they are trying to reflect.” Rather, she suggests that teachers should mediate the texts, motivating learners while authors make the text sufficiently interesting and attractive. Gee (1996), emphasises the importance of participating in the discourse of the text if one is to access it argues that “ in order to acquire an academic social language learners must be in a position to view
the acquisition of the academic language as an advantage to them and not as a burden (Gee, 2001). Hence, learners need to learn the vocabulary and the grammar of the mathematical language.

**RESEARCH METHODOLOGY**

A case study research approach was employed for the present study, to explore in depth the two Grade 4 teachers’ experiences and perspectives on language issues of the 2013 Grade 4 mathematics ANAs. The two teachers were an opportunity sample since they were the teachers of the learners who participated in the broader PhD study, which investigated the linguistic challenges of Grade 4 mathematics ANAs. One teacher had been teaching Grade 4 mathematics for the past seventeen years and the other one for twelve years. They had also administered the annual assessments since they were introduced in 2011. Therefore, the two teachers were considered to be sufficiently experienced in both the teaching of mathematics and administration of the ANAs to Grade 4 learners. They were also conversant with the challenges that learners experienced in learning mathematics and in writing mathematics tests. Semi-structured interviews were used to gather qualitative data from the two Grade 4 mathematics teachers. Because of the relatively small sample of only two teachers across only two schools, it means that what is illuminated here could not be considered representative of the general population of teachers in South Africa but rather to typify teacher challenges in the majority of South African schools where learners learn mathematics in English. Generalisation was therefore, more to type than to population. The names of teachers used in this paper are pseudonyms. The teachers’ experiences were meant to provide supplementary information for considering learner data and implications of the study. It is however, interesting that the findings that this research illuminates concur with Graven and Venkat’s (2014) research findings of the experiences of the annual assessments.

**DATA COLLECTION**

The two Grade 4 teachers whose classes participated in the broader PhD study were interviewed using a semi-structured interview so that a follow-up on questions could be done. The interviews were done after school for 30 minutes. The two teachers, Buhle and Anathi taught Mathematics in two classes at school B and one class in school A respectively. They shared their experiences on the linguistic demands of the Grade 4 mathematics annual assessments.

**FINDINGS AND DISCUSSION**

The thematic analysis made of the teachers ‘responses, five broad themes emerged as following:

- Teacher perceptions of the Grade 4 learners’ experiences of the language of the mathematics assessments
- Teacher perceptions of the learners’ experiences of the Grade 4 assessments in terms of reading skills
• Teachers’ views on the assessment policy that teachers should not read questions to the learners

• Teachers’ experiences of the levels of cognitive demand of the Grade 4 mathematics assessments

**Teacher perceptions of the Grade 4 learners’ experiences of the language of the mathematics assessments**

The two teachers agreed that mathematical language is difficult for their learners to understand. Anathi and Buhle explicated their views and the quotes are taken verbatim. Anathi explained that “All the learners are Xhosa speakers. They have English as medium of instruction, and are still learning to speak the language. Maths has its own language, that some of them find it difficult to understand” while Buhle had the following to explain:

They performed badly in the past years. Maths language and its terminology all the time is their problem e.g. find sum of; they don’t understand that sum is also total. During ANA they always ask for explanation from invigilator, they can’t do on their own. Question papers are long and they became exhausted and leave other questions blank. Word sums are a nightmare as they don’t know what operation they should use.

What the teachers observed concur with Halliday’s (1989) assertion that mathematical language is not complex for English second language learners only but even for English home language speakers learning mathematics in English. More recent, Barbu (2010, p. 2) also alludes to the difficulty of using English as a language of learning and teaching even within English home language contexts when he mentions that “learning English as it is used in an instructional context is likely to be considerably more demanding than acquiring basic conversational proficiency.” In the same view, Cummins (1980) put forward a hypothesis that it takes five to eight years for a child to master the linguistic skills necessary for academic language in a second language, like English. Anathi and Buhle testify that learners ask for explanations of the questions during assessments, because they are challenged by both the English language used to ask the questions and the mathematics language.

Abedi (2010) argues that mathematics learners are required to possess competence in both everyday language and maths specific language if they are to perform well in mathematics. This is contrary to what the learners the two teachers in this study describe. Buhle and Anathi perceived mathematics as constituting a unique language difficult to understand and this is confirmed by Barbu (2014) who observe that it is not easy for learners learning through their second language to achieve in mathematics because of the highly specialized mathematical terms with meanings that are different from those used in everyday language. The word ‘difference’, for example, is additionally difficult as it takes on another meaning from its everyday use. In this context, it means ‘subtract’ or ‘minus’. If a learner is not familiar with the mathematical meaning of the term, it becomes a source of error itself. Examples of some answers that were given by learners in the test, which show an everyday interpretation of the word ‘difference’, include: they
are most in soccer they are low in cricket Learner 39); the cricket has lower players (Learner A23); the cricket is small and soccer is the biggest (Learner 8). In this respect, Buhle also gave an example of learners knowing the word ‘total’ and not ‘sum’: e.g. “find sum of; they did not understand that sum means the same as total”. Thus Buhle perceived the language used in the mathematics assessment as complex. She described word problems as a ‘nightmare’ for learners because they did not understand the questions and did not know what to do.

In relation to the difficult language in the mathematics assessments, teachers as classroom leaders had tension and dilemma. In Buhle’s words, “learners always ask invigilators (teachers) to help them with explanations of the questions which they do not understand and can’t do on their own”. Both teachers could not state whether they gave assistance to the learners when they ask for it although this was unlikely as it was not allowed. A dilemma was posed by this rule for the teachers had to navigate between their knowledge of the local needs (support for language and reading difficulties) and at the same time comply with the national assessment policy which did not allow the teachers to assist the learners.

**Teacher perceptions on the learners’ reading skills**

Both teachers alluded to the fact that the reading skills for most learners were weak. Anathi thought

the learners’ reading skills are not fully developed. Some learners read words without attaching any meaning to what they read, as some of them are not used to independent reading. Learners do not understand the instructions given to them as they read words, but without understanding. Lack of reading skills affect their performance….

Likewise, Buhle added that “as they are slow in reading that makes them not to finish question paper and not to understand.”

Both Anathi and Buhle perceived that the learners’ reading skills are weak in relation to both reading words and reading without comprehension. Anathi’s view that learners’ reading skills were not developed was confirmed by interviews done to the teachers’ learners in the broader study in which some of her learners could not read questions, while others read fluently but failed to understand what the questions asked of them. In this sense reading was not accompanied by comprehension. An example of a learner failing to read is as follows:

Teacher: Benny, please read the question to me
Benny: Draw the re ... repet ... re ... refish ... reflex
Teacher: reflection
Benny: reflection of the a, a ... arr ... arrow on the v ... ve ... veksheken
Teacher: vertical
Benny: vertical (pauses, can’t read the word ‘dotted)
Teacher: dotted
Benny: dotted line

The following is an example of a learner who could read, but without understanding:

Teacher: Can you please read the question to me?
Peter: (Reads) Draw the reflection of the arrow on the vertical dotted line
Teacher: Do you understand the question?
Peter: No
Teacher: Is there a word that you don’t understand?
Peter (Points to the word ‘reflection’)
Teacher: Reflection?
Peter: And verti … vertical
Teacher: OK.

Pretorius and Lephalala, (2011) contend that comprehension is what reading is all about. Anathi viewed her learners as lacking independent reading skills as she writes, “…some learners read words without attaching any meaning … do not understand the instructions ….” Therefore, the whole point of reading was defeated.

Anathi also raised the issue of learners’ lack of exposure to different types of reading materials. This possibly accounts for the general lack of a reading culture in South Africa as noted by Pretorius (2002) among others. According to the South African Department of Arts and Culture, and Print Industries Cluster Council (2007), many learners in South Africa are seldom exposed to storybook reading and do not have books in their homes, they do not have a reading habit.

While Anathi stated that her learners’ problems concerned reading without comprehension, Buhle’s learners’ hurdle was said to be in reading slowly. As a result, Buhle’s learners did not finish answering all the questions. Buhle also observed the need for learners to be conversant with mathematics specific vocabulary like ‘difference’. Knowledge of mathematics specific vocabulary was therefore, confirmed as vital for learners to understand the questions.

Teachers’ views on the reading policy-Grade 4 learners should not be read to in the assessments

The assessment policy said that during assessments, Grade 1 and 2 learners may be read to if they could not read the questions for themselves, but from Grade 3 onwards, no teacher should read for the learners (DBE, 2012). Anathi agreed that “It is fine but Grade 3s and 4s should also be included. I think they are not fully independent, they need some assistance in reading.” In agreement, Buhle added that “the question papers on their own is a nightmare; also they believe on something from their educators mouth. They hear the instruction better by being told than reading, they understand better by being told.”

Both teachers agreed that even the Grade 4 learners should be assisted during the assessments. For Anathi, there should be mediation in reading the mathematics assessments for Grade 3 and 4 learners as well since some learners had not developed their reading skills sufficiently to be independent. This is consistent with Vygotsky’s (1978) observation that children's achievement, when assisted by an adult, improves. Teachers in this study believed that if they assisted learners in the assessments, they would have been aware of areas of difficulty for their learners. For Buhle, the assessment question papers are way beyond their capability. They did not understand them on their own. Buhle believed that learners understood better when the questions are read to them (they understand better when they are being told).
This was an important observation which needed to be considered. It makes clear that the learners have not developed some measure of competence in the English language at the oral level which allows them to comprehend statements read to them. The implication of this is that the learners have not sufficiently developed their competence in reading the written form of the language which explains their inability to comprehend what they read for themselves. This leads on to the fact that learners have not adequately developed their reading fluency which results in the short term memory being taxed as it can only hold a few items for a limited duration (Abadzi, 2008). By the time the slow reader is finished with the last words of a long question, the first words would have been lost and comprehension is compromised. When the teacher reads for them fluently, they are more likely to memorise all the words of the sentence/question and determine its meaning.

The two teachers were also asked whether learners would profit from the reading of the questions by the teachers. Anathi agreed and explained that “Most of the learners do not perform in the maths assessments. After they have written the assessments, I take normally the same questions from the assessments and they perform much better because of the explanation, but not explaining each and every question.” Buhle was also of the same opinion. For Anathi, mediation through reading and explanation of the questions helped learners to demonstrate transformation and process skills. This was also confirmed by the interviews that were carried out with Buhle and Anathi’s 2013 Grade 4 learners. On one hand, the learners’ performance in the assessments that they wrote without assistance from their teachers was very poor. On the other hand, learners’ performance in the interviews, where there was mediation from the interviewer improved greatly with most of the interviewed learners improving on more than half of the 15 questions that they answered. This confirms the teachers’ comments.

**Teachers’ experiences of the levels of cognitive demand of the grade four mathematics assessments**

Teachers were also asked their views about the cognitive demands of the Grade 4 mathematics assessments. Anathi alluded to the fact that the assessments were relevant and appropriate for Grade 4. This was because there was “quite a wide range of levels of difficulty which is good so as for learners to be able to identify, compare, solve problems or to match.” Without directly answering the question Buhle explained that “Maths should be taught in English from lower grade; then we won’t experience this disasters. Firstly additional language is not their mother-tongue; simple English should be used.” Rollnick (2004, p. 117) however, argues against the ‘dumbing down’ of texts for the sake of second language learners. For her, “Oversimplification can lead to loss of meaning and even accusations that the texts no longer reflect the discipline they are trying to reflect. Teachers should rather teach this language so that learners learn them, even if it is difficult.

Anathi argued that the cognitive level of demand of the problems given in the assessments was appropriate for Grade 4 level. If the range of levels of difficulty was considered appropriate for the learners, the implication is that Anathi sees the problem
as one that lies with learners who cannot read and who do not understand the language of mathematics. It was important for her that the levels tested learners in different learning outcomes. Although earlier in the interview she criticised the language of the assessments for being difficult for the learners to understand, she agreed with the variety of different activities and learning outcomes that the assessment test, which she claimed to be ‘relevant and appropriate for Grade 4.

For Buhle, the main issue compromising learners’ performance was the difficult language and similarly the language of instruction for learning. While not explicitly addressing the issue of cognitive demand, she advocated simple language in the assessments, however, relinquishing herself from the role of teaching the terminology and language of mathematics. Buhle raised a tension here in relation to the teaching of mathematics in mother-tongue. According to her, mathematics ‘should be taught in English from lower grades’. This implies access to mathematics in the English language earlier in their schooling. However, learners would then have difficulties learning mathematics in English in the foundation grades.

Buhle’s statement “… additional language is not their mother-tongue” shows that she noted difficulties with learners learning mathematics in an additional language. Buhle confessed to using isiXhosa in class when teaching mathematics although the language of instruction was ‘supposed’ to be English. Thus she said the truth

To be honest in class usage of code switching is too much during teaching as I should start them from naming numbers. Questioning for them is too advanced, e.g. Arrange from descending to ascending, instead of saying start with the bigger/smaller number.

Buhle raises a tension here in relation to her use of code switching. This is because ‘Questioning for them [learners] is too advanced’. The implication is that Buhle has to navigate between the knowledge of the local needs, i.e. learners who need explanations in the mother-tongue, and to comply with the language policy that from Grade four the LoLT should be English. This results in her having to rely on code switching in order to make her teaching accessible to learners. This tension concurs with the research by Brock-Utne (2007) and Webb and Webb (2013) in which they argue that learners benefit from code switching because they learn and understand better when they are taught in their home language. Another implication is that although the mathematics vocabulary is difficult to learn, it has to be taught in order to be known and for learners to be able to read and understand questions. Through judicious use of the home language and English, the LoLT, learners can be exposed to the target language and learn the mathematics language.

CONCLUSION AND RECOMMENDATIONS

Literature show how learners struggled with learning mathematics in a second language. This study has also illuminated that the two teachers concur with the literature on the learner challenges. Both teachers perceived the mathematics language to be a challenge for Grade 4 learners who had no enough exposure to the English language. From the teachers’ views it was not easy for the learners to learn in an additional language, let
alone the mathematics assessment language which is complex and ‘difficult to understand’. Both teachers expressed the view that reading skills for most learners were weak in relation to reading words, reading fast and fluently, and in reading with comprehension. The teachers recommended that reading skills needed to be developed by giving learners an opportunity to read a lot of material independently. The teachers also stated that learners would perform better if they were assisted with the reading of the assessment test items which they could not read on their own.

The study also illuminated a range of tensions and dilemmas that teachers faced and these included the dilemma of whether teachers should assist learners during assessments, satisfying the local needs of learners or comply with the rules of the assessment policy, not helping learners when they asked for assistance. The other issue was in relation to teacher managing the difficulties of teaching mathematics in English through the use of code switching during teaching. One teacher felt learners understand better if their home language is used together with English to teach mathematics, although the language policy at the school stipulated that from Grade 4, the LoLT is English. Teachers then find themselves in a quandary whether to continue teaching the learners in English which they do not understand or use the learners’ home language.

A mathematics teacher, as a leader in the mathematics classroom operate out of a driving desire to meet the needs of learners. The teachers as leaders believe that all learners can succeed and that all teachers need collaborative support to help their learners realize that goal of success (Robbins & Ramos-Pell, 2010). It is also critical for teachers to be proficient in the LoLT as well as cross-cultural competence in order to teach and communicate to learners successfully (Evans & Cleghorn, 2010). It is recommended that teachers teach the difficult language to learners and assist learners to understand the language. In terms of weak readers, it is recommended that the assessment questions be read to them or the language mediated in any way as is the case with Grade 1 and 2 learners, an assessment can only be considered valid if learners access what is asked of them. If not, then the assessment becomes invalid. Assistance in reading the questions would allow learners to demonstrate their mathematical skills to best advantage. The success of learning mathematics lies within the power structure of policy making. This is a sociological issue rather than a mathematics issue. It is also an issue relating to the fact that English Second Language learners need at least 5-7 years of English language learning before they can use it effectively to learn.

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LINGUISTIC COMPLEXITY AND RELATED STUDENT ERRORS IN MATHEMATICAL LITERACY EXAMINATIONS: IMPROVING INCLUSIVE ASSESSMENT PRACTICES FOR ENGLISH LANGUAGE LEARNERS

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ABSTRACT

Unnecessary linguistic complexity threatens the validity of examination items and thus compromises the fairness of the assessment for English language learners, that is, students for whom English is not their home language. The South African National Certificate (Vocational) Mathematical Literacy examinations have been consistently criticised for the language level used in examinations. This paper focuses on providing an in-depth description of the linguistic features of two Mathematical Literacy examinations and explores how these relate to the types of errors English language learners have made in these examinations. Fifteen students’ examination scripts were analysed. In total, 105 examination items were assessed according to their linguistic complexity, and 1396 student responses were analysed, of which 869 were errors whose source was inferred from the detailed working of the students. Several language features were found to contribute statistically significantly to the linguistic complexity of the examination items. Included among these are: words of seven letters or more; prepositional phrases; and complex and compound sentences. It was also determined that approximately 19.22% of the errors made by students were related to language features of the text. This implies a marked disadvantage for students who are less proficient in the language of assessment.

INTRODUCTION

There has been a global increase in linguistic and cultural diversity in classrooms (Khisty, 2006), challenging educators to develop strategies of teaching and assessing that effectively address the needs of these students. In testing the subject matter competency of students for whom English is a second language, language ability may confound their results where they are assessed in English (e.g. Abedi, Courtney & Leon, 2003). Abedi and Gándara (2006, p.38) point out that English language learners’ reading proficiency “plays a major role in their assessment outcomes since without proficiency in reading, students will have difficulty understanding test questions”. Abedi et al. (2003) list two effects that language background and proficiency have on test results: students’ language backgrounds affect their performance in content-based areas such as mathematics and science; and the linguistic complexity of test items may threaten the validity and reliability of achievement tests.
Barton and Neville-Barton (2003) explain that research has revealed complex and deep learning disadvantages in schools where the students’ language proficiency in the medium of instruction is extremely poor. Where there is unnecessary linguistic complexity in a test item, the validity of the item can be questioned for such students, as the construct measured may no longer be that which is targeted (Abedi, 2006). Abedi’s (2006) research revealed an increasing performance gap between English home language and English second language students as the language demand of the assessment was increased. It is therefore essential to not only talk of inclusive teaching and learning practices but also of inclusivity in assessment practice.

Currently, the NC(V) examinations are evaluated for their linguistic complexity in a relatively superficial manner, assessing only whether the language is pitched at an appropriate level and that no bias is evident (Umalusi, 2010). It is specified that “language used in all papers should be correct [and] there should be no grammar or typing errors” (p.22) and it is mentioned that the editing process be rigorous, yet no guidance is offered as to specifically what elevates linguistic complexity to an inappropriate level, and what would constitute unnecessary linguistic complexity. The most recent evaluation of the NC(V) includes criticism that in the 2015 Mathematical Literacy examinations: “instructions to candidates were not clearly specified” (Umalusi, 2016, p.7); “question papers included vaguely defined problems [and] ambiguous wording” (p.15); “questions were poorly framed” (p.15); “there were subtleties in the grammar that might have caused misunderstandings” (p.22); “there were questions featuring very complex syntax” (p. 23); and “rephrasing was necessary” (p.24). For it to be possible to ensure that English language learners are not disadvantaged in any examination, it must be explored and understood how to avoid these pitfalls.

This research focuses on two South African NC(V) Level 4 Mathematical Literacy examinations and evaluates these according to their linguistic complexity. The NC(V) is equivalent in qualification level to the South African National Senior Certificate. It further examines student errors made in the examination and analyses these according to whether the error can be attributed to the students’ mathematical literacy or to factors related to the linguistic complexity of the examination. The research questions it seeks to answer are:

- What is the linguistic complexity of the examination items?
- How are student errors related to the mathematical literacy demands and the linguistic complexity of the items?

These questions are asked with the view to generate practical guidelines for educators and assessors.

**Mathematical literacy in practice**

The PISA Governing Board (2010) describes the specific process of solving a mathematical problem embedded in a context. This is referred to as mathematical literacy in practice and is illustrated in the figure below.
The problem-solving cycle shifts between the real world and the mathematical world. Langley and Rogers (2005, p.1) write that “problem-solving abstracts from physical details”. The physical, real-world, setting provides a form of external memory, therefore aiding problem solving, but the mental activity required to make sense of these details occurs at a more abstract level. As soon as the real-world problem is posed, the input is classified and filtered and a mathematical model is generated. The problem thus becomes represented in the mathematical world. Individuals set up mental representations of the problem situation that can be manipulated to predict outcomes – the intra-mathematical work. The numerical result of this work must then be interpreted to make the real-world decisions for which the calculation was performed. This solution process continues in a cyclical fashion, as the model depicts.

MATHEMATICAL LITERACY IN PRACTICE IN WRITTEN EXAMINATIONS

Mathematical Literacy examinations are typically structured to include a lead-in text which provides the information necessary for solving the problem, as well as contextualising the problem. This text is often accompanied by graphics (e.g. tables, graphs, diagrams) which provide further information, and thereafter the specific questions are asked.
Problems are thus linguistically created, and sources of information are contextualised in text. The construction of a mathematical mental model as depending on four abilities. The first two involve reading for meaning: “the ability to transform each sentence in the text into a mental representation; and the ability to integrate the different pieces of information into a single coherent representation of the problem” (Lucangeli, Tressoldi & Cendron, 1998, p.258). In addition, “the ability to plan the steps necessary to arrive at the solution and the ability to execute the plan” (p.258) are required.

Figure 3 shows how mathematical literacy in practice is enacted in a written examination. The level of a students’ language proficiency will either allow them to understand the context and resume the mathematical literacy problem solving process with accurate information, or it will limit their understanding, causing them to enter the problem-solving process with inaccurate information. In the same way, once the solution has been calculated, the raw number obtained requires encoding back into the context through writing or presenting information in tables, graphs or symbolic notation.
THE NATURE OF MATHEMATICAL TEXTS

Mathematics does include a language component as there are words, symbols, phrases and grammatical structures without which it cannot exist. According to Halliday (1989), it is not possible for basic and everyday language to adequately describe scientific or mathematical concepts. Duval (2006, p.108) writes that it is in mathematics that we find “the largest range of semiotic representation systems”. Included are common forms such as those used in natural language as well as forms such as symbolic notations and graphs which are specific to mathematics (Duval, 2006). This constitutes the “styles of meaning and modes of argument…rather than the words and natural language structures” (K’Odhiambo & Gunga, 2010, p.80).

Mathematical speech and writing requires that students become proficient in both ordinary and mathematical English (Setati, 2002), therefore requiring a certain level of linguistic competence in the language of instruction. Patkin (2011) describes mathematics as possessing “unique linguistic forms” (p.2) and as making frequent use of key terms, such as those signifying the four operations of addition, subtraction, multiplication and division.

The language of mathematics is “informationally dense and structurally complex” (Hammill, 2010, p.1). Complex ideas are expressed in dense noun phrases; relationships are described by verbs; special terminology often conflicts with common use of the words; and logical connectives are used extensively (Hammill, 2010). This has the effect of “obscur[ing] the presence of people, distanc[ing] the reader from the author, and
portray[ing] the student as passive and mathematics as impersonal” (p.1). This can lead to English language learners struggling to comprehend the whole meaning of a paragraph, despite comprehending each of the individual sentences.

It is also difficult to separate the process of reading from the process of problem solving. Lewis (1989) found that the majority of errors on solving mathematical word problems occurred due to the misrepresentation of the problem structure as communicated by the text and not errors in computation. Abedi and Gándara (2006) report that research has revealed two significant conclusions: when linguistic complexity is reduced, the performance gap between English language learners and English home language students is reduced and in the process of reducing this complexity, the construct validity is not necessarily compromised.

ERROR ANALYSIS

Clements (1980) points out that it is difficult to distinctly categorise the source of any one particular error, as they closely interact and overlap. It is, however, possible to apply a theoretical hierarchy of errors to broadly classify what might have led to the student’s incorrect response. Data from researchers who have constructed various analysis hierarchies confirm that a frequent source of errors in written mathematical tasks is “reading and reading comprehension” (p.13). For English language learners, the linguistic item variables together with their own personal competence in the language will impact on their ability to respond correctly to any item. This leads to several recognisable errors.

Newman (1977) has proposed the following error categories into which student errors on mathematical tasks can be grouped: reading; comprehension; transformation; process; encoding. Reading errors arise when a student is not able to understand the actual words or phrases used in the problem. Comprehension errors are closely related, being those that are due to the student not understanding what it is that the item requires. This could be related to the language proficiency of the student, but could also be an indication that the student has not yet fully comprehended the mathematics concept involved. A transformation error occurs when a student is unable to decide what needs to be done in order to solve the problem. Processing errors involve the inability to carry out the method that has been identified as appropriate during transformation, and an encoding error results from the inability to communicate the solution, whether in written or spoken form.

Each error occurs at a specific stage in the problem-solving process. If Newman’s (1977) error categories are mapped over Figure 3, the model describing problem solving in examinations, it becomes clearer where these errors can be placed in this process.
METHODOLOGY

The site selected for this research was an urban vocational college in South Africa in the Eastern Cape. The September Mathematical Literacy examinations (Level 4, Paper 1 and 2) were selected for analysis. The scripts from a class of NC(V) Level 4 students were accessed. The criteria for selection was home language: if the student’s home language was not English, their script was included for analysis. Both exam question papers were analysed for their mathematical and linguistic complexity and fifteen students’ examination scripts were analysed for the source of the errors made. In total, 105 examination items were analysed, and of the 1396 student responses viewed, 869 errors were present and further analysed. This examination was internally set, that is, by lecturers from the selected site. Two examinations are written: the first paper is aimed at assessing basic knowledge and routine application of procedures and the second assesses the students’ ability to reason and reflect on the procedures they apply (Department of Higher Education and Training [DHET], 2014).

In order to answer the first research question, a linguistic complexity index was calculated for each item. Shaftel, Belton-Kocher, Glasnapp and Poggio (2006) investigated which language features impacted student performance the most in a general mathematics assessment administered to Grade 4, 7 and 10 students. Items were coded according to their linguistic complexity, taking into account “total number of words, sentences, and clauses in each item; syntactic features such as complex verbs, passive voice, and pronoun use and vocabulary in terms of both mathematics vocabulary and ambiguous words” (p.111). Their results revealed several aspects of linguistic complexity that “showed unique and statistical effects on item difficulty” (p.117). As a result, they developed a checklist of linguistic features that contribute to item complexity, which has been adapted for use here.

Figure 4 Sources of error in Mathematical Literacy examinations
Examination items are defined as each item for which a student can acquire points. A Linguistic Complexity Index was calculated per item according to the frequency of use of specific language features. Each item was coded by two independent raters and a Linguistic Complexity Index [LCI] was calculated based on these frequencies to allow the direct comparison of items regardless of their length. The number of instances of use of each language feature listed in the checklist was added, and the result divided by the number of sentences. The formula is given below:

$$LCI = \frac{\text{Number of words} + \text{Sum Level B} + \text{Sum Level C} + \text{Sum Level D}}{\text{Number of sentences}}$$

The students’ examination scripts were initially analysed according to which items had been answered incorrectly, in order to ascertain which items had more incorrect responses than others. Thereafter, these scripts were evaluated according to the types of errors the students appeared to be making.

Insight into the source of an error was derived from examining the process the student followed in attempting to respond to the item as evidenced in their demonstrated calculations. Errors were attributed to either a lack of mathematical literacy or to the student’s inability to fully comprehend the item. This lack of comprehension has been carefully considered to determine whether it was due to a lack of mathematical literacy itself, or due to the linguistic complexity of the item and, therefore, due to the language proficiency of the student.
Errors were categorised as due to one or more of the following sources:

- Language proficiency
  - Reading comprehension
  - Writing of solutions as textual descriptions
- Mathematical literacy
  - Viewing – comprehension and/or use of graphic sources of information
- Mathematical calculation errors
- Carelessness
- Indeterminate cause

A raw count of these error types was made per examination item in order to later analyse whether item complexity is correlated with the number and type of errors. This raw error count included both responses from students which resulted in a score of zero for the item, as well as those responses scoring less than full marks but more than zero.

The validity of the documentary sources can be evaluated in terms of their authenticity. The examination and answer scripts are authentic documents from the September examination period. The request for access to the documents and permission to use them in the study was made after the examination paper was produced and after the students had written the examination. It was not possible, therefore, for the research process to have in any way affected the authenticity of these documents. The examination is a typical example of a summative assessment, set by an appointed examiner and subjected to a peer moderation process.

Prior to acceptance of the examination as fit-for-use, it was carefully analysed as to whether the published assessment guidelines (DHET, 2014) had been adhered to. The papers, when considered together, adhered to the guidelines and were therefore considered to be fit-for-use.

The classification of the linguistic complexity of items was done by the researcher with the assistance of a subject expert in English First Additional Language and a subject expert in Mathematical Literacy. This increases the validity of the calculated complexity index. Error analysis was done by the researcher alone, but the involvement of a critical friend in the process compensates for the decrease in validity that this approach would otherwise have caused.

**RESULTS: LINGUISTIC COMPLEXITY**

After calculating the Linguistic Complexity Index for each examination item and lead-in text, it was noticed that a number of language features occurred with a much larger frequency than others. All of these features were listed by Shaftel et al. (2006) as features that contribute complexity to examination items. These frequencies are summarised in the figure below:
Words with seven letters or more were the most frequently encountered language feature. They are considered to be a major source of linguistic complexity according to Bergqvist, Dyrvold and Österholm (2012). In this particular examination, the majority of these words were those which appeared in the mathematical literacy curriculum and as such were part of the vocabulary with which students should have been familiar. These included: instalment, equation, formula, discount, perimeter, and expenses. Mathematical vocabulary, specifically, was explored by Shaftel et al. (2006) and found to statistically significantly negatively correlate with the mean results of Grade 4, 7 and 10 students. This was the only language feature which correlated across all three grades that they had assessed.

Halliday (1989) argues that the difficulty of mathematical texts can, to a larger extent, be attributed to grammar rather than specific vocabulary. There are specific phrases, similar to the special vocabulary, which are characteristic of mathematical texts. Such an example from the examination paper was the sentence “R6000 is invested at 5% compound interest per year” (Paper 1, Q1.9). This is a typical phrase which students of Mathematical Literacy would encounter in an examination paper. Halliday (1989), points out that such phrases are linguistically complex, thus English language learners may struggle to accurately comprehend them in an examination.

Certain language features were identified as being particularly important in indicating relationships between variables and communicating key information relevant to solving the problem posed. Of the language features contributing the most to the Linguistic
Complexity Index for this examination, these were: words of 7 letters or more; prepositional phrases; and conditional/comparative constructions.

Prepositional phrases are necessary when describing how nouns relate to one another. The following list provides examples, from the examination, of texts where a prepositional phrase was essential in communicating information required to solve the problem:

“...per month”
“...in cell E4”
“...on the graph”
“...on Friday at 10:00”
“...in kg”

Comparative constructions were also essential, where used, in communicating key information. Several items relied on such constructions to convey what information needed to be read from the graph, and what calculation had to be done. For example: “Which province had the greater increase in the number of cases reported over the period 2001 - 2005?” The increase would need to be calculated for both provinces, but the word “greater” indicates specifically what information should be provided as the answer.

Prepositions held a statistically significant negative correlation with the item means of Grade 4 students, in Shaftel et al.’s (2006) research, although not for the Grade 7 or 10 students they assessed. Comparative constructions only held such a correlation for the Grade 7 students assessed. In this study, it was prepositional phrases; words with 7 letters or more; and complex/compound sentences for which a statistically significant correlation was found in relation to the value of the Linguistic Complexity Index.

Many grammatical and spelling errors were found in this examination, and these contributed the most to the Linguistic Complexity Index in 9% of the examination items. This is a worrying aspect of this examination. Where many errors are present in a text, it is to be expected that the text will become more demanding for a native speaker of English to accurately comprehend the text, and, therefore that much more demanding for an English language learner. It is possible that this feature of the examination may have been the source of the reading errors rather than the magnitude of the entire Linguistic Complexity Index.

Despite Halliday’s (1989) assertion that grammatical features of mathematical texts contribute more to the linguistic difficulty level, it would appear from Shaftel et al.’s (2006) research, as well as this study, that technical vocabulary does play a significant role in contributing to the linguistic complexity. It is also clear that certain complex features cannot be eliminated from a mathematical text, if it is to retain its meaning.
RESULTS: STUDENT ERRORS

Errors were broadly classified as due to: mathematical calculation inaccuracies; an inability to comprehend or interpret graphics; an inability to decode or comprehend text or an inability to accurately encode mathematical answers in writing. Additional categories were: carelessness; question characteristics; errors whose source could not be determined; and items not attempted. Graphic-related and mathematical calculation inaccuracies were considered to be mathematical literacy-related, as the ability to interpret graphics is included in the learning outcomes for the subject, and the categories of reading and writing were grouped as language-related errors.

Language-related errors: Reading errors

In Question 2.4 students were asked to determine the maximum number of tickets a South African household could buy for the entire World Cup. The correct answer was 28 according to the table provided, which stated that each household could apply for a maximum of four tickets per match for a maximum of 7 matches.

24 tickets per match in a household.

Figure 6 Excerpt from student script (reading error)

This student did not read (or possibly understand) the second half of the relevant sentence stating that the maximum number of matches was 7.

2.4 tickets per match and up for the entire World Cup

Figure 7 Excerpt from student script (reading error)

This student’s response reveals a similar source of error as the first, although the answer is worded slightly differently.

Question 2.5 asked students what the difference was between the price of a Category 1 and Category 4 ticket for the Final. The student’s response given below, reveals that it was understood that Category 1 tickets were more expensive, but not that the Final is one particular match. They have also not specifically noticed the word ‘difference’, which, in the context of a Mathematical Literacy examination, indicates that subtraction is required.
There were several different types of reading errors that emerged in analysing the students’ responses:

- Not reading the entire text – usually ignoring the last section of a lead-in text or item
- Not noticing a particular word
- Not comprehending a particular word
- Not comprehending a particular phrase
- Understanding the lead-in text, but not what the item required

**Language-related errors: writing errors**

Some errors pointed out the inability of students to express themselves in writing, although in their responses it was evident that this was not due to a lack of comprehension of the lead-in text or item.

Question 1.3.3 in Paper 2 asked students whether someone would be on time for an interview, given her time of departure and travelling time. The correct response involved saying that she would be in time for the interview. A second relevant piece of information provided by many students was that she would arrive with 5 minutes to spare. One student replied:

The assessor did not award the student full marks as the person was not going to be given extra time, but would be arriving early. This was despite the fact that the student did seem to understand the information provided, but was unable to translate this understanding accurately into writing.

**Summary of error analysis**

The figure below maps the sources of error onto the problem-solving model referred to earlier. The percentages of the total errors attributable to each source are included:
Mathematical literacy-related factors were the source of marks lost in 65.93% of the errors made. Of this percentage, 18.75% of the marks lost were due to graphic-related errors. This represents 28% of marks lost due to mathematical literacy-related sources. The number of graphic-related errors was high for every item involving the use of a graphic source of information (i.e. tables, graphs and diagrams). In a similar manner, every item which involved the reading of relatively longer pieces of text resulted in numerous reading errors.

Writing was only indicated as the source of error where the student demonstrated an understanding of the source information and the item, but had lost marks due to an inability to convey this answer accurately in writing. These represented a small number of the marks lost due to language errors at 23% of the marks lost to language errors in the whole examination, and 3.57% of all marks lost in the examination. This is most likely a result of the low number of such items, but, similar to graphic-related and reading errors, for every example requiring written responses, a number of such errors were found.

Barton and Neville-Barton (2003) have estimated the variation in academic performance due to English language ability as being up to 10%. In this study, this was potentially as high as 19.22%, according to the percentage of marks lost due to language-related errors, over the whole sample.

Language errors were lower for linguistically simple items and higher for those more complex. Linguistic complexity is therefore a possible source of error. Data gathered by Howie (2005) indicated not only a correlation between mathematical achievement and the language component of an examination, but her data allowed the conclusion to be made that the language component affected achievement in mathematics. This causal conclusion cannot be made based on this data, but the findings do suggest the possibility that this might be the case for this sample in this examination.
PRACTICAL LESSONS FOR MATHEMATICAL LITERACY EDUCATORS AND ASSESSORS

Several practical lessons can be derived from the descriptions and discussions in this research. The lessons would be particularly pertinent to lecturers working in the same college from which the student sample was drawn and whose internal examination was used, however, these suggestions are expected to be valuable guidelines to other lecturers working in both the NC(V) context, as well as those working with other curricula.

Students for whom English is a second language need to be proficient in both ordinary and mathematical English (Setati, 2002). This is a complex task that requires more than just vocabulary lessons. Mathematics possesses “unique linguistic forms” (Patkin, 2011, p.2), with characteristic “styles of meaning and modes of argument” (K’Odhiambo & Gunga, 2010, p.80). It is essential therefore, that sentences and paragraphs are carefully deconstructed for students during class time, such that they can begin to understand how mathematical English is constructed. This is essential if a student is to recognise problem structures through word sums, accurately solve them, and relate the answer to the context in which the problem is posed.

It is difficult to separate the process of reading from the process of problem solving, and misrepresentation of the problem structure is frequently the result of a misunderstanding of the mathematical text (Lewis, 1989). The responsibility for assisting students in navigating this language lies with the Mathematical Literacy lecturer.

It is necessary to focus on vocabulary, as was clear from the description of linguistic complexity and its statistically significant correlates. Lecturers should deliberately draw students’ attention to new vocabulary where it appears, and provide them with a definition. They should not assume that students will be capable of deriving the meaning of the new word from the context of the lesson.

It is not appropriate to teach students to compensate for a lack of comprehension by identifying key words as cues for deriving a mathematical procedure to answer examination items. In this way, such students are not being allowed an opportunity to engage properly with problems in such a way that they can begin to acquire mathematical literacy, they are simply becoming test-wise. This is not a skill which can be applied in any world other than the world of the examination. It needs to be remembered that it is the students’ acquisition of mathematical literacy with which the subject Mathematical Literacy is concerned, and a pure focus on teaching students to pass a Mathematical Literacy examination does not further this cause.

LESSONS FOR MATHEMATICAL LITERACY ASSESSORS

Unnecessary linguistic complexity will compromise the construct validity of a Mathematical Literacy examination as it is possible that this will be a source of measurement error (Abedi & Gándara, 2006). The data in this study showed which language features contributed to the linguistic complexity of the examination.
Several language features were identified as being essential in conveying specific mathematical relationships and concepts. These included: prepositional phrases; conditional/comparative constructions; and words of 7 letters or more. It is therefore essential for certain complex language features to be used, but the number of such features per sentence should not be excessive. When many facts need to be given in a lead-in text, examiners should consider whether sentences can be broken up such that fewer ideas need to be processed in each sentence. It may also be helpful to present facts in a bulleted or numbered list. This would facilitate a reduction in the number of linguistically complex features per sentence and assist students in understanding the information conveyed in, for example, the prepositional phrases.

Some of the language features which contributed to linguistic complexity in this examination could be reduced without altering the meaning of the sentences. Abbreviations, for example, should be given alongside their extended form where they are first used. For example, write the full form of Unemployment Insurance Fund where the abbreviation UIF is first used. The use of passive voice is another example of a feature that added unnecessary complexity to the examination. Sentences should be written in the active voice where this is feasible and appropriate.

Cultural and contextual or experiential references can be avoided if scenarios are carefully considered with regard to the type of student who will be familiar with the context provided. Errors are unacceptable and entirely avoidable. They compromise the quality of the examination and introduce ambiguity that English language learners may not be able to overcome. Examiners should double-check spelling and grammar. Examinations must be proofread by someone who is competent in editing texts. Editors should, however, ideally also be familiar with mathematical language in particular so that meaning is not lost during the editing process.

CONCLUSION

This study has provided a detailed description of the linguistic complexity of NC(V) Mathematical Literacy examination items, which together with an analysis of the source of student errors for these items has revealed an image of what factors may contribute to increasing difficulty for English language learners. In addition to highlighting the significant factors that increased the linguistic complexity of these examination items, this study also revealed that up to 19.22% of the errors made by the participating students were attributable to language related issues. Students lost marks either due to difficulties in decoding the text, or in encoding their written answers in language. This is an important finding that highlights the risk to the validity of such examinations for English language learners. If issues of inclusivity of assessments are to be addressed, close attention needs to be paid to the language demands of the assessment. Equally, it needs to be emphasised that certain language features are a key characteristic of mathematical texts and cannot be eliminated. To mitigate the effect of these features, Mathematical Literacy lecturers need to include explicit focus on decoding these texts in their lectures.
The findings of this study are limited by its small scale, as well as by the choice to not include a comparative analysis of the scripts of English home language students. Key to the argument, however, is that if any errors can be attributed to language proficiency, where the focus of the assessment is to evaluate Mathematical Literacy, this indicates a need to carefully consider that the language demands of the assessment may be compromising its fairness and validity. What can confidently be concluded is that this is an issue deserving attention in discussions about inclusive assessment practices.

REFERENCES


ABSTRACT

The study is part of a larger project concerned with addressing the opportunities and challenges that science teachers usually face in their attempts to implement argumentation-based instructional model (ABIM) in science classrooms. Specifically, the study attempted to examine Pre-service Teachers’ (PTs’) perceptions of argumentation instruction as well as their motivation for using such an approach. The study involved a cohort of 25 (16 males and nine females) PTs who were enrolled in an institute of higher education in Eritrea. The data derived from their responses to an open-ended reflective questionnaire and reflective interview were analysed qualitatively using open coding and the generation of categories. The findings showed that most of the pre-service teachers: 1) held a positive attitude towards the use of argumentation instruction; 2) highly motivated to use the approach in their instructional practices; and 3) provided various reasons for wanting to implement argumentation instructions in their classrooms. Despite positive dispositions towards argumentation instruction however, some of them were hesitant to use the approach in the teaching practice.

Keywords: Argumentation, Argumentation-based instructional model (ABIM), pre-service teachers, science teaching, teacher motivation.

INTRODUCTION

This study was carried out in Eritrea, a country situated in the north-eastern part of Africa. The Eritrean National Education Policy statement envisages transformation of classroom discourse from a teacher-centred to a learner-centred method. The policy further stipulates that teaching method at all levels should aim at strengthening teaching-learning relationships that affirm the active participation of the learner in his/her own learning and development (MOE, 2003). In line with the policy intentions, the new learner-centred curriculum encourages learners to compare, contrast and distinguish different lines of reasoning (MOE, 2005). The aim of the curriculum accords with the views of scholars of argumentation (e.g., Erduran, 2006; Ogunniyi, 2007a) who contend that interactive classroom argument and dialogue encourage teachers and students to externalize their view points and present valid reasons for different stances.

In recent years, argumentation has emerged as a significant goal for teaching and learning science (Kuhn, 2010). As a result, research on argumentation in science
education has intensified exponentially within the last decade (Bricker & Bell, 2008; Jimenez-Aleixandre & Erduran, 2008; Sandoval & Millwood, 2008; Sampson & Clark, 2008). Proponents of argumentation maintain that argumentation-based instruction is effective in promoting students’ understanding of the nature of science (Sandoval & Millwood, 2008; Simon, Erduran & Osborne, 2006) and their conceptual understanding of core scientific ideas (Jimenez-Aleixandre & Erduran, 2008; Sampson & Clark, 2008; von Aufschnaiter, Erduran, Osborne & Simon, 2008). These scholars contend that argumentation brings about such outcomes because it encourages students to engage in learning at a higher cognitive level as they are constantly engaged in questioning, justifying, substantiating and evaluating theirs and their peers’ claims (Jimenez-Aleixandre & Erduran, 2008).

Although the theoretical support for the use of argumentation in science classrooms has been reported in several studies (e.g., Dawson & Venville, 2010; Ogunniyi, 2007a & b), its usage in science classrooms is still very limited (Newton, Driver & Osborne, 1999; Osborne, 2010; Sampson, 2009). The challenges encountered by most science teachers in implementing argumentation in their classrooms are well documented in the extant literature (e.g., Larson, Britt, and Kurby, 2009; Bartholomew, Osborne and Ratcliffe, 2004). Eritrean science teachers also faced similar problems to employ contemporary pedagogical strategies such as argumentation instruction in science classrooms (MOE, 2005).

To address the above challenges, science educators (e.g., Osborne, et al., 2004 a & b; Simon, et al., 2006) organised an on-going school-based argumentation-based professional development programmes for science teachers through Ideas, Evidence, and Argument in Science Education (IDEAS) project. A more detailed discussion of their work will be presented later. Adapting the work of these educators, the authors trained a cohort of Eritrean pre-service science teachers to implement a learner-centred curriculum using ABIM in science classrooms. Then after, the authors examined the effects of the training in enhancing PTs’ understanding of argumentation and their ability to use ABIM to implement a learner-centred curriculum in Eritrean science classrooms. Efforts were also made to examine the PTs’ perceptions towards teaching science through argumentation and their motivation for using it as a pedagogical strategy in science classroom. This paper however, will only present the findings of the later, i.e., findings pertaining to pre-service teachers’ perceptions of argumentation instruction and their motivation for using such an approach.

USING ARGUMENTATION AS AN INSTRUCTIONAL TOOL

Over the past two decades, in an attempt to address the problem posed by the failure of the traditional method of instruction, science educators have explored the contribution of collaborative discourse and argumentation to learning science (Osborne, 2010). Science educators (e.g., Kuhn, 2010; Sampson, 2009; Sampson & Blanchard, 2012; Simon et al., 2006) have indicated that argumentation helps students develop an adequate understanding of cognitive and sociocultural practices of the scientific community. In the same vein, Kuhn (2010) and Simon et al., 2006 assert that
argumentation engages students both in cognitive and social activities and processes that result in improved learning gains. Kuhn (2010), and Simon et al., (2006) go further stating that argumentation engages students in meaningful learning as it enables students’ ownership over construction and the evaluation of knowledge and challenges them to justify their understandings.

Other science educators (e.g., Duschl, 2008) argued that argumentation helps students to develop complex-reasoning and critical-thinking skills, understand the nature and development of scientific knowledge, and improve their communication skills. Erduran (2006) and Ogunniyi (2007a &b) attempted to explain the importance of interactive classroom arguments and dialogues from socio-cultural and psychological perspectives. To them interactive classroom arguments and dialogues can help teachers and students to clear their doubts, upgrade current knowledge, acquire new attitudes and reasoning skills, gain new insights, make informed decisions, and even change their perceptions. Jimenez-Aleixandre and Erduran (2008) have conducted comprehensive analysis of extant literature on argumentation and summarized the importance of introducing argumentation in science classrooms as follows. Argumentation (a) is critical to meaningful learning as it enables participation in cognitive and metacognitive process, (b) develops students’ communication skills, (c) promote students’ critical reasoning skills, (d) supports students’ understanding of scientific culture and practice, and (e) fosters scientific literacy.

The above discussions have shown the importance of the inclusion of explicit argumentation instruction in science classrooms. However, teachers rarely engage their students in argument construction and evaluation experiences (Abi-El-Mona & Abd-El-Khalick, 2006; Evagorou & Avraamidou, 2011; Knight & McNeill, 2011; Kuhn, 2010; Sampson, 2009; Sampson & Blanchard, 2012). The most commonly cited reasons for the scarce use of argumentation in science classrooms are: 1) teachers do not have an adequate understanding of the role of argumentation in real life scientific practices and 2) teachers lack pedagogical knowledge and skills necessary to implement argumentation-based lessons in their classrooms. To address the above problems (e.g., Erduran, Ardac, & Yakmaci- Guzel, 2006; Osborne, et al., 2004 a & b; Simon, et al., 2006) organised an on-going school based research under the theme learning to teach argumentation for professional development of teachers through IDEAS project, which is the focus of the next section.

SCHOOL-BASED RESEARCH PROJECTS ON PROFESSIONAL DEVELOPMENT OF SCIENCE TEACHERS IN ARGUMENTATION

In recognition of the importance of professional development of teachers, many scholars (e.g. (Jiménez-Aleixandre & Erduran, 2008; Osborne, Erduran, & Simon, 2004a; Simon, Erduran, & Osborne, 2006) have organized argument-based intervention programs aimed at training pre-service and in-service science teachers. An interpretive summary of the work of some science educators is presented below.
As part of the school-based research project in argumentation, Erduran, Ardac, & Yakmaci-Guzel (2006) conducted a case study of pre-service secondary school chemistry teachers in Istanbul, Turkey. The purpose of the study was to illustrate how teachers structure lessons and implement argumentation in secondary school classrooms after a series of training sessions. Seventeen pre-service teachers were trained using the IDEAS pack over a six weeks period. The findings indicated that the trained teachers incorporate those features of pedagogical strategies (e.g., group discussion and presentation) targeted by the training. The findings of the research project proved that the intended purpose of the study has been achieved successfully. Also, the researchers noted that there is a need to further develop tools that would identify not only the structure but the content of argument.

Simon, Erduran, & Osborne (2006) also organized professional development programme for secondary school science teachers in Great London for a period of one year. The focus of the study was on developing argumentation skills of teachers and on examining how the target teachers enhance their practice over time. Twelve teachers who were willing to practice teaching of argumentation were selected. Analysis of the data indicates that all teachers attempt to encourage a variety of processes involved in argumentation. The authors have also analysed transcripts of five teachers at a deeper level to identify teachers’ oral contribution that facilitate and support argumentation. The findings revealed that three out of the five teachers show a significant change and the remaining did not.

Osborne et al. (2004a) used similar procedures to examine the quality of teachers’ and students’ argumentation in both scientific and socio-scientific contexts. The focus of their study was to enhance the quality of subjects’ argumentation skills. The result from this study revealed that there is a positive development in the quality of argument of the targeted groups of teachers and students. Implication drawn from this study suggest that students need to be explicitly guided in developing and applying skills of argument in both scientific and socio-scientific contexts and that the application of relevant conceptual knowledge may be needed (particularly in science context) to ensure students are able to engage in argumentation effectively.

Erduran (2006) conducted a similar study on promoting ideas, evidence and argument in initial science teacher training. The aim of the study was to produce resources to support the teaching of ideas, evidence and arguments in the teacher training programme. The model of the training was based on a partnership between the school-based mentors and the trainee teachers. Both mentors and trainee teachers who attended the two workshops were introduced with the programme structure of the workshop and were allowed to reflect on their experiences with the lesson. Exemplary activity resources and feedback from trainee teachers and mentors were described. Erduran (2006) concluded that promoting ideas, evidence and argument in a science teaching is likely to engage both teachers and students in modes of thinking that characterize those of scientists.
Although space limitation did not allow us to present the work of other science educators who have done commendable contributions on argumentation-based teacher development programmes, implications drawn from the four studies reviewed suggest that science teachers need to understand the value of providing evidence to justify or refute a claim in science context. They also need to be aware and adapt the strategies required to facilitate the process of argumentation and move away from traditional approach of teaching.

PURPOSE OF THE STUDY

The aim of this study is to examine the pre-service teachers’ perceived views about the advantages and disadvantages of teaching science through argumentation. The study also explores the pre-service teachers’ motivation to teach science through argumentation. In pursuance of this aim, the study was guided by the following questions:

What perceptions of the advantages and disadvantages of teaching science through argumentation do the pre-service teachers hold?

Are the pre-service teachers motivated to teach science through argumentation in their future classrooms?

METHODOLOGY

As indicated earlier, this case study involved 25 (16 males and 9 females) pre-service teachers who enrolled in an Institute of Higher Education in Eritrea. The PTs were diverse in terms of age, gender, socioeconomic backgrounds, ethnicity and religious beliefs. All the 25 PTs participated in an argumentation-based intervention training programme. The main purpose was to equip them with the pedagogical knowledge and skills that could enable them to deploy argumentation-based instructional model in science classrooms. The PTs were introduced to the concept of argumentation and its role in science teaching. They were also familiarized with Toulmin’s argumentation pattern (Toulmin, 1958/2003). More details about the intervention training programme have been reported in earlier publications (Senait & Ogunniyi, 2017). The study adopted predominately a qualitative interpretive research method (Najike & Lucas, 2002). The data-set was primarily derived from the PTs’ responses to an open-ended reflective questionnaire consisting of eight items.

The questionnaire was developed through a sequence of refinements; drawing critiques from five science education experts. The correlation of the ranking of two of the experts based on Spearman Rank Difference stood at 0.92, signifying a strong face validity, content validity and construct validity. Prior to the main data collection, a pilot testing of the adjusted eight open-ended questionnaire items was conducted. For this study only three open-ended questionnaire items are used for soliciting views about the advantages and disadvantages of teaching science through argumentation and their motivation to teach science as argument. Reflective interviews were also administered to elicit more detailed responses in relation to the pre-service teachers’ written narratives on the open-ended reflective questionnaire. During these interviews, PTs were provided their
questionnaires and asked to read, elaborate and justify their responses. By doing so, the authors were able to assess not only PTs’ perceived views about teaching science through argumentation and their motivation to use it as an instructional approach in their classroom, but the PTs’ reasons for their responses as well.

Data derived from the reflective questionnaire and reflective interviews were compiled into interpretable themes and analysed qualitatively using open coding and the generation of categories (Strauss & Corbin, 1990). Content analysis approach (Silverman, 2001) was used by establishing categories and then counting the number of instances those categories are used in a particular section of text, thus determining/gauging the level of significance of the categories’. In this study, inter-rater reliability was utilized to establish trustworthiness of the data. Mays and Pope (1995) indicated that “the analysis of qualitative data can be enhanced by organizing an independent assessment of transcripts by additional skilled qualitative researchers and comparing agreement between the raters” (p.110). In compliance to their view, the first author and co-author who had sound knowledge about qualitative analysis coded the data and identified broad codes/themes independently. The initial inter-rater agreement was 83%. After discussion and further review, both reached an agreement of 92% which was deemed adequate for the purpose. Dependability was also attained by tracking and documenting the implementation of the study.

RESULTS

We report our results in relation to our research questions and combine the descriptive data with verbatim data. To ensure confidentiality participant pre-service teachers are designated as PT1, PT2 and so on.

**Perceived advantages of teaching science through argumentation**

The analysis of the PTs’ responses to the reflective questionnaire and reflective interview depicted in Table 1 below identified several justifications for the use of argumentation in science teaching. Similar justifications are then grouped and ranked in a descending order of occurrence.

As can be seen in Table 1, the majority of the PTs indicated that the use of argumentation instruction in science classrooms provides a suitable learning environment for students to discuss on controversial issues and supply evidence to either support or oppose one’s claim. This is indicated more explicitly in PT5’s response to the reflective interview.

The use of argumentation-based instruction in a science classroom initiates students to discuss on controversial issues and supply evidence to argue for or against each other’s claim.

Some PTs were of the view that the use of argumentation instruction in science classrooms creates a conducive learning environment for students to externalize their thoughts without any intimidation. This was concisely articulated by PT13 who stated that: *Teaching science through argumentation encourages students to express their ideas freely in dialogue and discussion.* While some PTs indicated the role of
argumentation instruction for knowledge construction, others noted its importance in enhancing students’ conceptual understanding of scientific concepts.

Table 1: Pre-service teachers’ perceived views about the advantages of teaching science through argumentation

<table>
<thead>
<tr>
<th>Response/broader theme</th>
<th>Frequency</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argumentation instruction provides a platform for discussion and encourages students to support or refute a claim by giving reasons</td>
<td>18</td>
<td>72</td>
</tr>
<tr>
<td>Argumentation instruction provides a context for students to externalize their thoughts freely.</td>
<td>16</td>
<td>64</td>
</tr>
<tr>
<td>Argumentation can help students to develop a deeper understanding of a concept</td>
<td>13</td>
<td>52</td>
</tr>
<tr>
<td>Argumentation instruction assists students to construct their own knowledge claim</td>
<td>13</td>
<td>52</td>
</tr>
<tr>
<td>Argumentation instruction can help students develop higher-order thinking skills</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>Argumentation instruction encourages students’ curiosity for further exploration of ideas</td>
<td>8</td>
<td>32</td>
</tr>
<tr>
<td>Argumentation instruction increases students’ confidence in their own knowledge</td>
<td>5</td>
<td>20</td>
</tr>
</tbody>
</table>

Some other PTs highlighted the potential of argumentation instruction in developing students’ cognitive thinking skills and in arousing their curiosity to further investigate scientific phenomena more deeply. Few PTs expressed that the use of argumentation instruction in science classrooms could enhance students’ confidence to express their views during small and whole classroom discussion.

**Perceived disadvantages of teaching science through argumentation**

The PTs were also asked to reflect on the perceived disadvantages of using argumentation instruction in a science classroom. The PTs listed many disadvantages related to the use of argumentation-based instruction in a science classroom. A summary of their views is presented in Table 2. A considerable number of PTs viewed that the use of argumentation instruction in science classroom can result in misconceptions among the students. These PTs elaborated their views noting that teaching science through argumentation can cause misconception if the teacher fails to round off the lesson or if students fail to get the correct answer at the end of the discussion. This is concisely articulated by PT2 and PT18:

I believe that argumentation can help students to think critically and come up with new ideas. However, when students do not get the right answer at the end of argumentation their minds are very confused. This causes a lot of misconceptions among students.

If the teacher does not close the lesson it can cause spread of misconceptions, especially among low-achieving students.
Another aspect considered as a disadvantage by the PTs was frequent use of argumentation instruction in science classroom can reduce students’ motivation for learning. One such PT said:

The attention span of some students may not be good enough to follow all of the discussions taking place during argumentations. Thus, if argumentation instruction is used time and again it may decrease students’ motivation for learning.

Table 2: Pre-service teachers’ perceived views about the disadvantages of teaching science through argumentation

<table>
<thead>
<tr>
<th>Response/broader theme</th>
<th>Frequency</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argumentation instruction can create misconceptions</td>
<td>15</td>
<td>60</td>
</tr>
<tr>
<td>Frequent use of argumentation instruction can decrease student motivation for learning.</td>
<td>11</td>
<td>44</td>
</tr>
<tr>
<td>Argumentation instruction might not be helpful for students who come into the learning environment with limited or no prior knowledge.</td>
<td>9</td>
<td>36</td>
</tr>
<tr>
<td>Argumentation instruction causes the loss of significant instructional time.</td>
<td>7</td>
<td>28</td>
</tr>
<tr>
<td>If there are no available resource materials that support teachers argumentation instruction can be hard to come up with argument-based tasks that facilitate argumentation for every topic</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Argumentation instruction can cause classroom management problems</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Argumentation instruction may not benefit students if the teacher lacks adequate pedagogical knowledge and skills of argumentation instruction</td>
<td>4</td>
<td>16</td>
</tr>
</tbody>
</table>

Additionally, Table 2 highlights that the use of argumentation instruction in science classroom might not be helpful for students with limited or no prior knowledge about a topic. For instance, PT5 said: “Argumentation is not an effective learning tool if students do not have well developed prior knowledge of essential concepts”. Although PT10’s view is not too different from that of PT5, he further extended his view noting that argumentation instruction can be a waste of time if students are unable to generating knowledge claim due to lack of prior knowledge about a topic. This is succinctly articulated in PT10’s response to the reflective interview.

The students who lack prior knowledge may not be able to come up with a claim that needs to be substantiated. If the student cannot participate due to the lack of prior knowledge or knowledge of the concepts under investigation, argumentation can be a waste of time for them. A more direct learning strategy may be more beneficial for them.

Implementing argumentation instruction without ensuring the availability of resource materials that encompass argument-based tasks was considered by some PTs as a disadvantage of using it in science classrooms. Few PTs were also of the view that argumentation instruction can result classroom management problems especially if the
teachers does not have adequate pedagogical knowledge on how to handle small group and whole classroom discussion.

Although all PTs indicated one or two disadvantages of using argumentation in the classroom, four PTs particularly did not value argumentation in science classrooms. We will allude to it later. However, it is important to note that the majority of participants valued argumentation as a means to enhance the quality of their students’ learning in science.

**Motivation to teach science through argumentation**

We also explored whether or not the PTs are planning to use argumentation instruction to teach science in their future classrooms. The results show that all but four PTs had the motivation to teach science through argumentation and provided some reasons to justify their motivation. Table 3 presents a summary of their responses.

<table>
<thead>
<tr>
<th>Response/broader theme</th>
<th>Frequency</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>I will use argumentation instruction because it encourages students to explore scientific ideas in-depth</td>
<td>19</td>
<td>76</td>
</tr>
<tr>
<td>I will use argumentation instruction because it makes learning accessible to all students as it forces all students to think and share ideas.</td>
<td>16</td>
<td>64</td>
</tr>
<tr>
<td>I will use argumentation instruction because it makes learning science enjoyable.</td>
<td>13</td>
<td>52</td>
</tr>
<tr>
<td>I will use argumentation instruction because it results in acquisition of social interaction skills.</td>
<td>11</td>
<td>44</td>
</tr>
</tbody>
</table>

Although the majority of PTs explicitly stated that they planned to use argumentation in their instruction, some of them did not think they would use argumentation to teach every topic stipulate in their curriculum. PT21 puts this succinctly as follows.

I do not think I will use argumentation instruction for every topic I teach but I will use it as I see its appropriateness for the topic I am teaching. For instance, I will definitely use argumentation instruction to facilitate my students’ learning on topics such as acid and base, periodic table and heat transfer. However, there is no way that I can teach the topic atoms and related topics through argumentation. These topics are very abstract in nature and it would not be wise to teach such topics through argumentation. Instead, I will use demonstrations and modelling when teaching these topics.

Others expressed similar views on the use of argumentation instruction in their future classrooms. For instance, PT12 said:

Although I realized how argumentation instruction can benefit my students I do not want to bore them by using the same method of instruction every day. As prospectives teachers we need to use different methods of instruction in order to keep our students engaged in the lesson we are teaching.
These results indicate that the PTs consistently maintained that one could not teach every science topic in their curriculum through argumentation. One theme that emerged repeatedly in PTs’ responses was that science topics are too difficult for young students to understand on their own. In view of this, they expressed tendency to control the construction of knowledge in the classroom in the most efficient way possible using direct instruction approach. While some PTs stated that they would not use argumentation instruction very frequently because it hindered their ability to cover the curriculum in the specified time frame, other noted that using the same method of instruction could bore students and thus decrease their motivation to learn science.

The four PTs that consistently expressed negative views towards the use of argumentation instruction in science classroom provided justifications that are similar to the two exemplary statements displayed in Table 4 below.

**Table 4: Suggested justifications for lack of motivation to teach science through argumentation**

<table>
<thead>
<tr>
<th>Response/broader theme</th>
<th>Frequency</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>I strongly argue that argumentation instruction is not a useful instructional approach to teach science. It takes a lot of time to implement it in the classroom. Instead of spending time in having students argue, I can go over the details of the topic with the students, have them review the material and make connections with real life applications of the concepts covered during the instruction.</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>I do not think I will use argumentation instruction in my future classrooms. Instead, I will prefer to have discussions that result in a definite response. When you use argumentation students get confused, which can result in many misconceptions.</td>
<td>4</td>
<td>16</td>
</tr>
</tbody>
</table>

A close examination of these responses indicates that these PTs held a negative view of argumentation instruction because they believed argumentation did not result in a definite answer. They argued that the ambiguity caused by argumentation would confuse students and not help them learn science. Second, they thought that the time spent on argumentation could be spent on exposing students to the details of the topic under investigation, and thus bring about better learning outcomes for students.

**DISCUSSION**

As revealed in the reflective questionnaire responses and reflective interview responses, the PTs indicated several advantages of teaching science through argumentation. Our findings seemed to show that PTs’ perceptions about the advantages of teaching science through argumentation are in agreement with the view of many science educators who have proven the effectiveness of argumentation instruction in helping students to externalize their ideas and justify their knowledge claims using evidence (e.g., Duschl, 2008; Sampson & Blanchard, 2012; Ogunniyi, 2007a & b). Another salient finding from this study is that PTs’ perceptions towards teaching science through argumentation agree with the view of (e.g. Venville & Dawson, 2010) who have shown the potential of argumentation in knowledge building and in enhancing students’ conceptual
understanding of scientific concepts. As highlighted in the reflective questionnaire and reflective interview responses, some PTs believe that argumentation instruction is a useful mechanism for developing students’ confidence and improving their curiosity and cognitive thinking skills. The perceptions of these PTs are well documented in the extant literature in the area of argumentation (e.g. Erduran, 2008; Ogunniyi, 2007a & b; Osborne, 2010). Although most of the PTs acknowledged the advantage of teaching science through argumentation they consistently argued that it should not be used in every science topic in the curriculum. The major reason given was students cannot learn science on their own. Their perceptions have probably been influenced by the way science is taught in schools and higher institutions of learning. In agreement with the advocators of social constructivists, we argue that the focus and nature of classroom instruction should change from traditional teacher-centred approach to instructional approaches that promote and support student engagement in scientific argumentation.

Our findings also highlighted the perceived disadvantages of using argumentation instruction in the classroom. For instance, a considerable number of PTs point out that teaching science through argumentation may reduce students’ motivation for learning, create misconceptions among students and might not be helpful for students with limited or no prior knowledge about a topic. The perception of these PTs seemed to be in sharp contrast with what was reported in earlier studies (e.g., Cross, Taasoobshirazi, Hendricks, & Hickey, 2008; Ogunniyi, 2007a & b; Venville & Dawson, 2010). These earlier studies indicated that engaging students in argumentation tends to: result in more secure understanding of pre-existing concepts; expose them to new ideas; motivate them to engage in meaningful learning; help them to extend their prior knowledge; and possibly to eliminate their misconceptions. Whatever arguments can be raised, it seemed evident that some PTs still had limited understanding of the role of argumentation in science teaching even after their exposure to the intervention programme. Notwithstanding from their well-justified reasons of some of the PTs, we would still contend that argumentation instruction could still be complementary to other forms of instruction.

While expressing their concerns some PTs highlighted that if the instructional activities are not managed properly, it may have a negative impact on classroom management. It may not benefit students if the teacher does not have adequate pedagogical knowledge and skills that are required to implement argumentation instruction in the classroom. Our findings seemed to be consistent with the view of science educators (e.g., Erduran, 2008; Erduran, et al., 2006; Simon, & Johnson, 2008; Simon, et al., 2006) who contended that for effective implementation of argumentation-based pedagogy teachers should hold adequate pedagogical knowledge and skills on how to teach science through argumentation. The PTs further noted that argumentation instruction might not be a useful instructional approach if resources materials are not readily available to teachers. That is why science educators (e.g., Osborne, et al., 2004b) put considerable effort to develop curriculum resources for teachers to teach science through argumentation. Our findings have also showed that with the exception of four PTs all the PTs participated in this study expressed their motivation to teach science as an argument.
From the forgoing discussion, it seems evident that with the exception of four PTs all the PTs were in favour of argumentation instruction and had motivation to teach science through argumentation. These four PTs argued that argumentation instruction does not bring better learning outcomes for students. Instead, the ambiguity caused by argumentation would confuse students as it did not result in a definite answer. In this regard, the impact of an examination-driven curriculum on these PTs and even practicing teachers in Eritrea and other African countries cannot be over exaggerated. Schwab (1962) calls this the “rhetoric of conclusion” approach to science education in which the construction of scientific knowledge is conveyed as empirical, literal and an irrevocable truth.

CONCLUSION

The findings of this study showed that the majority of the PTs held positive attitudes towards the use of argumentation for engaging their students in meaningful science learning. Yet, they indicated one or two disadvantages of using argumentation instruction in science classroom. Thus, becoming aware of these perceived disadvantages may help teacher educators to design better interventions (especially in their methods courses) that will empower them with adequate understandings, knowledge and skills to successfully implement argumentation in their classrooms. The results further showed that PTs had a high motivation to teach science through argumentation in their future classrooms. In spite of their motivation to use argumentation instruction to teach science, the PTs shared their hesitations to use it to teach every topic stipulate in their curriculum. Our findings also seem to confirm that PTs’ motivation to teach science through argumentation seemed to be influenced by their attitude towards argumentation instruction. Factors that promote or hinder teachers’ perceptions and motivation to teach science through argumentation would however require further investigation.

REFERENCES


ABSTRACT
There is scientific consensus that anthropogenic climate change is occurring and its effects are already being seen across the globe. National science standards and many state standards require teachers to teach about climate change causes and its impacts. The purpose of this study was to find out how pre-service teachers think and feel about teaching climate change during such polarizing and politicizing times. A survey of 19 multiple-choice questions and one short response question was conducted across a sample of 44 pre-service teachers. Rasch analysis was used to validate the instrument and to look for trends in data. Six interviews were conducted, recorded, and later transcribed. Several themes emerged in this study. Themes include: concerns about students feeling helpless; offending students, parents, and administration; teaching with biased perspectives; and about having enough knowledge about climate change to teach it effectively. The role of the media and politics in contributing to climate change misconceptions was highlighted as an additional theme in interviews. Perhaps the most significant finding found across qualitative and quantitative analysis was that pre-service science teachers uphold a misconception that there is a debate over the occurrence of anthropogenic climate change within the scientific community. The authors of this study propose a call to educate pre-service science teachers about the reality of anthropogenic climate change as well as instruction on how to go about demystifying student misconceptions.

Key words: science education, pre-service teachers, climate change, attitudes, Rasch analysis

INTRODUCTION
There is vast scientific consensus of the reality of anthropogenic climate change (Oreskes, 2004). The latest report by The Intergovernmental Panel of Climate Change (IPCC) states that human activities influence the Earth’s climate system and that effects of climate change can be seen on all continents and across oceans (The Intergovernmental Panel of Climate Change, 2014). Climate change can no longer be discussed in future tense and language surrounding climate change reports has shifted from prevention towards social and economic adaptation (Noble, et al., 2014).
Despite scientific consensus on climate change, there has been a significant decline in the public’s concern about climate change since 2009 (Smith & Leiserowitz, 2014). Leiserowitz and Smith (2012) conducted a time series analysis found that climate change skepticism has risen in recent years. The percentage of Americans who associated global warming with skepticism or conspiracy theories rose from 7% in 2002 to over 20% in 2010 (Smith & Leiserowitz, 2012). Several studies have investigated potential reasons for this increase in skepticism and drop in concern. Hypotheses include a correlation to increased cold weather events (Capstick & Pidgeon, 2014), issue fatigue (Smith & Leiserowitz, 2012), decline in trust surrounding the “Climategate” scandal, and the slowing of the economy (Stoutenborough, Liu, & Vedlitz, 2014).

The declination of public concern about climate change may also be attributed to heightened political polarization in recent years. After anthropogenic climate change was placed on the international policy agenda in the early 1990’s, there was a conservative movement to deemphasize the need for the government to spend resources on environmental problems (Jaques, Dunlap, & Freeman, 2008). The conflict between the conservative agenda and climate change action lies in the threat to regulate fossil fuels thereby hindering economic growth (Oreskes, 2004).

If there is any chance of minimizing anthropogenic climate change impacts, the public will be required to play a significant role in limiting greenhouse gas emissions. A study by O’Connor et al. explored the relationship between risk perception, knowledge, and people’s willingness to take environmental action (O'Connor, Bord, & Fisher, 1999). O’Connor et al. defined risk perception in the context of climate change and its perceived likelihood of negative consequences to oneself and society. Findings from the study show that risk perceptions and knowledge increase behavioral intentions towards climate change action. However, people’s prior beliefs about what causes climate change may be a powerful predictor of behavioral intentions (O'Connor, Bord, & Fisher, 1999). Any prior beliefs about what causes climate change may have equal or greater impact on a person’s intentions to act or vote for climate change action than new knowledge or education.

Numerous studies have been conducted to uncover misconceptions held by the general public, K-12 students, pre-service and in-service teachers about climate change. Many similar misconceptions were held throughout the variety of subjects of these studies such as confusing climate with weather, believing that all environmental harms contribute to climate change, relating climate change to air pollution and acid rain, and relating climate change to the ozone layer depletion (Groves & Pugh, 2002; Papadimitriou, 2004; Leiserowitz, 2012; Aron, Francek, Nelson, & Bisard, 1994; Boon H. J., 2010; Gowda, Fox, & Magelky, 1997).

The vast extent of misconceptions surrounding climate change held by educators, students, and the public provides evidence for a need for climate change education. Adolescence marks a development in cognitive abilities such as forming beliefs and worldviews, thus creating a potential window for influence (Stephenson, Peterson, Bondell, Moore, & Carrier, 2014).
The importance of teaching about climate change is promoted by the National Academy of Sciences. Climate change is addressed throughout the Next Generation Science Standards (NGSS), specifically in section ESS3.D: Global Climate Change in which anthropogenic causes, future impacts, and importance of modeling systems is discussed. NGSS state Grade Band Endpoints for understanding the complex concepts behind climate change for grades 5, 8, and 12. Students should understand how human activities, such as how burning fossil fuel contributes to global warming and how knowledge and behavior can help reduce human vulnerability to climate change by the end of grade 8. By the end of grade 12, students should use models to predict and manage future impacts of global climate change and understand the importance of science and engineering practices to manage consequences.

Research shows there is a call for climate change education throughout adolescence to prevent misconceptions about the causes of climate change and overcome skepticism in adults (Stephenson, Peterson, Bondell, Moore, & Carrier, 2014). Yet, anthropogenic climate change remains a controversial and polarizing issue among the general public, despite scientific consensus. There is a systemic inconsistency between the importance of climate change education and the growing controversy surrounding climate change. This dichotomy begs the question: what are the attitudes of teachers towards teaching climate change? Moreover, what are the attitudes and concerns of those teachers who have yet to enter the classroom and how do they intend to incorporate climate change in their science curriculum? Several studies have been conducted to investigate the quality and quantity of climate change knowledge held by teachers (Groves & Pugh, 2002) and best practices for teaching climate change (Fortner, 2001) (Heffron & Valmond, 2011) (Boon H., 2014), but there is a severe lack of research on how teachers think and feel about teaching climate change. This study explores the attitudes of pre-service teachers towards teaching climate change to better understand how climate change will be incorporated in adolescent science education.

METHODS

The sample population for this study consisted of pre-service science teachers enrolled at a Midwestern university receiving licensure in 4th-12th grade science education. This sample provided a range of science curriculum aligned with standards that incorporated teaching climate change (NGSS Lead States, 2013). Any unintentional bias that surfaced throughout this research stemmed from the authors’ conviction to teaching about climate change. Furthermore, cultural biases or implications may have impacted this study. This study was conducted primarily by white middle-class women and the sample population consisted predominately of white, middle-class students in the Midwest.

This study triangulated data methods using a quantitative instrument, a short response question, and interviews. An anonymous survey was gathered involving quantitative and qualitative data from 44 pre-service science teachers. The participants provided no identifying information such as gender, race, or cultural backgrounds to ensure anonymity and participation in the survey was strictly voluntary.
The survey consisted of 19 multiple choice questions concerning pre-service teachers’ attitudes towards teaching climate change. A Likert Scale was used for responses. Question #20 on the survey instrument was designed as a free response question and asked participants to the following question: “When teaching about climate change in the classroom I am MOST concerned about.” Out of 44 pre-service science teachers, 41 participants completed the anonymous free response question. The survey was constructed to ascertain a broad range of the participants’ opinions. It was validated by a group of science educators. The validity of the instrument was determined using the Rasch analytical process of determining if the questions do in fact measure what was intended. In terms of reliability, there was inter-rater reliability (.92) established in the analysis of the qualitative portion of the methodology in determining the major themes emerging from the data.

This study used psychometric analysis in the form of Rasch measurement to develop, validate, and closely analyze quantitative and qualitative assessments by using an ordinal rating scale as oppose to a linear rating scale (Boone & Staver, 2014). Rasch measurement allows for comparisons across respondents as well as across instrument items to determine the weight of the responses (Boone & Staver, 2014).

To maintain a linear scale of agreement, negatively phrased item numbers were flipped (Questions 4, 6, 7, 9, 16, and 18). This recoding of items is a common technique to facilitate analysis of survey items that reflect a single trait, such as positive attitudes towards teaching climate change in the classroom. For the purpose of Rasch measurement, five items were dropped from the survey to maintain a single trait analysis. These items, Questions 3, 5, 11, 14, and 15, were analyzed separately to reveal independent findings. Question 20 was a free response question that was also analyzed independently. Winsteps software was used to run the Rasch measurement analysis.

Qualitative data analysis was conducted via interviews. A total of six 30-45 minute interviews were conducted with voluntary pre-service science teachers from the initial sample population. The participants were knowingly recorded throughout the interview and the conversations were transcribed. The first half of the interview consisted of four broad questions. The questions consisted of the following:

- What is the first word or image that comes to mind when you think of climate change?
- Do you think teaching about climate change is important? Why or why not?
- Do you have any reservations or concerns about teaching climate change in future classrooms? If so, what are they?
- Are there any benefits to teaching about climate change? If so, what are they? Are there any negative consequences to teaching about climate change? If so, what are they?

In the second half of the interview, participants discussed four climate change lesson plans provided by the interviewer. Participants were asked what lesson plans they were
more likely to teach. This activity provided a space for participants to think about how they might incorporate climate change in their curriculum. The provided lesson plans were pre-selected to represent a range of activities surrounding climate change. The lesson plans consisted of building a greenhouse to understand the greenhouse effect, interpreting data over time, understanding sea-level rise, and conducting a debate over climate change in class and were adopted from their original sources (NOW on PBS, 2014) (National Center for Atmospheric Research, 2014) (California Academy of Sciences, 2014) (Hutchings & Epstein Ojalvo, 2010). All lessons were formatted uniformly so as to eliminate possible bias due to appearance and visual presentation.

RESULTS

The following sections explore the findings from the surveys and interviews used throughout this study.

SURVEY FINDINGS

For the survey, the lower the Total Score of an item, the easier it is to agree with that item. The measure of each item reflects the positive attitudes of pre-service teachers towards teaching climate change. The higher the measure, the easier it is to agree with positive statements towards teaching climate change. Question 2, “When teaching about climate change, I will welcome student questions” reflects the highest measure of 3.46 logits across all 44 respondents. Another finding is with item 11, which represents Question 16, “I do not wonder if I have the necessary background knowledge to teach about climate change.” This item received the lowest measure of -2.44, reflecting that respondents found this item more difficult to agree and whether they have the background knowledge to teach climate change.

The items that misfit, or score an Outfit MNSQ higher than 1.3. These items are Question 18, Question 19, and Question 9. The misfit suggests an item does not act predictably. It is the authors’ view that the behavior of these items should be monitored over time, and based upon the authors’ defining of the construct it makes sense to retain these items. In running the Person Entry, ten misfits were found. That is, one person unpredictably agrees or disagrees with a question that their pattern of agreement on other questions does not “fit.” It should be noted that when sample size is small, items are more likely to misfit.

Rasch measurement uses multiple ways of validating the instrument used. The most important aspect of this plot is the top trace of numbers that one can observe. One can observe a sequential series of numbers 1-4. This provides evidence that each rating scale step is providing measurement information, which suggests a well-functioning rating scale within the instrument.

Winsteps Item Entry Table reveals a positive linear ordering and rating scale for survey items and reinforces the instrument was functioning properly. The operational range of each item (Figure 1) showed a range of possible answers. The observed mean was highlighted in Figure 1. This mean reflected a general agreement to survey items. The mean lay between strongly agree and agree for survey questions 2, 7, 17, 19, 1, 7, 4, and
3, but shifts from agree to disagree for questions 8, 6, 10, 9, and 11. This reflects a pattern echoed in the Wright Map demonstrating questions 8, 6, 10, 9, and 11 were more difficult to agree with.

Winsteps Mean Observed Categories

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Figure 1. The predicted average response and operational range of each item.

The Wright Map of Item Measures indicated a hierarchy of item answers ranging from items that are easier to agree with (top) to items that are less easy to agree with (bottom) (Figure 2). This hierarchy used measures along a logit scale in order to reveal gaps and groups of items. There is a significant gap between Question 2 and the Question 7. This indicated respondents found “I intend to incorporate climate change in future classrooms” much easier to agree with than the rest of the answers, such as Question 7; “Climate change is not controversial and should be taught in the classroom.” This suggested respondents intended to teach climate change in the classroom much more than they believe that it is not controversial. Questions 13 and 12 were found to be least easy to agree with, revealing a trend towards low confidence in having enough knowledge to teach climate change. Conversely, Questions 7, 17, 19, and 1 are found easier to agree with suggesting that respondents intend to teach climate change, do feel it is important to teach climate change, and will seek out additional resources for teaching climate change.
A general analysis of survey responses supported findings from Rasch Measurement analysis (Figure 3). When asked if respondents intended to incorporate climate, 97.5% agreed or strongly agreed and 100% of respondents strongly agreed or agreed that it is important to teach students about climate change. However, when asked questions concerning their efficacy of teaching climate change, responses indicated concern or doubt. Only 61.4% of respondents agreed or strongly agreed that they understand climate change well enough to be effective in teaching it.
Survey findings suggested there is confusion among pre-service teachers concerning whether or not climate change is addressed in the Standards (38.7% Disagree or Strongly Disagree, 61.3% Agree or Strongly Agree). There seems to be similar discrepancies surrounding the consensus of climate change. Approximately 25% of respondents strongly agree there is scientific consensus on the reality of climate change, 44% agree, and 30% disagree or strongly disagree.

**QUALITATIVE FINDINGS**

Findings gathered from the short response questions and interviews reveal similar themes. The themes emerging from the interviews were: Concerns about confidence in teaching and clarifying misconceptions, concerns about offending beliefs of students or parents, concerns about teaching without bias and representing all perspectives fairly, concerns about students feeling helpless, doomed, or sad, and concerns about school and administration.

A theme discovered in interviews were concerns of students feeling helpless or doomed when taught about climate change. This theme emerged with a discussion of how to incorporate climate change and how to empower students to prevent a feeling of helplessness.

“I feel like it’s good to kind of relate it back to what students can do…They might start thinking well, if the earth is warming what does that mean and how is that going to change my life? It could get scary for them so I think to have them come up with ways that might help, to give power back…” – Joann

When asked if there are drawbacks to teaching about climate change, Susan shared concern about students feeling sad or doomed but also alluded it as a driving force to care more about climate change:

“I know if I were in 7th grade, if someone would have shown me a picture of a polar bear floating around on an ice cube, I would have been hurt. So I think having these truths come out in the classroom might be painful for the kids.” – Susan

Concerns about teaching without bias and representing all perspectives fairly existed among interview participants and the short responses. Two participants seemed concerned about representing “both sides of the climate change argument”:

“…having the kids doing research on it and find different views about climate change, that way they can start asking questions…” - Amanda

“So I think it’s important to present all sides to the argument surrounding climate change and to not necessarily give one specific argument about it.” – Joann

“Well the only reservations I have are about myself, because I feel so strongly about it. I mean this is a why I am going into teaching is to teach about climate change. I want them to think for themselves. I don’t want to be overly passionate about it so they think they need to change their beliefs to fit mine.” - Susan
The participants seemed concerned that climate change is controversial and the need to validate differing viewpoints. Susan showed concern about her own bias shifting student viewpoints on climate change. All three participants placed importance on students thinking for themselves and coming to their own conclusions.

Participants mentioned that climate change is “controversial” and voiced anxiety as to how to navigate such “controversial” issues. Most participants were concerned about the reaction of parents.

“I’m not so much afraid about what the kids say and do as so much the parents. I see myself sitting at parent-teacher conferences and explaining myself. I see them (the kids) changing their minds…that’s probably going to be challenging for everyone.” – Susan

Participants alluded to politics and the media as sources of controversy and misconceptions for students, parents, and even themselves. Another theme emerged focusing on how pre-service teachers were concerned with the impact of politics and the media on climate change. The word “politics” was often used in a negative context to represent the pro-climate change and anti-climate change arguments, including the media representation of either extreme. In four of the six interviews, participants mentioned and even validated both sides of the climate change debate:

“I’m not really a political person. You hear it a lot in campaigns. The earth’s changing, we’re hurting the environment, we need to become more economically friendly.” – Amanda

“I think the way I would approach it, because it is a politically charged issue, is that I would try to give lots of evidence first.” – Susan

When asked where differing ideas about climate change arose, Cathryn answered:

“I think that different (interpretation) is in the media. Even if there was research done on it, someone could read the results and come up with well, this means this and another person reads the results and think, well, no, this means something else.” – Cathryn

Brit echoed Cathryn’s idea that the media is a source of misconceptions for students:

“…they get a lot from the media so they develop misconceptions and the media portrays things differently.” – Brit

Bobby also discussed misconceptions portrayed by the media. He alluded to debates that misrepresent the argument concerning the existence of climate change:

“….I think many students in the United States, or citizens, see that it’s a debatable topic…I think maybe 90% of the scientists don’t see it as a debatable topic…. It should be taught as a science fact, not as something might happening or might impact us…” – Bobby

Susan was an outlier to the negative connotations participants gave to the word “politics” regarding climate change. Instead of viewing politics in a destructive light, Susan referenced politics as a means to think critically:
“Creating critical thinkers that vote is important. We can look at policies, we can look at organizations that are trying to help with global climate change, …and government agencies, what are they trying to do to help with global climate change?” - Susan

The theme of politics and the media was connected to the idea of holding a debate in the classroom as a means to implement climate change in lesson plans. Holding a debate in the classroom became a source of inconsistency and indecisiveness for participants.

“..parents play a role in how their kids views things and like their political background so it could become a debate in the class depending on what your students views are… their parents may have a different belief and you don’t want the parents to get mad at you as the teacher.”- Amanda

Brit also struggled with using debate in the classroom, stating her concern of emphasizing politics rather than science.

“I don’t want to bring too much politics into the classroom; I don’t want to teach politics. I think where I want to bring it in is identifying prior knowledge, prior misconceptions.”

Even Bobby addresses the idea of debating in the classroom. Earlier in the interview he stated concerns that climate change is not a debatable topic, yet when asked about using a debate in the classroom he stated it could be a positive teaching tool:

“I think a debate could be a good way to talk about climate change… a way to flesh out the ideas of climate change…” - Bobby

Susan, however, maintained her attitudes towards using a debate in the classroom stating that climate change is not a debatable topic.

“I don’t feel like you should be debating it, like “Is it real?” that question really needs to be off the table. I’m going to approach it in a way where science shows it is as real. If you don’t believe it, fine, but I’m going to show you this change in sea level rise activity along with other things that will help you gain an understanding. I don’t really want to debate it.” -Susan

A concern about confidence in teaching material and clarifying misconceptions was emphasized throughout five out of the six interviews and was mentioned in nearly half (46%) of all short responses. Respondents wondered if they could correct student misconceptions and if they had sufficient background knowledge about climate change. Examples of short responses include:

“Not having the necessary background knowledge to address students' questions and concerns.”

“Students counteracting, saying climate change does not exist. Is there enough evidence to back up climate change? Is there too much evidence against climate change?”
Interview participants echoed similar concerns:

“This…you don’t really learn about climate change in university classes. If I were to teach it, I don’t know much about it myself.” - Amanda

“I will be teaching high school students, they will probably have preconceived notions about climate change…getting them to change their mindset would be a difficult thing. I think it’s easy to say, “Here’s the facts, believe them.” But I don’t think it’s easy for them to believe them when they think elsewise.” - Bobby

Along with doubting their efficacy in teaching climate change, participants held misconceptions. Cathryn admits to her misunderstandings:

“See I don’t know because I have a lot of misconceptions about it. So that goes back into I need to do more research personally.” - Cathryn

Brit demonstrates a common misconception in confusing CFC’s as source of global warming:

“There are some people that think we’re not impacting our climate at all. They don’t believe in the fact that CFC’s are contributing to greenhouse gases…” - Brit

CFC’s contribute to the hole in the Ozone layer, which does not contribute to global warming. Another misconception was in their terminology. Participants interchanged global warming with climate change.

“There’s so many things with climate change and global warming and then is climate change a part of global warming?” - Amanda

The idea of using the words “global warming” to denote politically charged ideas and “climate change” to denote the scientific phenomenon was mentioned multiple times. When I changed the phrase from “climate change” to “global warming,” Joann voiced a change of meaning from science to politics:

“Climate change is the natural fluctuations that the earth goes through…I feel I want to say that global warming is more like the political term”. - Joann

Brit also voiced concern about the phrase “global warming” to denote politically charged ideas. Brit says she wants to desensitize the phrase global warming so that people think of the warming and cooling patterns of the earth in a historical context instead of the political implications of global warming:

“And I want to desensitize… students to the phrase “global warming” I want them to realize it’s not just us…But when they hear global warming not to automatically think that it’s NOW. I’m trying to make it more of a scientific term than political term.” – Brit

The qualitative findings point towards the conflicted feelings and beliefs held by the pre-service teachers when considering the teaching of climate change, including
hesitance due to lack of content knowledge, concern about parental and administrative response, and ability to address media and political influences.

**DISCUSSION**

After comparing quantitative and qualitative findings, trends in attitudes towards teaching climate change appeared. Short response findings and survey findings mirrored interview responses. Pre-service teachers shared concerns about climate change aligning with school administration expectations and curriculum standards. They also stated worries about students feeling doomed and want to empower students when teaching about climate change. Findings reveal a desire to represent multiple viewpoints and a well-documented belief that climate change is controversial. The idea of climate change fostering a concern about offending parents and students were found in short response, interviews, and survey findings (a little over 70% agreed or strongly agreed that they worried about offending parents and students). Interviews allowed for a greater scope of attitudes towards teaching climate change and uncovered sources of concern. Pre-service teachers struggled with bringing political viewpoints into the classroom, especially in the form of a debate, in fear of fueling controversy, offending students, and introducing misconceptions.

Perhaps the strongest theme was low self-confidence in teaching about climate change. Survey findings showed that pre-service teachers agreed they intended to teach climate change and agreed that teaching about climate change was vital; they lacked confidence in teaching about climate change. This finding echoed similar concerns with confidence in being able to correct student misconceptions. Participants often stated concern about their lack of knowledge of climate change as well as concern about how students aligned to a strong belief system instilled by parents and the media.

This study showed that pre-service teachers believed teaching about climate change was important and intended to teach it. They demonstrated apprehension about teaching climate change and upheld a core belief that anthropogenic climate change is a controversial topic. Many themes reflected pre-service teachers’ concerns about teaching this issue: offending students, parents, administrators, as well as meeting standards, stumbling into heated debates with students, and even the need to represent “all sides” fairly. The idea of a growing controversy is supported by recent studies that show a rise in climate change skepticism with the public (Smith & Leiserowitz, 2012). What is surprising is that pre-service teachers uphold the misconception that climate change is still debated within the scientific community.

Recent research states that the scientific community has reached a consensus on anthropogenic climate change and agrees that impacts of climate change can be seen worldwide (The Intergovernmental Panel of Climate Change, 2014). The danger of thinking scientists are debating climate change lies in its ability to strengthen misconceptions in the students.

The idea of a scientific debate along with any anxiety over teaching controversial topics also amplified concerns associated with low-efficacy. Any apprehensions about
teaching a controversial issue may be emphasized by a lack of conviction; thus, proliferating hesitation towards teaching about climate change.

This study indicated a need to educate pre-service teachers about climate change in a way that addresses misconceptions. It is imperative for pre-service teachers to dispel the myth of a scientific debate concerning climate change. Not only would pre-service teachers benefit from more background knowledge of climate change content, but they would also benefit from learning various teaching strategies that address climate change. If there is any hope of mitigating climate change effects, it will require an educated and concerned generation of students and teachers.

CONCLUSION

This study found pre-service teachers are generally apprehensive about teaching climate change. They believed that teaching climate change is important and they reported intent to teach about climate change in their future classroom, but they vary as to how they might teach it. Pre-service teachers also share concerns about offending students, parents, and administrators, and making students feel scared or helpless. They believed the media and political agendas perpetuate misconceptions, many of which they hold themselves. Pre-service teachers report low-efficacy about teaching climate change and are not sure if they can ameliorate student misconceptions. A definitive need exists to educate pre-service teachers about climate change, so they are able to meet national science standards and correct recurring misconceptions. Boyes & Stanisstreet (1992) found that well-developed science content courses on issue-specific environmental issues, such as global climate change, are recommended for pre-service teachers in order to ameliorate their misconceptions.

Time restrictions and sample size population were limitations to this study. The sample population of pre-service teachers was restricted to the Midwestern university. Future studies would benefit from a more culturally diverse perspective reflecting the diversification of students learning about climate change. Future research could be a comparison to in-service teachers attitudes towards teaching climate change. By studying veteran teacher attitudes, we could more accurately reflect efficacy issues in pre-service teachers and discuss potential solutions. Also, a deeper investigation into the role of politics and the media and their impacts on science education would supplement this study. It is clear that misconceptions exist for pre-service teachers, begging the question; Where do pre-service teachers get their misconceptions and how does the role of the media and political parties impact their own pre-constructed ideas?

REFERENCES


LESIONS LEARNT FROM A LEARNING STUDY ON TEACHING THE MOLE CONCEPT

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ABSTRACT

Learning Study is an iterative and collaborative process that can serve as the vehicle for investigating the development of teachers’ topic-specific pedagogical content knowledge. The Learning Study was conducted by the author, three experienced Physical Science teachers and science education experts who formed part of a professional learning community. The collaborative process of planning a lesson to teach the mole concept is described to highlight aspects such as focusing on student performance and critically analyzing teaching practice that contribute to professional learning. The pre-testing and post testing of students in the Learning Study was used in refining the lesson and these results indicated there was some improvement in students problem-solving related to the mole but no significant improvement in conceptual understanding. In terms of teacher development, the preliminary findings indicate that the iterative process has an impact on aspects of teachers’ topic-specific pedagogical content knowledge such as the use of representations in teaching the mole concept.

Key words: stoichiometry; learning study, professional learning community

INTRODUCTION

The topic of stoichiometry, which deals with the quantitative aspects of chemistry (Kolb, 1978), is an important topic in the secondary school curriculum. However, stoichiometry is considered both difficult for teachers to teach and for students to learn (Gulacar, Overton, Bowmanc, & Fynneweeverd, 2013). It is within this context of poor student performance in stoichiometry that a Learning Study, as a professional learning activity for teachers to improve their topic-specific pedagogical content knowledge was undertaken. The purpose of this paper is to provide a critical analysis of the lesson developed on the mole concept in the Learning Study. The rationale for this is twofold. Firstly, to document the lesson as a form of scholarship and learning and secondly to make the lesson accessible to various audiences including teachers and the science education research community (Lesson Study Project, n.d.). By creating an artefact for the research community the actual lesson can be built on by other teachers since developing the lesson involved the systematic inquiry of teaching and learning. This paper will therefore outline the key features of a Learning Study that make it a valuable
vehicle for teacher development and the potential impact the lesson developed collaboratively can have on student learning.

BACKGROUND AND THEORETICAL FRAMEWORK OF THE LEARNING STUDY

THE CHEMISTRY TOPIC: STOICHIOMETRY

A concept review of stoichiometry highlights that the mole concept is a key concept to understanding the skills and concepts needed to master stoichiometry (Silberberg, 2006). The mole concept, refers to the amount of substance containing a number of elementary units such as atoms, molecules or formula units equal to number of atoms found in twelve grams of the carbon isotope C-12 (Silberberg, 2006). However, there a few concepts in chemistry that prove as challenging (Furio, Azcona, Guisasola, & Ratcliffe, 2000; Kolb, 1978). Chemistry teachers identify the ‘mole concept’, as one of the most difficult concepts for learners to grasp due to the mathematical application of the mole (Dierks, Weninger, & Herron, 1985; Gulacar et al., 2013). When teaching stoichiometry teachers therefore tend to focus on the algorithmic aspects such as mathematical calculations rather than developing conceptual understanding (Agung & Schwartz, 2007). This is evident based on the wealth of literature that spans over four decades related to the teaching and learning of stoichiometry (Fang, Hart, & Clarke, 2015). Evidence of learners’ lack of proficiency in stoichiometry in South Africa has been highlighted with the inclusion of stoichiometric calculations in the final matriculation examinations over the past few years. The national reports on learner performance in these questions (e.g. Department of Basic Education, 2014) highlight the lack of basic understanding of stoichiometric concepts and an inability to solve stoichiometric problems with recommendations that teachers need to teach the topic better and require professional development interventions to do so.

PEDAGOGICAL CONTENT KNOWLEDGE

In order to teach a topic conceptually teachers require pedagogical content knowledge, or PCK. Shulman (1987, p. 8) defined PCK as the ability of teachers to transform their content knowledge and pedagogical knowledge into an understanding of how particular topics are organized, represented, adapted and presented for instruction to meet the diverse interests and abilities of students. Researchers have used the construct and developed models of PCK in various studies to develop an understanding of teacher knowledge (Abell, 2008). One such model developed by South African researchers is that of topic-specific PCK, or TSPCK. TSPCK has been defined as ‘a theoretical construct referring to the capability needed to transform teachers’ own comprehension of a given topic into formats that are suitable for teaching’ (Mavhunga, 2012, p. 20). This model was used as the framework for planning a lesson on the mole concept as part of a professional learning activity with three experienced Physical Science teachers to develop their PCK. The TSPCK model is presented in Figure 1.
The components of TSPCK within this model are based on the idea of the transformation of teachers’ understanding of subject matter knowledge, or SMK, into forms that are accessible to learners. This transformation is described as the result of teachers knowing and reasoning their comprehension of a specific topic through the five different components (Mavhunga & Rollnick, 2013). The first component, learners’ prior knowledge includes knowing alternative conceptions about the topic. The second component deals with a range of dissections of a topic like decisions relating to what concepts are core and which are peripheral; what pre-concepts are to be in place prior to teaching; which concepts are important in teaching the topic and their sequencing when teaching the topic, referred to as curricular saliency. The third component, namely what makes it easy or difficult to teach the topic, relates to learning difficulties but also contextual factors that could hinder learners grasping the topic. The fourth component, representations, refer to all forms of representations such as graphs, pictures, analogies and models to help learners understand the topic. Finally, the fifth component, conceptual teaching strategies are the conceptual strategies based on the content of the topic. This includes knowing what specific conceptual discussions and/or actions to bring to the teaching of these concepts in order to expand on an area of difficulty. The conceptual teaching strategies go beyond the use of just pedagogical strategies but are informed considerations of the conceptual architecture towards mediating learning in the topic. These components played a central role in the planning of the lesson described in this paper to facilitate the development of the participating teachers’ PCK.

PROFESSIONAL LEARNING COMMUNITY

To teach effectively teachers need to continuously inquire into and improve their own teaching and according to Hargreaves and Fullan (2012) this cannot be done as an isolated individual but rather as a part of a team in a school or community. Professional
learning communities convened and centred around explicit discussions of the transformation of content knowledge for particular topics therefore offers the potential to improve teachers’ conceptual understanding and understanding of learner errors (Brodie, 2011, 2014; Rollnick & Mavhunga, 2015). Professional learning activities that build a teacher community by allowing teachers to work in groups and discuss issues, promote reflection and allow for some type of action research that allows them to focus on data from their own classroom that connects with other forms of knowledge are considered exemplary strategies for professional learning (Brodie, 2013; Lee, 2005). But what is a Professional Learning Community, or PLC? There is no universal definition for a PLC, but the general consensus is that when a group of teachers share and critically interrogate their practice in a reflective, collaborative, inclusive, learning-orientated and growth-promoting way, one exists (Stoll & Seashore Louis, 2007). Such collaboration, based on learning principles that enable effective practice to be developed has the potential to contribute to improving student learning and raising student achievement in schools (Mitchell & Sackney, 2007). It was within this context that the lesson developed through a Learning Study and described in this paper was developed.

**LEARNING STUDY**

During a Learning Study teachers work collaboratively in a systematic way, often with researchers over an extended period of time to identify aspects of student learning of a topic in order to improve teaching (Nilsson, 2008). Learning Study is an iterative process of planning a lesson, teaching and observing the lesson, reflecting and analyzing practice to make improvements and re-teaching the lesson (Pang & Marton, 2003). Learning Study has therefore been described as a type of action research (Adamson & Walker, 2011; Nilsson, 2014). Learning Study is underpinned by variation theory that views teaching as a continuous process of changing students’ ways of seeing by directing learning at something that needs to be learnt by focusing on critical features by highlighting variation (Adamson & Walker, 2011). Variation theory as applied to learning is a pedagogical focus on the relationship of student learning and conditions of learning in which a group of teachers organise learning around an object of learning with emphasise on the variation and invariance along certain dimensions of variation (Pang & Marton, 2013).

**ACTIVITIES OF THE PROFESSIONAL LEARNING COMMUNITY CONDUCTING THE LEARNING STUDY**

**Members of the PLC**

The South African University of the Witwatersrand, at which this study was conducted, offers a Master’s degree in Science Education by course work and a research report. It was from the pool of post graduates that experienced teachers that a PLC was constituted to conduct the Learning Study. The respective supervisors of each teacher were also coopted as experts in science education to form part of the PLC. Sipho, a teacher from Zimbabwe, teaches at a township school in the west of Johannesburg and has been teaching senior Physical Science since 2008. Sipho’s supervisor, Maggie initially obtained a B.Sc in education, teaching for a few years before moving into teacher
education. She has had experience in the development of research-based teaching and learning materials and teacher development programmes. Tendani teaches at a township school in the east of Johannesburg and he is also from Zimbabwe. He has been teaching senior Physical Science since 2009. Ellen, Tendani’s supervisor has extensive experience in chemistry education and science teacher education. As an expert, Ellen has published papers on the teaching and learning of science relating to second-language teaching of science, students’ alternative conceptions and conceptual change strategies, improving teaching of difficult chemistry topics and the development of teachers’ PCK. Sizwe, also originally from Zimbabwe has been teaching senior Physical Science for eight years. He is currently teaching at a township school in the west of Johannesburg. Sandra, Sizwe’s supervisor worked in the chemical industry before moving into teacher education. Sandra has extensive experience in working with the development of preservice teachers’ TSPCK. Pseudonyms have been used to maintain anonymity of the participants.

The Activities of the PLC

The activities of the PLC included planning the first lesson and conducting the Learning Study. This included piloting the lesson and administering the diagnostic tests to students, meeting to analyzing classroom practice and student performance and make improvements based on the feedback before teaching the lesson again through another three cycles of planning and teaching the lesson. The schedule of this plan is summarised in Table 1 and included group sessions and an individual meeting with each teacher participant to finalize the reworked the lesson plan.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Key outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning Workshop with team</td>
<td>• Familiarise participants with construct of TSPCK</td>
</tr>
<tr>
<td></td>
<td>• Developing CoRe for the Mole concept for the lesson</td>
</tr>
<tr>
<td>Planning Meeting with team</td>
<td>• Discussion of conceptual teaching strategies in CoRe</td>
</tr>
<tr>
<td></td>
<td>• Generate lesson plan based on the CoRe</td>
</tr>
<tr>
<td>Piloting lesson by researcher</td>
<td>• Teach the pilot lesson to a group of Grade 11 learners</td>
</tr>
<tr>
<td></td>
<td>• Assess student achievement using pre-test &amp; post-test</td>
</tr>
<tr>
<td>Discussion Meeting with team*</td>
<td>• Analyze practice and student performance</td>
</tr>
<tr>
<td></td>
<td>• Reflect on lesson and discuss improvements</td>
</tr>
<tr>
<td>Planning session with teacher*</td>
<td>• Discussion of improvements and generate lesson plan</td>
</tr>
<tr>
<td></td>
<td>• Arrange resources for lesson</td>
</tr>
<tr>
<td>Teaching of revised lesson by teacher*</td>
<td>• Teach the revised lesson to a group of Grade 11 learners</td>
</tr>
<tr>
<td></td>
<td>• Assess student achievement using pre-test &amp; post-test</td>
</tr>
</tbody>
</table>

* These activities were iterative for each cycle of the learning study with all three participating teachers.
THE LEARNING STUDY

The action research cycle of Learning Study consists of five basic steps (Pang & Marton, 2003). As illustrated in Figure 2, the process is cyclical and includes planning and evaluation, typically of one lesson, that pools the experiences of teachers to enhance student learning (Nilsson, 2014; Pang, 2003). Step one in the flow chart is selecting the object of learning, usually a capability, value or concept that needs to be learnt, often something that students experience as problematic or difficult (Adamson & Walker, 2011; Nilsson, 2014; Pang & Marton, 2003). In this case, object of learning was the big idea for teaching stoichiometry, the mole concept. The second step, is to determine student pre-conceptions by analysis of students conceptions usually a pre-lesson test or informally by scanning through questioning (Pang & Marton, 2003). In this case the diagnostic reports from the Department of Basic Education served to ascertain that in general the problem was widespread and served as the rationale for this Learning Study. In addition to this a pre-test was also administered to students but after the first lesson in the cycle was planned to determine the preconceptions of the specific students being taught. The third step is the planning and implementation of the lesson, which in Figure 2 is separated out as two sub-steps, co-planning and conducting the lesson (Nilsson, 2014).

Figure 2. Steps in a Learning Study using a CoRe as a planning tool
The planning was collaborative and the output was a completed Content representation, or CoRe for the mole concept. The CoRe was a key tool in helping teachers identify critical aspects for student learning (Nilsson, 2008) of the mole concept since the prompts in the CoRe help teachers focus on important aspects to consider when teaching a topic such as key content ideas, student preconceptions and ways of framing ideas to support student learning (Loughran, Mulhall, & Berry, 2008). The lesson was then implemented by the first author as participant-researcher and the lesson that was video recorded. Step four involved evaluating and revising the lesson and also consisted of two sub-stages which included giving the students a posttest to understand how students understanding of the object of learning and its critical features had changed (Nilsson, 2014; Pang & Marton, 2003). The second sub-stage was to collaboratively analyze the teaching of the lesson, which each participant had watched in order to share their experiences of the lesson focusing on teacher instruction in order to revise the lesson based on the experience of delivering the lesson (Adamson & Walker, 2011; Nilsson, 2014). In the next cycle, the revised lesson was taught by one of the participating teachers, Sipho and the same procedure was followed with changes been integrated into the third cycle, with Tendani teaching the lesson, with Sizwe teaching the final cycle in this iterative process (Adamson & Walker, 2011; Nilsson, 2014). The final step is to report on and disseminate the aims and results of the Learning Study to other practitioners and researchers in the field of chemistry education (Pang & Marton, 2003). This paper presents an analysis of the students’ pre-test and post test scores, which were primarily used to work at refining the lesson described below.

**THE LESSON ON THE MOLE CONCEPT**

For the purposes of this Learning Study the object of learning was the mole concept. The specific aspect of the object of learning was an understanding of the mole as the SI unit for amount of substance and the relationships between the amount of substance, the mass of a substance, the volume of a gas and the number of elementary particles. The general aspect of the object of learning was the capability of using the mole concept in stoichiometric calculations. The lesson was conducted by each teacher with students from their respective schools as a revision lesson. These were conducted on Saturday mornings as part of the schools’ intervention programmes. The lesson typically lasted two hours, and the students were given a recess half way through the lesson.

The construct of topic-specific PCK guided the planning of the activities. The product of the first planning meeting was a lesson with four activities. Each activity was specifically designed around the TSPCK components learner prior knowledge or what is difficult to teach. The first activity is described here and aimed to develop a common understanding of the term amount of substance, since students often confuse the word amount for mass (Fang et al., 2015). The activity used to deal with this aspect of learner prior knowledge was the predict-observe-explain strategy working in groups of four. The activity is summarised in Figure 3. The activity highlighted that a spoonful as an amount was not useful in describing the amount of substance as the mass of a spoonful.
of each substance was different in order to introduce the scientific meaning of the term amount.

In the first cycle of the Learning Study, the mathematical relationship between mass and amount of substance was only introduced in activity four. However, based on the discussion meeting after the teaching the first lesson Sandra emphasised the importance on using the three levels of representation together, since this was a descriptor for exemplary TSPCK.

164 Sandra: One of the things we’re promoting is the use of representations. For example, for that experiment you’re doing, which is at a macro level, you would try and put things down symbolically as an equation. So I suggest we move from that point and use different levels in that instant, in a segment.

This idea was incorporated into all three planned activities. The teaching sequence in Activity 1 showing the representations integrating the three levels of representation in chemistry are show in Figure 4. In the second cycle, when the students had measured out a spoonful of each substance and found the mass, they used the sub-microscopic pictures of atoms to explain the differences in the mass of a spoonful of the substances in terms of the particles that make up the substances. They were then introduced to the mathematical relationship involving amount of substance and mass and calculated the amount of substance in a spoonful and reported back to the class.
The final sequence of the lesson based on the discussion and analysis of the lesson after each cycle is outlined in Table 2. The sequence is based on the last lesson cycle. The purpose of the activity is linked to the TSPCK components *learner prior knowledge* or *what is difficult to teach*. In the description of the activity the integration of representations and aspects of student learning are described. The aspects of variation theory used in these activities are provided in Table 3.

**FINDINGS AND DISCUSSION**

**Preliminary findings on development of Teachers’ TSPCK**

The construct of TSPCK was used to plan a conceptual lesson on the mole. Through the collaborative interrogation of practice during the meetings of the PLC each activity was reworked to include all three levels of representation. This was an important development for all involved as Gabel (1999) confirms that many teachers do not consider integrating the three levels of representation into their own thinking. The video recordings of the planning sessions and the lessons are currently being analyzed to develop a more complete picture of how the activities of the professional learning community contributed to the teachers TSPCK development.

**Findings based on student performance in the pre-test and post-test**

The purpose of the lesson was to develop students’ understanding of the mole concept. Before each lesson the students completed a pre-test and a post-test after the lesson.
<table>
<thead>
<tr>
<th>Purpose of Activity</th>
<th>Description</th>
</tr>
</thead>
</table>
| Develop an understanding of the term amount based on learner prior knowledge | • Provide students with pile of five cent and ten cent coins and ask students to make two piles of coins of equal amounts. **Representation** at a macroscopic level  
• Define the term amount of substance and its unit the mole as one of the seven fundamental quantities measured in science. **Curricular saliency**  
• Link definition of mole to mass number on periodic table and relative atomic mass and molar mass using the periodic table. **Representation** at a symbolic level |
| Use of a concrete analogy of a dozen to understand the mole as a counting unit based on what is difficult to teach | • Allow students to find the mass of a dozen five cent and a dozen ten cent coins and then hand out envelopes with multiples of a dozen types of coins with the mass to work out how many dozen. **Representation** at a macroscopic level.  
• Link the analogy to the amount of substance showing samples of one mole of different substances, use sub-microscopic pictures to account for differences in mass and introduce the mathematical relationship between mass and amount of substance. **Representations** at macroscopic, sub-microscopic and symbolic level. |
| Consolidate the previous two activities based on what is difficult to teach based on different ways to calculate amount | • Revise the analogy of a dozen and use the envelopes with multiples of a dozen five cent and ten cent coins and ask students to work out the number of coins. **Representation** at a macroscopic level.  
• Link the analogy to Avogadro’s number and let students calculate the mass of 0.1 mole of substance in order to measure it out. **Representation** at a macroscopic level.  
• Introduce the mathematical relationship between amount of substance and number of elementary particles. **Representation** at symbolic level.  
• Use electrolysis of water transparency to show different volumes of gases represent different amounts of gases. **Representation** integrating macroscopic, sub-microscopic and symbolic representations.  
• Introduce the mathematical relationship between volume and amount of gas and in groups students determine the amount of gas produced in pictures of reactions of metals with acid that produce the same amount of gas with balanced chemical equations and submicroscopic representations of reactions. **Representation** integrating three levels of representation. |
| Develop understanding of molar volume based on learner prior knowledge and what is difficult to teach | • Revise the three different mathematical relationships for calculating the amount of substance which will be used when solving stoichiometry problems. **Curricular saliency** as preparing students for solving stoichiometric problems.  
• Allow students to work in groups and calculate the mass of a reactant and the number of elementary particles and the volume of a gas and the number of elementary particles if given the amount of the substance. **Representations** at macroscopic and symbolic level. |
| Consolidate the series of activities and provide students with opportunity to practice based on what is difficult to teach | |

Table 2: Summary of Lesson to teach the mole concept based on lesson planned in the Learning Study
<table>
<thead>
<tr>
<th>Kept Invariant</th>
<th>Varied</th>
<th>What needs to be discerned by students</th>
</tr>
</thead>
<tbody>
<tr>
<td>The scientific meaning of amount of substance</td>
<td>Students’ understanding of the word amount</td>
<td>Students’ understanding of the term amount differs from that of their peers.</td>
</tr>
<tr>
<td></td>
<td>Different physical quantities in science and their units</td>
<td>The mole is the SI unit for the physical quantitatively amount of substance</td>
</tr>
<tr>
<td>A dozen coins</td>
<td>Type of coins: 5 cent coins and 10 cent coins</td>
<td>Coins have qualitatively different properties based on which type of coins they are</td>
</tr>
<tr>
<td></td>
<td>Type of coins: 5 cent and 10 cent coins</td>
<td>The mass of a dozen five cent coins differs from the mass of a dozen ten cent coins</td>
</tr>
<tr>
<td></td>
<td>The mass of a collection of multiples of a dozen coins</td>
<td>From the mass of a dozen coins the multiples of a dozen can be determined</td>
</tr>
<tr>
<td></td>
<td>Multiples of a dozen five cent coins and ten cent coins</td>
<td>Knowing that a dozen represents twelve the number of coins can be determined.</td>
</tr>
<tr>
<td>The amount of substance</td>
<td>Different types of substances (macroscopic)</td>
<td>The same amount of different substances have different masses</td>
</tr>
<tr>
<td>(Number of particles)</td>
<td>Submicroscopic representations of different substances</td>
<td>The difference in mass of the same amount of different substances is due to different particles</td>
</tr>
<tr>
<td></td>
<td>Different types of substances (symbolic)</td>
<td>The same amount of different substances has the same number of elementary particles</td>
</tr>
<tr>
<td></td>
<td>The space taken up by the different types of substances</td>
<td>The space taken up by the same amount of substance is not the same</td>
</tr>
<tr>
<td>The phase of a substance</td>
<td>The amount of gas represented in chemical equation</td>
<td>The volume of the gas depends on the amount of gas</td>
</tr>
<tr>
<td>(gaseous phases)</td>
<td>The volume of two different gases (macroscopic)</td>
<td>The volume of the gas depends on the amount of gas</td>
</tr>
<tr>
<td></td>
<td>The number of particles of two different gases</td>
<td>The volume of a gas at the same temperature and pressure depends on the amount of gas</td>
</tr>
<tr>
<td>The volume of gas</td>
<td>Different chemical reactions that produce gases (macroscopic)</td>
<td>The volume of the gas produced in the reactions is the same</td>
</tr>
<tr>
<td></td>
<td>Different chemical reactions that produce gases (submicroscopic)</td>
<td>The number of particles is the same when the volume of gas is the same</td>
</tr>
<tr>
<td></td>
<td>Two different chemical reactions that produce gases (symbolic)</td>
<td>The amount of gas is the same when the volume of gas is the same</td>
</tr>
<tr>
<td>The amount of substance</td>
<td>Different formula to calculate the amount of substance</td>
<td>The mass of a substance, volume of a gas and number of particles can be calculated</td>
</tr>
</tbody>
</table>
Before the scheduled meeting after each lesson in the cycle the pre-test and post-test were scored since in a Learning Study, the results are used to ascertain how well the students developed the capability, in this case a conceptual understanding of the mole concept (Pang & Marton, 2003). The questions used are included in the Appendix. The questions were scored dichotomously, a ‘0’ for an incorrect choice and a ‘1’ for the correct choice by both the researcher and the teacher who taught the lesson. The percentage scores for the pre-test and posttest for cycle 1 (N = 12), cycle 2 (N=20), cycle 3 (N=27) and cycle 4 (N=19) of the Learning Study are shown in Figure 5. As is evident the performance in the questions relating to molar volume, identifying one mole of substance and calculating the mass of a substance in 6 moles improved overall. During cycle 2, however, ten percent of learners who answered question 1 correctly in the pre-test answered it incorrectly in the post test. Due to the small number of students in each class, a Wilcoxon Paired Signed Rank test was conducted on each question. For the conceptual questions relating to molar volume and identifying one mole of substance there was no significant difference in the scores. However, there was a significant difference in question 3 where students were required to calculate the mass of 6 moles of calcium carbonate.

DISCUSSION ON STUDENT PERFORMANCE

Despite the focus been on developing a conceptual understanding of the mole, students did not show a significant improvement after the lesson. This was disappointing since the lesson aimed at making clear distinctions between amount of substance, mass,
volume of gases and number of particles as suggested by Furio et al. (2000). Fang, Hart, and Clarke (2016) suggest that even when the mole concept is taught conceptually, unless a meaningful link is made between molar mass and relative atomic/molecular mass students continue to struggle with the mole concept. Although students were provided with sub-microscopic representations and had to count protons and neutrons that contribute to relative atomic/molecular mass the link was not emphasised. These representations were only used to explain why the mass of the same amount of substance is different. Secondly, although variation theory underpinned the activities the pattern of variation and invariance was not made explicit to students and this is important to assist students in discerning and focusing on critical aspects of the object of learning simultaneously (Pang, 2003; Pang & Marton, 2013). One of the most profound realisations as a researcher involved in this Learning Study was based on comments made by students when they were interviewed about the lesson. They stated that what stood out for them was the practical component of the lesson. The use of macroscopic representations in learning stoichiometry was a novelty for the students and is consistent with the way teachers teach stoichiometry as confirmed by confirms the findings of a study conducted with Nigerian teachers that most teachers use an algorithmic approach when teaching stoichiometry (Okanlawon, 2010). According to Taber (2013) the symbolic knowledge domain cannot be separated from the macroscopic and sub-microscopic domains of chemical knowledge. Integrating the three levels of representation is therefore important in teaching stoichiometry as was done in this lesson. Finally, the length of the lesson, as a single lesson needs to be reconsidered. The length of the lesson and the number of activities in this revision lesson without planning for repetition or consolidation contributed probably contributed to the shortfalls in terms of students’ developing a conceptual understanding of the mole. Time is required for students to process information in order to build new knowledge into their existing schema (Loughran, 2010). The key realization here is that this lesson should be conducted as a series of lessons that build in opportunities for consolidation of ideas.

This paper has provided an overview of a Learning Study that was the vehicle to develop teacher knowledge through collaboration in order to improve practice and ultimately student performance. The lesson has been described to disseminate and report on the Learning Study (Pang & Marton, 2003) in order to outline the key features of a Learning Study that contribute to the professional development of teachers. The performance of students played a key role in analyzing the lesson in order to improve the teaching of the mole concept. Although student performance in conceptual questions was not significantly different, the description of the process is aimed at making the Learning Study accessible to teachers and the science education research community that can be built on by others (Lesson Study Project, n.d.).

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APPENDIX

Question 1
Each cube represents a volume of 22.4 dm$^3$ at STP.
In which of the three pairs of cubes, Set A, Set B or Set C, is there 1 mole of substance in each cube and which of the three pairs cannot contain 1 mole in each cube?

- N$_2$ (g)
- H$_2$ (g)
- O$_2$ (g)
- Hg (f)
- SO$_2$ (g)
- S (s)

Set A Cubes  Set B Cubes  Set C cubes

(a) Each pair contains 1 mole of substance.
(b) Set B and Set C contain 1 mole of substance. Set A does not.
(c) Only Set A contains 1 mole. Set B and Set C do not.

My choice is: ____________

Explain the reasons for your choice.

Question 2
Which of these three sets in the diagram below contains 1 mole of tin, 1 mole of magnesium, and 1 mole of sulphur in each tube?

<table>
<thead>
<tr>
<th>Set 1</th>
<th>Set 2</th>
<th>Set 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>(a)</td>
<td>(a)</td>
</tr>
<tr>
<td>(b)</td>
<td>(b)</td>
<td>(b)</td>
</tr>
<tr>
<td>(c)</td>
<td>(c)</td>
<td>(c)</td>
</tr>
</tbody>
</table>

Key:
(a) Tin
(b) Magnesium
(c) Sulphur

(a) Cannot tell by just looking at them as more information is needed.
(b) Set 1 has one mole of substance as they contain equal volumes.
(c) Set 2 has one mole of substance as they contain equal masses of substances.

My choice is: ______

Give a reason for your choice.

Question 3
How many grams of calcium carbonate are in 6 moles of calcium carbonate, CaCO$_3$?
(Molar mass: 100 g.mol$^{-1}$)
(a) 0.06 g
(b) 6 g
(c) 60 g
(d) 600 g
AFFORDANCES AND LIMITATIONS OF INTEGRATING LEARNERS’ SOCIO-CULTURAL BACKGROUND INTO SCIENCE TEACHING

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ABSTRACT

The study involved three Grade 9 Natural Sciences teachers reflecting on their classroom practice and on the phenomenological importance of integrating learners’ socio-cultural backgrounds into science teaching and learning. In this qualitative case study each teacher was interviewed five times using a semi-structured interview schedule to determine their willingness, challenges and benefits obtained from their experiences as they incorporated learners’ socio-cultural practices, experiences and beliefs when teaching some Natural Sciences topics. Additional information was obtained through analysis of documents related to teaching such as curriculum documents, lesson plans and teachers’ reflective journals. This was meant to answer the research question: What are the teachers’ views on affordances and limitations of the integration of learners’ socio-cultural backgrounds into science teaching? Findings from the study illuminate aspects of the role of learners’ socio-cultural practices, experiences and beliefs in science teaching and learning; processes by which individual teachers can improve the quality of their practice; and support mechanisms that teachers need to make science more relevant and meaningful to learners. Central to these findings is the contribution to the debate on the relevance and meaningfulness of science education, particularly with a focus on making it a reality in South African science classrooms. For the three teachers, reflection improved their knowledge, awareness and control of themselves and their classroom practice when teaching socio-culturally diverse learners that are typical of South African science classrooms.

Keywords: Learners’ socio-cultural background, affordances, limitations

INTRODUCTION

Integrating learners’ socio-cultural background in science teaching requires teachers’ skills, knowledge and appreciation of the importance of what learners bring to the science classroom. In a process of looking backward (reflecting on their experiences whilst incorporating learners’ socio-cultural backgrounds in teaching science) and looking forward (positioning themselves in their future teaching practice), teachers shared their experiences in this study. When faced with a new teaching experience, teachers are deeply concerned about how they can navigate the uncertain and complex challenges they are likely to face. The study reported in this paper aimed to capture the
reflections of teachers on their experiences as they integrated socio-cultural issues into their science teaching. This investigation sought to explore and report on the teachers’ willingness to continue integrating learners’ socio-cultural practices, experiences and beliefs; the challenges faced in the process; and the benefits derived from their experiences of such integration when teaching some science topics. The study was based on the assumption that teachers' experiences, when incorporating learners’ socio-cultural backgrounds in teaching, will encourage a transition away from traditional teaching approaches that rely solely on textbooks and curriculum guidelines.

The study sought answers to the following research question: What are the teachers’ views on the affordances and limitations of integrating learners’ socio-cultural backgrounds into science teaching? This study is part of a larger study that explored teachers’ knowledge and understanding of their learners’ socio-cultural practices, experiences and beliefs; and how the teachers use this knowledge to provide situationally appropriate learning experiences for their learners. Hence, by exploring teachers’ experiences, the researcher encouraged teachers to reflect on their experiences of integrating socio-cultural perspectives into their science teaching. Research has shown that reflection is important for teachers’ empowerment in general, and for making sense of their teaching practices in particular (Beijaard & Verloop, 1996).

**AFFORDANCES OF INTEGRATING SOCIO-CULTURAL ISSUES INTO SCIENCE TEACHING AND LEARNING**

Generally, the public is reticent to embrace the integration of cultural perspectives into science teaching and learning. The inclusion of culture in science teaching is not simply to challenge the existing status of western science, but also to provide opportunities to identify the most appropriate learner-specific instructional strategies (Young, 2014). The argument is that instructional strategies, examples and teaching-and-learning materials should be developed and derived from the learners themselves, rather than imposing ready-made cookbook recipes divorced from the learners’ worldviews. In addition, situating the process of teaching and learning in a particular cultural context provides a means through which science can be made relevant and meaningful to the learners (Kalolo, 2015).

In the context of chemistry learning, relevant and meaningful education can be defined as involving contextualised learning, which places emphasis on the need for learners to know what they learn, and pays attention to learner input (Westbroek, Klaassen, Bulte & Pilot, 2005, 2010). In other words, the learners should feel motivated to learn and be given an opportunity to participate actively. In addition, it should provide every learner with opportunities for quality, relevant and sustainable science education (Kalolo, 2015).

Realisation of the importance of culture, in providing relevant and meaningful learning, dates back to the 1970s. For instance, Schwab (1973) suggested that any educational event should involve the learner, the teacher, the subject matter and the social and cultural context. In concurrence, Dewey (1973) reiterated the importance of connecting school activities with learners’ everyday-life experiences in order to achieve genuine
learning, understanding and growth. Bruner (1996) also expressed appreciation for the usefulness of culture in providing the means through which learners construct their worlds, perceptions and understandings of what they learn. Culture also appears to influence the learning preferences of learners (Boykin et al., 2005; Charlesworth, 2008). Consequently, some scholars advocate for the integration of culture into curriculum design, teaching, learning and assessment (Hood, Hopson, & Frierson, 2005; Swartz, 2009).

The focus of the debate is on learner-centred classrooms with an aim to improve learner academic performance, thereby providing equity in science education, which Elmesky (2011) expresses as accepting how diverse learners know, articulate and think, and what they bring to the science classroom. With reference to the Taiwanese curriculum, Chang (2005) and Lewthwaite, McMillan, Renaud, Hainnu and MacDonald (2010) advocate for a science curriculum that is indicative of learners’ lived experiences. Consideration of cultural perspectives appear instrumental in science teaching and learning, for example: Robottom and Norhaidah (2008), in a study related to Islamic learners, found that the meanings learners make in science are shaped and constrained by their culture; and Ozdemir and Clark (2009) noted that culturally diverse Turkish learners interpret the concept of force differently from each other. Hayes (2010) contends that children learn ‘better’ when teaching relates to their home language and culture; when their competencies are recognised; and when teaching takes place in a familiar context.

LIMITATIONS OF INTEGRATING SOCIO-CULTURAL ISSUES IN SCIENCE TEACHING AND LEARNING

According to Baquete, Grayson and Mutimucuio (2016), Indigenous Knowledge (IK), which is knowledge within the learners’ socio-cultural backgrounds, is sometimes ignored or even refuted. This is because teachers may view it as being at odds with scientific knowledge as some of it is formed on the basis of religious beliefs or assertions made by authority. Sometimes teachers are not willing to integrate learners’ socio-cultural backgrounds into their teaching due to negative attitudes emanating from their lack of knowledge of IK. This has been confirmed by Ogunniyi and Hewson (2008) who point out that South African teachers, particularly those ‘westernised’, are unfamiliar with African Indigenous Knowledge Systems (IKS) and with strategies for integrating IKS into the conventional science classroom. It is also unfortunate that teachers receive limited professional development support on how to integrate IKS into the science curriculum (Ogunniyi, 2007). Similarly, Govender (2009) states that teachers lack relevant skills on how to incorporate IKS into their teaching of science subjects.

Teachers’ attitudes play an important role in determining their practice in the science classroom, particularly when it involves new and unfamiliar practices. They may not view learners’ socio-cultural practices, experiences and beliefs as valuable to science teaching, but rather as inferior to science knowledge. This view is exemplified in a South African study by Keane and Moyo (2010) of Gauteng science teachers’ ideas about IKS and their attitude towards its inclusion in the science classroom. The study findings
revealed that Black township teachers were inclined to consider the inclusion of IKS into their science lessons, but claimed that IKS is likely to be better understood by rural teachers. Such claims can be viewed as a lack of commitment on the part of those township teachers because they were defensive from the start, implying that there was hardly any suitable IKS for inclusion in an urban setting. Predominantly White and more westernised teachers from suburban schools were skeptical from the start, as they undervalued IKS as a primitive means of interpreting natural phenomena. Such responses show that both groups of teachers had a negative attitude towards IKS. From this, one could infer that these teachers would not even try to incorporate IKS into their science lessons. To compound the situation, the South African National Curriculum Statement (NCS) Grades R-12: Curriculum and Assessment Policy, does not give guidelines on how teachers can integrate IKS into science teaching.

The current study reports on teachers’ views on the affordances and limitations of integrating learners’ socio-cultural backgrounds into science teaching based on their reflections on their experiences. Asking teachers to reflect on such personal experiences may shift their views of teaching, from delivery of universal science principles and laws, towards experiential learning that incorporates culture, local knowledge and science, which provides an opportunity for integration (Chinn, 2007).

METHODOLOGY

This investigation adopted a qualitative approach. The participants were asked to reflect on their experiences of incorporating learners’ socio-cultural practices, experiences and beliefs into the teaching of various concepts under the Grade 9 topic ‘human reproduction’. Qualitative research is a naturalistic approach that seeks to understand phenomena in context-specific settings, where the researcher does not manipulate the phenomenon of interest (Patton, 2002), but probes for deeper understanding rather than examining superficial features (Johnson, 1995).

Three Grade 9 Natural Sciences teachers were selected from three different township schools for this study using Patton’s (2002) notion of purposeful sampling. Each teacher had been trained on how to integrate learners’ socio-cultural backgrounds in their teaching. Hence they had an interest in the study. The three science teachers, Pamela, Phila and Siya (pseudonyms), were of different ethnic backgrounds and spoke different home languages (Sepedi, IsiZulu and Tsonga, respectively). Most importantly, their learners came from diverse backgrounds, which formed a rich tapestry for the exploration of the affordances and limitations of the integration of learners’ socio-cultural backgrounds into science teaching.

Data collection involved providing teachers with video clips of particular classroom episodes of lessons they taught while integrating learners’ socio-cultural practices, experiences and beliefs into different concepts under the ‘human reproduction’ topic. It was anticipated that, by providing the participants with video clips of some of the classroom episodes, this would stimulate recall. The three teachers were then interviewed five times each, using a semi-structured interview schedule. A total of 15 interviews, each lasting approximately 30 to 45 minutes, were conducted. The
interviews probed teachers’ thinking about, and understanding of, the affordances of integrating socio-cultural issues into science teaching. The researcher used teacher and learner actions to revisit the classroom situations, thereby exploring the nature of the teaching-and-learning process, as recommended by Loughran, Mulhall and Berry (2004). Teachers kept reflective journals in which they recorded their experiences, as a means to remember, recall, reconstruct, re-create and represent what they had learnt from their teaching practice while integrating learners’ socio-cultural backgrounds. These journals, together with curriculum documents and teachers’ lesson plans, were analysed to compliment interview data. The data from these documents helped to determine the relationship between teachers’ thought processes when they planned and taught whilst integrating learners’ socio-cultural background and their thought processes during reflection after teaching. This was important in assessing teacher development.

Coding and analysis of teachers’ responses, gathered from interviews and documents, were done using the constant comparative method (Merriam, 1998). This analysis was used to form categories, which led to themes and patterns (Saldana, 2009). These themes are used as the basis for argument, discussion and interpretation of the data in relation to the research question. To promote dependability on the data, coding was done as soon as data were collected and then recoded after some time and then results compared (Krefting, 1991). This was meant to check for consistency thereby ensuring accuracy. Figure 1 below (compiled by the author) depicts a visual representation of the research design used in this study.

![Figure 1: Visual representation of the research design used in this study](image)

Only findings from the interviews, which answer the research question, are reported in this paper.
RESEARCH FINDINGS

The findings from the interviews and the analysis of documents (teachers’ reflective journals included) show teachers’ viewpoints about the affordances and limitations of integrating learners’ socio-cultural backgrounds into science teaching. The three teachers’ responses in the interviews allowed them to reflect on their actions during the teaching-and-learning process. They pointed out that such experiences improved their knowledge of good teaching practices; and their awareness of how learners’ socio-cultural practices, experiences and beliefs can impact on the depth and extent of content coverage. They also shared how the integration process promoted the use of pedagogical representations that made science concepts more comprehensible to the learners. The teachers mentioned some of the challenges they encountered during the planning, and during the teaching-and-learning process. It was evident that the teachers examined their pedagogical experiences to determine the affordances and limitations of integrating learners’ socio-cultural backgrounds into the planning and teaching of lessons. The themes are presented in the form of four assertions and discussed below.

Theme 1: The integration of learners’ sociocultural backgrounds into science teaching promotes the planning and presenting of lessons intended to make scientific concepts comprehensible to learners.

The teachers indicated that having knowledge of learners’ pre-instructional ideas about a topic – which arises from learners’ socio-cultural practices, experiences and beliefs – is important in lesson planning. Such knowledge helps them to organise and structure appropriate subject matter to be taught. The following are some of the teachers’ responses:

Pamela: It helps me on how to structure my teaching with the learners in mind. Yes I could just easily follow the textbook but unfortunately learners will not come out in the open to share what they know and how they feel about the concept.

Siyakazi: Learners present issues about their beliefs that make me discuss certain science concepts regarding the topic that I had not planned for.

Phila: Talking to learners makes you realise how much they know which may even surprise you. I now believe in a way learners should lead the lesson and not the other way round.

The teachers were prepared for their learners’ likely responses to their teaching, the type of questions learners might ask and what misconceptions they might display. Teachers were prepared for addressing these misconceptions, and had planned how they would react to learners’ divergent responses to the questions asked. Teachers indicated that, by integrating learners’ socio-cultural backgrounds into the lesson plans, they were able to select authentic and appropriate activities and examples. Some of the activities involved community engagement, learners engaging in role playing and argumentation (Toulmin,
1958) on different cultural beliefs and practices such as traditional circumcision (initiation), ancestral appeasement in some cases to curb infertility in humans and soliciting the expertise of a ‘sangoma’ (traditional healer). Teachers described how such knowledge and practices enabled them to structure their lessons in such a way that the unfamiliar science content actually encouraged the learners to interrogate their own prior knowledge:

Phila: I tried to prepare for questions learners would ask. Yes sometimes I was caught unaware but my responses were more reasonable than when I did not plan for it.

Pamela: Just imagine how I would have reacted to the learner who said that the boys needed to toughen up while reacting to the newspaper report that boys die during initiation. I would have snapped had I not known that it is their cultural practice of preparing young boys for manhood.

The three teachers admitted that more time was spent on lesson planning in order to design well thought out activities and strategies that incorporate learners’ sociocultural practices, experiences and beliefs. They consulted many sources of information such as fellow teachers, community members and different textbooks, since different sources addressed topics and/or concepts differently.

**Theme 2: The integration of learners’ socio-cultural backgrounds into science teaching helps to inform teachers about the potential conflict between learners’ worldviews and scientific knowledge.**

The three teachers acknowledged the important role that the integration of learners’ socio-cultural backgrounds into science teaching played in informing them of some of the belief systems and practices learners hold, and how they can be counterproductive in science learning. An example is the practice of witchcraft, which the teachers said they failed to explain scientifically. The teachers shared how they tried to explore various ways of harmonising the conflict between learners’ worldviews and science knowledge. Teachers also mentioned that, because of the conflict between learners’ worldviews and scientific knowledge, learners sometimes held onto their pre-instructional ideas at the expense of developing scientific concepts. Accordingly, the teachers pointed out that they became aware that learners might fail to use or apply knowledge learnt because of that conflict. When asked if they had any belief systems that made it difficult for them to teach science or to reject science, Siya and Phila dismissed having such belief systems. Siya emphasised his point:

Siya: No I don’t have such beliefs, practices or experiences that interfere with my work. In any case my job is to teach science, hence there is nothing that can go against it.
However, Pamela had a different experience and she admitted that her religious beliefs sometimes made it difficult to handle certain science topics. This is encapsulated quite well in her response:

Pamela: *(laughing)* Oh yes, in my case, I am a Jehovah’s Witness. Religion for me is very important. For instance, when it comes to the reproductive system and we start talking about contraceptives, and abortion also come into play, religiously it’s out of the question for me.

Pamela elaborated that there were learners who also held the same conviction as herself, and such learners cannot separate scientific issues from their religious beliefs. She indicated that such learners become emotional about their religious conviction and this negatively affects their understanding of scientific concepts. Pamela added that she always tried her best to plan and address such contentious issues, like abortion, in the lesson; and she made an effort to separate her personal beliefs from the teaching of science. Though Pamela knew that she was going against her religious beliefs, she said that the right thing to do, in her role as a teacher, was to teach all aspects of the syllabus.

When asked about their experiences, as they incorporate learners’ socio-cultural practices, experiences and beliefs in their teaching, teachers pointed out that learners possess pre-instructional knowledge which can impede their learning and understanding of scientific concepts. The teachers gave examples of some learners who were not convinced that infertility is a result of biological problems, but rather of witchcraft or ancestral curses. According to the teachers, learners’ belief systems could present disharmony in a science class. The following excerpts attest to their experiences:

Phila: Sometimes I wonder how learners understand the scientific concepts when they strongly believe in witchcraft, and also that their ancestors have power to change the human reproductive process and the nature as well.

Siya: I am forced to explore the topic or concept in detail in order to try and make the learner(s) understand the scientific explanations.

Pamela: It is not always easy for me to come up with scientific explanations of learners’ cultural practices and beliefs.

Siya made reference to lightning and infertility, the causes of which he painstakingly and scientifically explained to the learners. The teachers pointed out that their knowledge of the existence of such beliefs makes them aware of how the learners’ worldviews can be at loggerheads with the scientific knowledge. As a result, teachers indicated that they make an effort to explain the concepts in different ways by using examples familiar to learners, or they provide activities that interest learners, in an attempt to harmonise the two knowledge domains.

All three teachers acknowledged the role that integration of learners’ backgrounds played in informing them about the conflict that may exist between learners’ worldviews and the teaching of scientific concepts. To show his awareness of this role, Phila
described how he was taught science when still in school, when the teachers focused on pure scientific concepts divorced from their lives. As such, he said:

Phila: If I had been taught science the way I am teaching these Grade 9s, I would be a scientist right now (laughing).

Most importantly, the teachers indicated that their experiences of integrating learners’ socio-cultural backgrounds made them view the goal of teaching as that of actively engaging learners in the learning process, and allowing the learners to evaluate what they already know against the new knowledge. The teachers acknowledged that the incorporation of learners’ experiences in the teaching-and-learning process motivated learners to apply relevant concepts learnt to their lives, and at the same time to critique their prior knowledge instead of taking it at face value.

**Theme 3: The integration of learners’ socio-cultural backgrounds into science teaching presents certain teaching-and-learning problems and challenges.**

Teachers acknowledged their failure at times to solicit information from community members and to integrate or authenticate the practices and beliefs learners bring to the science classroom. Teachers reminisced from their experiences that integration of learners’ socio-cultural practices, experiences and beliefs requires extensive involvement of elders who bear that knowledge, and who sometimes are unwilling to share their ideas with the public. Teachers indicated that sometimes they had insufficient information regarding a particular traditional practice or belief, which made it difficult to use such information. Faced with such a predicament, the teachers indicated that they sometimes had to abandon the exploration of some ideas brought in by learners, even though these ideas could have been important in assisting with learner acquisition of scientific concepts. For instance, they said:

Siya: In a number of times I brushed off aside learners’ ideas because I did not know much about it. For example, the issue of witchcraft in causing infertility in women.

Pamela: When I grew up I never heard of some of the beliefs and practices learners are mentioning, for instance, the ancestral curses, because I grew up in a Christian family. Hence I failed to pursue such issues.

According to the teachers, they failed to properly incorporate some of the ideas learners raised due to their limited knowledge of such issues. At the end, the teachers felt that it defeated the purpose of providing learners with an opportunity to articulate their pre-instructional knowledge, if that knowledge was not used in the teaching-and-learning process. On that note, Pamela also mentioned that it was unfortunate that details about some traditional practices are only known by that particular group of people unless a sangoma (traditional healer) was consulted. For instance, the teacher mentioned that she really wanted to know more about traditional methods of contraception, but was not
willing to go and ask due to her religious beliefs. The teachers’ reflections show that they sometimes failed to solicit information from community members regarding learners’ socio-cultural practices and beliefs for incorporation in science teaching.

The teachers also expressed their concerns in terms of teaching-and-learning time spent when integrating learners’ socio-cultural backgrounds into science teaching. The teachers viewed the practice as time consuming in terms of effort and lesson preparation. They pointed out that, inasmuch as the science curriculum document prescribes that IKS should be incorporated into science, there are no suggested teaching strategies and practical work that could be done in the classroom. As a result, they spent more time consulting with other teachers or community members to source the information.

The teachers also pointed out that there are many possibilities for misconceptions arising from the learners’ worldviews, and that it takes a great deal of probing to correct and bring out the correct scientific concepts. As a result, they said, much time is spent trying to address these learner misconceptions, and in the end completion of the syllabus is compromised.

DISCUSSION

The findings have been presented in three themes, stated as assertions, which show teachers’ appreciation for the integration of learners’ socio-cultural backgrounds into science teaching. These include promotion of teachers’ planning and presentation of lessons with an intention to make scientific concepts comprehensible to learners; informing teachers of the potential conflict between learners’ worldviews and scientific knowledge; and making them aware of the problems and challenges associated with this practice. These resonate well with Moon’s (2004) findings that teachers’ reflections could result in new knowledge and conceptions, continuous professional development, new ideas and solutions and the creation of a personal philosophy.

Teachers’ acknowledged their failure at times to solicit information from community members, and to integrate or authenticate some of the practices and beliefs learners brought to the science classroom. Such implementation problems were also highlighted by Hayes (2010) who suggests that such integration requires extensive involvement of elders who bear that knowledge, and that it is not easy or clear on how best such a proposal can be implemented, considering that most of the community members who have this knowledge are not conversant with modern teaching techniques. On that note, in a study on culturally relevant teaching in science, Mensah (2011) emphasised that science teachers need collaborative support with diverse others in making connections and developing practices in culturally relevant ways. Findings from an earlier study by Wenger (1998) also underscored the need for teachers to work within a community of other practising members to enhance their capabilities to teach science that is relevant to the socio-cultural practices, experiences and beliefs of learners.

The research findings also revealed that the teachers’ own religious belief systems may constrain teachers from integrating learners’ socio-cultural backgrounds into science teaching, as evidenced by one teacher, Pamela, who had strong Christian beliefs.
Pamela’s situation is in line with findings from a study where prospective teachers were found to possess tacit ideas about teaching which acted as filters in preventing them from considering unfamiliar and discrepant ideas (Thomas & Pedersen, 2003; Kellner, Gullberg, Attorps, Thorèn & Tärneberg, 2011). Teachers’ awareness of such constraints helped them to discuss those conflicting issues from academic (scientific), religious and moral standpoints. This is explained by Aikenhead and Jegede (1999) who point out that teachers’ cultural values, beliefs and practices could play a significant role in the selection of content to be taught, teaching strategies and in anticipating their learners’ responses in class.

The teachers indicated that learners sometimes failed to distinguish their religious and traditional beliefs from science learning, or to relate the two. This is similar to the findings of studies carried out in the USA and Canada, which showed that many learners who had strong religious values and beliefs tended to hold negative attitudes towards school science (Roth & Alexander, 1997; Ebbenshade, 1993). These are in accord with findings that indicate that learners bring, to the science classroom, some social-cultural beliefs that create gaps between what learners are taught and what they learn (Okafor, 2011; Eniayeju, 2010). In a way, the teachers tried to employ collateral learning, which Jegede (1995) proposes as a means of harmonising the conflict between learners’ worldviews and science, which Aikenhead (1994) describes as the single largest obstacle to meaningful learner achievement in science.

In their reflections, the teachers also realised that sometimes community members were not forthcoming in sharing their knowledge or expertise regarding IKS. Such issues were also raised by Hayes (2010), who argues that it is not easy or clear on how best to involve elders who bear that knowledge, considering that these community members are not conversant with modern teaching techniques.

**CONCLUSION**

From the findings it emerged that the learners’ traditional and religious backgrounds, and equally the teachers’ backgrounds, may influence the teaching and learning of some of the science topics, particularly human reproduction and associated concepts. It means, therefore, that acknowledgement of such beliefs, by integrating them into the teaching process, can help to address such issues, which can be an impediment to the understanding of science concepts if left unarticulated. The teachers realised that science teaching and learning should not only focus on content acquisition, but should also be relevant to learners’ lives by harmonising school and home experiences. By determining affordances of this practice, the researcher intended to use the findings as a spring board for capturing the feasibility of incorporating socio-cultural issues into different science topics.

The study has the potential to initiate the very much needed debate and discussion on how science teacher support can be designed to meet the goals of educational reforms. It should, however, be noted that student teachers can be taught incorporation of contextual knowledge (CK) as a pedagogy rather than as additional content, which they can use to elicit learners’ pre-conceptions and address difficulties arising from learners’
socio-cultural practices, experiences and beliefs. The teacher educators can draw on examples of some beliefs or practices among their own student teachers to demonstrate CK incorporation, and student teachers can be assessed on such pedagogy during classroom teaching practice in schools.

REFERENCES


THE EFFECT OF ARGUMENTATION INSTRUCTION ON SCIENCE TEACHERS’ CONCEPTIONS OF THE NATURE OF SCIENCE

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This study, involving a cohort of 18 educators, is part of a larger project known as the Science and Indigenous knowledge Project (SIKSP). The aim of the study was to explore the effect of a Dialogical Argumentation Instructional Model (DAIM) on the educators’ conceptions of the Nature of Science (NOS). Using a questionnaire, interviews and reflective essays the results showed a significant difference between the educators’ pre- and post-conceptions of NOS most probably because of their exposure to DAIM. The educators shifted from a naïve view of science as a body of infallible truths about nature, whose path is clearly known, to considering science as a tentative, dubitable and revisionary inquiry. Likewise, they moved from a negative view of argumentation instruction to becoming enthusiasts of the new approach. The implications of the findings for instructional practices are briefly highlighted in the paper.

Key words: Educators, conceptions, Nature of science, argumentation instruction

INTRODUCTION

In line with the worldwide curriculum reforms in the last two decades, the South African Department of Education (DOE) implemented a new curriculum which urged educators to shift from a teacher-centred to a learner-centred instructional approach. The implementation of the new curriculum was inevitable as a way to counter the inherited exclusivist, racially-based apartheid curriculum that was neither sensitive to the demands and postulates of a democratic society nor concerned with the emergence of multicultural classrooms. However, it is one thing to implement a new curriculum and another to equip educators with necessary knowledge and instructional skills demanded by the new curriculum. As it turned out, the educators were ill-prepared to implement the new curriculum and the crash programme to which they were exposed failed miserably to equip them for their onerous task (Ogunniyi, 2007a & b). It was to ameliorate this that 18 educators participated in this study as a way to enhance their professional development.

Deliberative curriculum theory assumes that curriculum developers would engage all stakeholders, especially educators, in curriculum development activities through a process of mutual deliberation (Curry, 1992). However, the conventional top-down approach adopted by the developers of the new curriculum is a classic example of what Havelock’s research, development and diffusion (RDD) or Schon’s centre-periphery curriculum model (MacDonald & Walker, 1976). Educators were neither properly
consulted nor explicitly informed why traditional instruction (which had for long been effective in passing the fact-oriented examinations) should be replaced with one that emphasized discussion, process skills and group activities (Ogunniyi, 2007a). Despite the teachers’ negative disposition to the new approach, however, the extant literature has consistently shown that classrooms which encourage dialogues, arguments, discussions, learners’ interactions and reflectivity tend to encourage learners to externalize their thoughts, clarify their doubts and even change their views if and when necessary (Erduran, Simon & Osborne, 2004; Simon & Johnson, 2008).

A number of reviews have shown that attempts to improve educators’ knowledge of the NOS or use classroom discourse without proper training and mentoring have largely been unsuccessful (Erduran, Simon & Osborne, 2004; Simon & Johnson, 2008). It is a well-known fact that educators, to a great extent, determine learners’ image and content of science. However, if educators’ view of science is inadequate what they convey to their learners would be a corruption of what is intended. In light of this, the study explored the 18 educators’ present notions of NOS. Also, as numerous studies have shown, educators and consequently their learners, generally hold inadequate understandings of NOS (e.g., Abd-El-Khalick, 2005; Lederman, Wade & Bell, 1998; Ogunniyi, 2006). It was to ameliorate this problem that the educators involved in the study were exposed to DAIM.

THEORETICAL FRAMEWORK

The study is underpinned by two theoretical argumentation frameworks namely, Toulmin’s (2003) Argumentation Pattern (TAP) and the Contiguity Argumentation Theory (CAT) (Ogunniyi, 2007a). TAP draws largely from the Aristotelian deductive-inductive form of argument. Essentially, TAP involves such elements as: data (evidence); warrants or justification linking data with the evidence; backings that provide additional support for the evidence; qualifiers or contingent conditions under which a claim is valid; and rebuttals or contradictory statements to a given claim. As a framework based on Aristotelian logic TAP has no room for non-logical, contextual or socioculturally nuanced arguments which often arise in classroom discourses (Ogunniyi, 2007a & b). The levels of TAP adopted for the study is modified from the ones developed by Erduran, Simon and Osborne (2004) and Simon and Johnson (2008) as follows:

Level 1: Non-oppositional arguments or arguments with simple claims versus counter-claims.

Level 2: Arguments supported with claims, data, warrants or backings but contains with no rebuttals.

Level 3: Arguments consisting of a series of claims supported with data, warrants, backings and only occasional weak rebuttals.

Level 4: Arguments supported with at least one strong rebuttal.
Level 5: Arguments supported with claims, data, warrants, backings and with more than one strong rebuttal.

CAT draws on both Aristotelian logic and the *Ubuntu worldview* - a central African way of perceiving the world in terms of coupling, interconnectedness and interrelatedness of ideas to attain cognitive harmony. As a cognitive theory, CAT assumes that when distinctly different ideas come together they are likely to first repel each other. They then seek commonality between their compatible basic micro- and macro-elements or what Hempel (1966) would call “internal and bridge principles” (p.72) respectively alongside of concomitant processes invoke by the governing generalizations that they are assumed to conform. It is after this that the two distinctly different ideas become connected and coalesce to form a higher form of consciousness or a deeper level of interconnectedness than was previously possible (Ogunniyi, 2007a). CAT recognizes five cognitive categories into which an idea can move within a person’s mind namely: dominant; suppressed; assimilated; emergent; and equipollent as shown below:

- **Dominant:** The most prevailing or appropriate worldview in a given context
- **Suppressed:** The worldview that becomes subdued or subordinated to the dominant one.
- **Assimilated:** The worldview that capitulates to, or is subsumed by the dominant one.
- **Emergent:** A worldview arising from a new experience.
- **Equipollent:** Two distinctly different but co-existent worldviews exerting equal cognitive force on a person’s worldview (Ogunniyi, 2007a).

**PURPOSE OF THE STUDY**
The aim of the study was to determine the effects of DAIM on the educators’ pre- and post-test conceptions of the nature of science.

**METHOD**
The study exposed a cohort of 18 educators to a series of lectures on the history, philosophy and sociology of science for three hours per week for six months. This was to acquaint them with the historical development of science from precursor natural philosophy of Greek science to modern science era starting from the 17th century. In addition, they were exposed to reading materials on the works of renowned historians, philosophers and sociologists of science as well cosmologists and scientists. Worthy of note in this regard are the works of scholars like Beveridge, Campbell, Carnap, Cline, Frank, Goldfield, Habermas, Hall, Handy, Harre, Hempel, Kuhn, Medawar, Merton, Nagel, Popper, Stocking, Toulmin, Hawking and Ziman. Specifically, the topics covered included: the pre-Socratic scholars’ notions about the universe; Greek science and the controversies surrounding the nature of matter; medieval science of motion (including significant contributions made by western and non-western scholars); Ptolemaic geo-centric system versus the Copernican heliocentric system; alchemy versus modern chemistry; debates on the nature of atoms; Semmelweis’ childbed-fever
DIALOGICAL ARGUMENTATION INSTRUCTIONAL MODEL (DAIM)

DAIM underpinned by TAP and CAT was used to drive all the classroom discourses and hands-on activities in form of cognitive tasks. DAIM construes argumentation as starting from the individual (intra-argumentation), then to small groups (inter-argumentation) and finally to whole group (trans-argumentation) where the final collaborative consensus is reached (Fig. 1).

Next, the educators were randomly distributed to five groups. Each group was assigned a number of time-based cognitive tasks which they tackled first as individuals, then in small groups and finally in the whole group. The individual task involves brain-storming to respond to a number of worksheets questions. This was followed by further arguments and intensive discussions in the small- and whole- groups respectively before collaborative consensus was reached on the various tasks (Fig 1). During the whole period, the facilitator moved from group to group by asking thought-provoking questions as well as sorting out incipient problems. It is also important to state that no group or role was permanent; each section usually had different leaders. Also, it was at the whole-group stage that the types of TAP or CAT mobilized to perform the tasks were identified with the assistance of the facilitator who had been well-trained for the purpose.

The first one and a half hours of each three-hour session involved interactive lectures on a given topic followed by one hour of hands-on investigations in a medium of arguments, dialogues and class discourse. The last 30 minutes was used to clarify issues
and ideas raised during the whole session followed by reading assignments the following week. More details about DAIM have already been published (Ogunniyi, 2007a).

THE INSTRUMENTS

The assessment instruments consist of the NOS questionnaire, interviews and two reflective essays. Again, the details of the development of these instruments (including the establishment of their validity, reliability, credibility or dependability) have been published elsewhere (Ogunniyi, 2006 & 2007a). However, because the present NOS questionnaire consisting of 10 items was derived from a previous longer one consisting of 18 items on NOS and instructional practices (inter-rater reliability = 0.91), it was submitted to three well-known NOS experts for further validation and triangulation purposes. The inter-rater reliability based on their agreement-disagreement with each item of the new instrument stood at 0.99 using a modified Kuder-Richardson formula. This indicates a very high agreement among the experts. The data set collected from the NOS questionnaire is displayed in Table 1. In addition, to the questionnaire and the reflective essays, the educators were interviewed. However, because of space limitation only a synopsis of the data analysis is reported in the paper.

RESULTS AND DISCUSSION

Table 1 provides the educators’ responses to the items of the NOS questionnaire. The focus of this analysis is an exploration of their response choices relative to a model based on the agreement/disagreement of the panel of NOS experts. In agreement with the model or experts, 67% and 100% of the educators respectively disagreed with the notion that science tells the truth about nature (Item 1). Truth is a metaphysical term that connotes absolute knowledge. According to Habermas (1971) modern science does not really coincide with knowledge as such. To him, “Compared with “absolute knowledge” scientific knowledge is narrow-minded… “Scientism” means science’s belief in itself: that is, the conviction that we can no longer understand science as one form of possible knowledge, but rather must identify knowledge with science” (Habermas, 1971, p. 4). According to Popper (2001):

“Our best knowledge, by far our best, is scientific knowledge. Yet scientific knowledge too is only conjectural knowledge… The truth is absolute and objective …We are constantly seeking it and often find it only with difficulty; and we keep trying to improve our approximation to the truth” (p.55).
### Science teachers’ pre-post-test conceptions of the nature of science

<table>
<thead>
<tr>
<th>Statements</th>
<th>% A(Pre-)</th>
<th>% D (Post)</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Science tells us the truth about nature</td>
<td>33 (0)</td>
<td>67 (100)</td>
<td>D</td>
</tr>
<tr>
<td>2. A scientific knowledge is trustworthy because it has been proved by experiments.</td>
<td>56 (11)</td>
<td>44 (89)</td>
<td>D</td>
</tr>
<tr>
<td>3. Scientific facts can be tested and every test should give the same result.</td>
<td>39 (33)</td>
<td>61 (67)</td>
<td>D</td>
</tr>
<tr>
<td>4. Philosophical, religious, psychological or linguistic questions are irrelevant to science.</td>
<td>28 (22)</td>
<td>72 (83)</td>
<td>A</td>
</tr>
<tr>
<td>5. Scientists may be influenced by their philosophical, sociological and psychological frameworks or mind set.</td>
<td>83 (100)</td>
<td>17 (0)</td>
<td>A</td>
</tr>
<tr>
<td>6. Before a scientific discovery is accepted, many scientists have to test and confirm its validity,</td>
<td>94 (100)</td>
<td>6 (0)</td>
<td>A</td>
</tr>
<tr>
<td>7. Scientific truths are the same for everybody and not on personal beliefs or situation.</td>
<td>33 (17)</td>
<td>67 (83)</td>
<td>D</td>
</tr>
<tr>
<td>8. Scientific theories are like maps of reality.</td>
<td>94 (83)</td>
<td>6 (33)</td>
<td>D</td>
</tr>
<tr>
<td>9. Scientists do not just accept any claim even if made by renowned scientists.</td>
<td>61 (11)</td>
<td>39 (94)</td>
<td>D</td>
</tr>
<tr>
<td>10. A scientific investigation must follow a fixed step-by-step procedure.</td>
<td>56 (44)</td>
<td>39 (67)</td>
<td>D</td>
</tr>
</tbody>
</table>

**Note:** N =18; post-test in brackets; t =5.33 at 0.05 level

As to whether scientific knowledge is trustworthy on account of having “been proved” by experiments, 44% and 89% of educators agreed with the experts (model) at the pre- and post-test respectively. Most renowned philosophers of science and scientists are of the view that experiments are merely to confirm rather than verify or prove scientific knowledge. To prove or verify would only lead to an infinite regress of data collection (e.g. Hempel, 1966; Popper, 1968; 2001). Also, in line with the model, 61% and 67% of the educators at the pre- and post-test respectively disagree with the notion that every scientific test should yield the same result (Item 3). No matter how rigorous or sophisticated methods are used, it is nigh impossible to attain “same” results from replicated experiments. Rather, scientists look for generally close results because every replication is subject to subtle contextual differences, human error and practical skills differentia in handling apparatus. In most cases what is accepted as valid is obtained through triangulation rather than the exactitude of the results (Ziman, 2000).
However, contrary to the model only 28% and 22% respectively agreed that there is no need to consider philosophical, religious, psychological and linguistic questions to understand what science is (Item 4). The fact is that scientists are not immune to some degree of personal philosophical, sociological, religious or cultural commitments other than science alone. Indeed, scientific research “cannot be completely cleansed of personal elements” (Ziman, 2000, p. 102). Ziman (2000) contends further that it is nonsensical to suppose that scientists can produce knowledge that is completely untainted by collective interests and cultural values that shape their lives. In line with the model, 83% and 100% respectively agreed that scientists may be influenced by their philosophical, sociological and psychological frameworks or mind set (Item 5). Likewise, 94% and 100% respectively agreed with the model that a scientific discovery is accepted only after much testing and confirmation by other scientists (Item 6).

In agreement with the model, 67% and 83% at the pre- and post-test respectively disagreed that scientific truths are the same for everybody rather than on personal beliefs or situations (Item 7). This is not necessarily the case; otherwise there would be no need for argumentation—a common feature of the scientific enterprise. In contrast to the model, however, 94% and 83% of the educators respectively construe scientific theories as maps or representations of reality or an instrument that helps us see order in a complex natural world (Item 8). The panel disagreed with this instrumental notion of theories probably because the word “like” i.e. “similar to”, or “typical of”, appears too definitive. The instrumental view of theories focuses primarily on the functions of theories (Grandy, 1973). Many scientists also subscribe to the same notion of scientific theories as being like maps. The renowned scientist, Ziman (2000) however, prefers the word “analogous” to “being like” maps. Without going into semantics, the word “analogous” seems preferable in that it connotes similarity only in some respects rather than just being “like maps”. Scientific theories, unlike maps dealing with the “observables” e.g. roads, houses, buildings and so on, deal largely with the “unobservables” (Nagel, 1961, Popper, 1968, 2001; Ogunniyi, 2005, 2006).

In agreement with the model, 39% and 94% respectively disagreed with the statement that scientists do not just accept any claim even if made by renowned scientists (Item 9). While this claim may be valid, scientists do take the claims made by renowned scientists seriously (Ziman, 2000) e.g. Einstein, Newton, Witten, Hawking, Kraus and others. Also, in line with the model and contrary the view held by many historians, philosophers and sociologists of science and scientists, only 39% and 67% disagreed with the statement that a scientific investigation necessarily follows a fixed step-by-step procedure (Item 10). The most popularly accepted view in the literature is that while certain procedures may be common, there is no one rigid method of science. In all, this cohort of educators can be said to hold some valid notions of NOS; though much more at the post-test than at the pre-test.

Although one cannot make any generalization at this exploratory stage, there are significant perceptual shifts between the educators’ pre-test and post-test stances on NOS most probably as a result of their encounter with DAIM. The t-value between the
pre- and post-test stood at 5.33 at 0.05 against a t-value of 2.26 or 3.25 at 0.05 and 0.01 respectively. With these significant differences between their pre- and post-test conceptions of NOS one is 95% or 99% confident that DAIM must have had a positive impact on their understanding of NOS. The data obtained from the NOS questionnaire and reflected essays support this assertion. This finding is also corroborated by earlier studies showing the positive effects of argumentation instruction on educators’ understanding of NOS (e.g. Erduran, Osborne & Simon, 2004a; Ogunniyi, 2006, 2007a & b; Osborne, 2010; Simon & Osborne, 2004; Simon & Johnson, 2008). To obtain further insight, some excerpts derived from the educators’ responses to the NOS questionnaire and their reflective essays (including sources of their viewpoints) were also examined:

**ITEM 1: SCIENCE TELLS US THE TRUTH ABOUT NATURE**

**Excerpts from the educators’ responses to NOS questionnaire**

- Roland at pre-test: I agree-Not all the truth, but certainly a substantial amount [Science, media].
- Roland at post-test: Disagree- Science does not tell us the absolute truth, but gives the probability thereof. We all suffer from scientism, believing that it can provide answers to all problems.” [studies]
- Paul at pre-test: Disagree: Science helps us to try and discover more about the natural world i.e. to help us increase our knowledge/understanding of it [Media, Personal experience]
- Paul at post-test: Disagree-Science attempts to give an explanation for everything in the world. What was “truth yesteryear” may not hold today as modern technology helps to give science a better explanation.” [Media, own experiences]
- Lebo: I disagree-what holds today might change tomorrow, as new inventions and research are being carried out.” (Books, media)
- Lebo at post -test: I disagree. There is no absolute truth in science because science is dynamic [Literature].

**ITEM 2: SCIENTIFIC KNOWLEDGE IS TRUSTWORTHY BECAUSE IT HAS BEEN PROVED BY EXPERIMENTS.**

- Lebo at pre-test: I disagree. What holds today might change tomorrow, as new inventions and research are being carried out (Science, media).
- Lebo at post-test: I disagree. The experiments performed do not always give one the expected results. (Science).
- Duwi: at pre-test: Agree, science is not followed blindly, but there is always some empirical evidence that make people believe it (Personal view).
- Duwi at post-test: It can be trusted, because it does work and has contributed to many of men’s problems.
- Zeno: I agree: Everything that scientists come up with has been tried and tested, therefore we can accept it as trustworthy until someone else comes up with a different theory and proves it (science).
• Zeno at post-test: I disagree. Science knowledge is tentative, subject to change as new information becomes available through, for example, the latest technology (Research journals, news media) Ahmed.

ITEM 3: SCIENTIFIC FACTS CAN BE TESTED AND EVERY TEST SHOULD GIVE THE SAME RESULT.

• Roland at pre-test: It can be tested and should give the same results. Nature is not capricious [Med study]
• Roland at post-test: The same result can only be obtained if all the conditions are exactly the same [Science, Media]. If the variables stay the same the outcomes would be the same. If the results differ however this should be explained. [Science].
• Lebo at pre-test: The result would be the same provided the conditions are kept the same [Literature].
• Lebo at post-test: I disagree- the experiments performed do not always give one the expected results (Science).
• Paul at pre-test: I agree to certain conditions e.g. water boils everywhere at 100 C, if it done under exactly the same conditions at different places [Personal/textbooks].
• Paul at post-test: Not all knowledge can be scientifically proved—many deductions are made or conclusions are drawn from experiments and theories [Personal ant Textbooks]

EXCERPTS FROM REFLECTIVE ESSAYS

The representative excerpts below are derived from the educators’ reflective essays:

Scientific truths
• Audu at pre-test: My belief is that science should not be taught as if it has answers to all Q’s (questions) relating to physical world [Source: Science].
• Audu at post-test: Science should not be perceived as having find (found) all “truths” about the natural world…
• Duwi at pre-test: Science attempts to explain what happens and does not have the truth since it have (has) limitations [Influenced by personal experience with science at school and work].
• Duwi at post-test: Truth is a relative concept which can be refuted by another paradigm [personal]
• Paul at pre-test: Science help us to try and discover more about the natural world i.e. to help us increase our knowledge/understanding of it [Media, Personal experience].
• Paul at post-test: Science is a “tool” or a means for discovering facts about the natural world. We use science to search after truths [ SIKSP and Med studies].

Scientific investigation
• Zeno at pre-test: No, not really. The procedure that is followed could be very different depending on whether it is done in a natural setting (e.g. in a forest/school ground) or under contrived settings (such as in a laboratory). Different modes of inquiry may be needed to do observations.
• Zeno at post-test: No, I do not agree with this statement. Science textbooks would like us to believe that the scientific method is a simple, recipe-like procedure of OBSERVATION, HYPOTHESIS, EXPERIMENTATION, DATA COLLECTION, ANALYSIS &
EVALUATION, CONCLUSIONS etc. Most scientific investigations, however, do not follow this rigid procedure.

- Lean at pre-test: There is no step by step procedure to do science. Different methods are used for scientific investigations.
- Lean at post-test: There are no fixed steps to scientific investigation. There is no one path that leads us to scientific knowledge.
- Duwi at pre-test: Yes, there is always a starting point where one finds himself or herself in and then from there a particular procedure is followed.
- Duwi at post-test: No, One could start anywhere depending on what type or nature of the problem at hand.

From the foregoing, the poignant question of course is, “What took place during the various dialogical argumentation sessions to bring about perceptual changes among the educators? Table 2 provides some insight to what occurred in Danny’s group during a hands-on gari processing cognitive tasks. Gari is a staple food derived from the root tuber of cassava plant, *Manihot esculenta* and eaten in many African, Caribbean and some other tropical regions. It is noteworthy that Danny’s personal experience (having come from an area where gari is a staple food) played some role in influencing group 3 in preferring Method B to A and C. Further, a number of the groups identified some scientific, educational and cultural values of the methods they chose. The cultural values relate to the sour taste, smell, texture, storability and so on. Incidentally, the fermented gari is a special delicacy among certain cultural groups. Group 1 for instance, preferred method A over B and C because of what they called “the natural method” such as: peeling the tubers; soaking in water for 3-4 days; crushing/pulping by hand and so forth.

**Table 2 Summary arguments used by group 3 to select a particular method of processing gari**

<table>
<thead>
<tr>
<th>Names</th>
<th>Claim</th>
<th>Evidence</th>
<th>Warrants</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Group 3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Franco</td>
<td>Method B</td>
<td>Physical properties: rough granules; quite dry; taste; texture; powdery but not as fine as those of A &amp; C; fibres present; no (little) smell, etc.</td>
<td>Produce powders; drying process; use of graters; soaking to remove cyanide, etc.</td>
</tr>
<tr>
<td>Danny</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sima</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bren</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The facilitator from a gari-eating area like Danny’s guided the whole group to identify some of the cultural and educational values of indigenous methods of gari processing. He also, assisted the whole group to recognize that their arguments fell within levels 1-4 of TAP as well as ranged between a predominantly naïve to a more robust view of NOS.
EXCERPTS FROM TWO INTERVIEWS

Interview with Danny

Interviewer: How has DAIM helped you to be willing to participate in open discussions?
Danny: DAIM has made me to learn about various perspectives… the class becomes an enriching environment for class discussions.

Interviewer: What specific aspects of DAIM influenced you to change your view about the new curriculum?
Danny: The activities in the bi-weekly workshops which included group discussions and reflexive thinking enabled me to have diverse opinions with fellow science teachers. These diverse views they are cultural or scientific…

Interviewer: Try to be more specific about aspects of DAIM that influenced your changed view.
Danny: Group discussions, interactions, sharing of ideas, freedom to query others, dialoguing, argumentation in the groups…

Interviewer: What about the gari processing tasks?
Danny: The individual activity helped me to think critically and reflect on my background knowledge …This is different from rote learning where you just accept what others say but you think first, you dialogue with yourself, question, make claims, and seek for evidence and rebuttals before deciding what or not to accept.

Interviewer: Which of the groups (small or large) did you find most fruitful in your knowledge building?
Danny: Both. You change your view. Science is debatable and liable to change depending on evidences and that make science interesting… you do not see science as cast in stone because under certain conditions things might change…so, be less rigid in making claims.

Interviewer: To what extent did your experience with the DAIM-based activities on gari processing enhance your awareness of the educational and cultural value of IK and the new curriculum as a whole?
Danny: The intra-argumentation made me to value more the scientific processes involved in the indigenous methods of gari processing. For example, we saw how cyanide was removed to get the product. I valued the wisdom of indigenous people even though they didn’t do chemistry but performed the work of a chemist.

Interviewer: Anymore?
Danny: By examining the physical properties of gari in terms of texture, taste, etc. and as I reflected on the use of grater, our discussions on the soaking process and the consequences of the steps taken, we saw only method B as the one that could lead to the production of solid gari but neither A nor C….

Interviewer: So, you persuaded your group members?
Danny: After much arguments and discussions about the steps used in each method alongside my claims and the evidences, my group chose method B, which had rough granules compared to A and C with fine products.

Interviewer: What did you gain in the large group?
Danny: What we thought in our groups and in the other groups came to the same thing. This
assured me that the view we held in our group was valid. There were arguments and counter arguments, but we ironed these out and, with the help of the facilitator, we reached a valid conclusion.

Interviewer: Thank you.
Danny: Thank you, too.

**Interview with Sena**

Interviewer: What specific aspects of DAIM influenced you to change your view about the new curriculum?

Sena: The collaborative and interactive classroom arguments and dialogues with the SIKS group helped me to share my ideas, interact with others and to gain insights about the new science-IK curriculum. The series of lectures by…also introduced me on how to use DAIM to implement a learner-cantered curriculum in my own study…

Interviewer: What specifically did you gain in the small group?

Sena: The small group discussions e.g. on gari processing helped me to see the cultural values of IK. If you start with students’ basic cultural background it makes science sensible to them. DAIM in form of intra-, inter- and trans-argumentation were particularly helpful but the most important to me was the inter-argumentation stage. Here, everyone has the opportunity to talk, especially, for a shy person like me. Besides, in my culture, women are not given the chance to talk as much as they would like…

Interviewer: So, you could not select any of the methods?

Sena: Not really.

Interviewer: What about the whole group?

Sena: In the large group, only a few people could talk. There is not much time to talk.

Interviewer: To what extent did your experience with the DAIM-based activities on gari processing enhance your awareness of the educational and cultural values of the science-IK curriculum?

Sena: DAIM-based activities on gari processing broadened my understanding of what the sociocultural aspect of science entails. The activities also increased my awareness of the need of including students’ traditional cultural knowledge (IK) in science classes. I strongly believe that such activities could help teachers and their students to realize the educational value of IK and to take an action to convince the wider community that IK is not primitive and outdated.

Interviewer: What specific activities did you personally find beneficial in your instructional practice?

Sena: The specific learning outcomes, the lesson plans, even modelling the lesson… Finally, the debriefing and closure to reflect discuss and evaluate their critical thinking and higher-order thinking and so on.

Interviewer: Thank you for your willingness to participate in this interview.

Sena: Pleasure.

We can go on and on, the same pattern of responses is revealed in the other items. Although not all indicated the sources of their viewpoints, several attributed their perceptual shifts to SIKSP- namely, the project that exposed them to DAIM. However, it suffices to say that the educators’ increased knowledge of NOS and related issues,
exemplified in Table 1 and the excerpts above, suggests a kind of evolutionary development in their understanding of NOS. This constructivist view accords with Ziman’s (2000) contention that conceptual understanding of NOS is not a passive activity but rather, it is an evolutionary process involving a dynamic interaction between what is known with what is just being learned to solve a given cognitive task (Ziman, 2000).

Danny’s and Senait’s comments above provide some insight into how their knowledge of NOS increased as they participated in the various aspects of DAIM starting from the individual- to the small-group- and finally whole-group activities. They attributed their enhanced understanding of NOS to lectures, classroom discourses and DAIM-based hands-on activities which involved arguments, dialogues and collaborative consensus-making. In terms of CAT both Danny and Senait made cognitive shifts from a narrow to a more nuanced, holistic and socially relevant understanding of NOS by becoming more appreciative and aware of the scientific processes involved in the indigenous method they had chosen.

Danny’s incremental understanding of NOS

Looking at Danny’s group as a case in point, one could easily see how the members of his group mobilized their claims, counterclaims and provided pieces of evidence, warrants and backings (grounds) to justify their claims about why they considered one indigenous method of gari processing better than the other two (e.g. Erduran, et al, 2004; Ogunniyi, 2005, 2006, 2011; Simon & Johnson, 2008). Specifically, Danny carried out self-conversation (intra-argumentation) at the individual stage while at the small-group stage Danny was actively involved in dialogical argumentation with members of his group and represented the group in arguing that Method B was the most effective method for producing high-quality gari.

The facilitator (a well-trained research assistant) played the devil’s advocate role by moving round to ask thought-provoking questions. He led the whole group at the trans-argumentation stage to identify the levels or types of TAP and CAT reached during the discussions. He also made them aware that their arguments at the various levels ranged between levels 2 and 4 of TAP namely: arguments supported with grounds but no rebuttals; arguments consisting of claims supported with grounds and occasional weak rebuttals; and arguments supported with grounds and at least one strong rebuttal; and that on no instance did any group mobilize level 5 of TAP i.e. arguments with more than one strong rebuttals. In terms of CAT, they mobilized in a descendant order mainly scientifically dominant, equipollent, suppressed, emergent and assimilated cognitive worldviews.

CONCLUSION

With few exceptions, the findings show that DAIM enhanced the educators’ argumentation skills; increased their understanding of NOS; buttressed their awareness of the scientific processes embedded in IK; and helped them to shift from their negative view to a positive view of the new curriculum regarding the integration of science and
IK in their classrooms. The implications of the findings are that this cohort of educators is more likely to convey a more valid understanding of NOS to their learners than would have been the case if they had not encountered DAIM. In view of these findings and earlier ones, it is safe to state that efforts directed at transforming instructional practices among educators as well as helping learners to resolve possible conceptual conflicts between school science and IK should also consider DAIM as a potential instructional strategy.

REFERENCES


NOVICE UNQUALIFIED SCIENCE TEACHERS’ CHANGE IN PCK OF THE PARTICULATE NATURE OF MATTER AS IDENTIFIED BY THEIR CONTENT REPRESENTATIONS

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ABSTRACT

Newly qualified graduates teaching without formal teacher qualifications and teaching experience have little or no basis for the understanding of transformation of Content Knowledge (CK). This study, grounded within a Professional Development Intervention (PDI) seeks to trace the development of 16 Novice unqualified graduate teachers’ Topic Specific Pedagogical Content Knowledge (TSPCK) through construction of a Content Representation (CoRe). The TSPCK construct, also theoretical framework for this study, was defined in terms of five categories that collectively enable transformation of CK which are: learner prior knowledge, curricular Saliency, what is difficult to teach, representations and conceptual teaching strategies. Data consisted of initial and final teacher constructed CoRes before and after teaching. For the four case study teachers, video-recorded lessons together with pre- and post-lesson teacher observation interviews and field notes were utilized. The findings revealed that the use of initial CoRe enabled the novice unqualified teachers to engage with the construct TSPCK. Their response to the initial CoRe prompts for categories: curricular saliency, what is difficult to teach and learner prior knowledge were acceptable unlike representation and conceptual teaching strategies which were challenging. For the selected group of four case study teachers who taught the topic under consideration, evidence of the acceptable and more refined responses were observed either in their teaching and/or in the interviews. The teachers’ experience in teaching of the lesson might have contributed to the much improved responses in the group’s final CoRe. These findings reveal that novice unqualified teachers’ PCK of the particulate nature of matter was starting to develop during the PDI.

Keywords: Novice teachers, Professional development, PCK

INTRODUCTION

Shulman’s (1986, 1987) introduction of the notion of Pedagogical Content knowledge (PCK) in 1986 sparked interest in a large number of researchers who responded by expanding and refining the construct. Although PCK has been characterized by some researchers as elusive e.g. (Kind, 2009), others have acknowledged that PCK is a useful construct, providing specialized knowledge, specific to disciplines and topics and largely gained through teaching experience. According to Shulman, PCK encompasses exciting and new ways of teaching content knowledge (CK) so that the ideas become
understandable to others, is by including ‘the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations’ (Shulman, 1986, p. 9).

This study engages a group of novice unqualified teachers with little or no PCK since they have not taught before. Numerous studies exist investigating both experienced practicing and pre-service teachers’ PCK e.g. (Bertram & Loughran, 2012) but few examine the case of unqualified novice teachers. The teachers in this study are recruited by Teach South Africa (TSA) and placed in disadvantaged high schools to teach science. This model is similar to that of Teach America (Xu, Hannaway, & Taylor, 2011) which recruit unqualified science graduates to teach science in high schools in the USA. The shortage of qualified science teachers leads to the deployment of non-science majors to teach science in high school. Kriek and Grayson (2009) argue that the limited CK of these teachers leads to ineffective teaching approaches. Research conducted on beginning teachers shows that they are often left to succeed or fail within the confines of their classrooms and that they face challenges that involves pedagogy (Ingersoll & Smith, 2004). Luft (2009) suggests that there is a need for science induction programmes to support beginning teachers and Supovitz and Turner (2000) argue that high-quality professional development should focus both on CK and PCK. In South Africa, where this study is conducted, teachers face challenges with CK, which impacts negatively on its transformation (Rollnick & Mavhunga, 2016). This study explores how teachers’ PCK of particulate nature of matter develops through amongst others construction of a Content Representation (CoRe) and teaching experience during a Professional Development Intervention (PDI). Several international studies in science education have used CoRes for pre-service teachers PCK development (Bertram & Loughran, 2014) and others have adopted CoRes as a data collection tool (Bertram & Loughran, 2012). However, there is no studies in science education that have adopted a CoRe as both data collection tool and means of introduction to PCK in novice unqualified graduate teachers and traces CoRes’ responses in their teaching.

This study aims to answer the research questions:

- What is a group of novice unqualified graduate teachers’ understanding of TSPCK before the PDI?
- To what extent does a targeted PDI influenced the development CoRes in particulate nature of matter, which translates into TSPCK of novice unqualified graduate teachers?

THEORETICAL FRAMEWORK

As stated above, this study explores the novice unqualified teachers’ ability to articulate transformation of CK. Shulman (1986, p. 9) asserted that PCK ‘goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching’. This study is grounded within the PCK construct as a theoretical framework. Although PCK is seen by many science researchers as a useful construct, there are some debates that
exist regarding its nature. This has led to the development of a model of teacher professional knowledge and skill (TPK&S) including PCK by Gess-Newsome (2015) which was used as a starting point in this study. The model accommodates both personal and canonical PCK through the inclusion of a construct known as Topic-Specific professional knowledge (TSPK) which focuses on the teaching of a specific topic and distinguishes between the PCK knowledge and practice. The latter is relevant to this study since the focus is on: a CoRe construction which is an example of the manifestation of canonical TSPK Gess-Newsome (2015) in the actual teaching of particulate nature of matter. TSPK is linked to classroom practice and to student outcomes through a series of contextual filters. The model’s three principal constructs feed back into each other through teacher learning by practice and interaction with students. Hence TSPK refers teacher knowledge while the term PCK is reserved for the personal construct as it appears in practice.

In this study, the construct of TSPK was further refined and Topic Specific Pedagogical Content Knowledge (TSPCK) of Mavhunga & Rollnick (2013) was used which is the specific knowledge needed for transformation of CK for teaching purposes.

The TSPCK construct in Figure 1 consist of five categories:

**Learner prior knowledge** - knowledge of student’ common misconceptions and alternative conceptions about specific content.

**Curricular saliency** - understanding the order in which topics are addressed and the depth to which a topic should be covered.

![Figure 1: Edited. Consensus model for PCK](image-url)
What is difficult to teach - the ability to identify gate keeping concepts, within a topic, that are difficult to understand.

Representations - knowing a range of subject matter representations including examples and analogies.

Conceptual teaching strategies - knowledge of effective instruction strategies for particular misconceptions, known areas of difficulty to learn and the educational purpose of available curriculum materials.

The above model suggests that canonical TSPCK is topic specific. The CoRe template used in this study was adapted to accommodate the five categories of TSPCK.

LITERATURE REVIEW

The review below focuses on empirical studies done on PCK and the particulate nature of matter, how PCK is portrayed or captured and professional interventions related to PCK.

Empirical studies on PCK

Unqualified novice teachers are faced with teaching challenges at the beginning of their teaching career. These challenges are related to their understanding of the content, and discipline of science instruction (Adams & Krockover, 1997) hence the need to develop their PCK. Kind (2009) further argues that a better understanding of PCK will better prepare beginning teachers for working full-time in schools. Several studies investigating the PCK of pre-service teachers found that they: do not anticipate teaching difficulties, portrayed some budding PCK and encountered challenges with regard to the relationship between the macroscopic and sub-microscopic representation of matter (Jong, Van Driel, & Verloop, 2005). In line with pedagogical approach, Geddis, Onslow, Beynon, and Oesch (1993) discovered that novice teachers tend to adopted a transmission model of teaching whilst experienced teachers developed a step-wise strategy. Luft (2009) indicated that the PCK of beginning teachers tend to build more at topic level. This study focuses on PCK of teachers at a topic specific level as supported by the Consensus model for PCK Gess-Newsome, Taylor, Carlson, Gardner, Wilson and Stuhlsatz (2017).

Content Representations (CoRes)

The nature of PCK has been described differently by different researchers. PCK is elusive nature which is described as tacit and hidden (Kind, 2009). This is partially because it is not yet used as a conceptual tool explicitly by teachers. Tools used to portray PCK have been developed to gain access to this tacit construct (Loughran, Mulhall, & Berry, 2004). Loughran et al. (2004) came up with two complementary elements for capturing and representing one’s PCK in meaningful ways, called CoRe and Pedagogical and Professional experience Repertoires (PaP-eRs). A CoRe can be used as both a research tool for accessing science teachers’ understanding of the content (Williams, Eames, Hume, & Lockley, 2012) and as a way of introducing pre-service teachers to PCK (Bertram & Loughran, 2014). This study utilized a CoRe as both data
collection tool, introduction to PCK and traced CoRes’ responses in the teaching. Numerous studies examining PCK of pre-service teachers through the use of a CoRe found that CoRes developed through a collaborative process, assisting the pre-service teachers to focus on the big picture of the topic and to consider alternative ways of planning for their teaching (Williams et al., 2012). This finding supports a recommendation made by Bertram and Loughran (2012) that the CoRe tool could be explored in enhancing pedagogical models that might assist pre-service and beginning science teachers.

PROFESSIONAL DEVELOPMENT

According to Grigg, Kelly, Gamoran, and Borman (2013) professional development may take different forms, such as in-service training and mentoring. Zwiep and Benken (2013) argue that in the literature on teacher professional development, the knowledge, perceptions of the teacher and the role that rigorous content plays are critical emphases. This supports the purpose of the professional development in this study where novice teachers’ PCK of the particulate nature of matter may be influenced. Supovitz and Turner (2000) argue that high-quality professional development should focus both on deepening CK and PCK. Luft (2009) compared four different types of induction programmes to support beginning teachers and find that science-specific and e-mentoring programmes assisted teachers in applying inquiry instruction which strengthened their PCK.

EMPIRICAL STUDIES ON PARTICULATE NATURE OF MATTER

The particulate nature of matter is a key basic concept of chemistry and several studies suggest that learners from early schooling often have difficulties in understanding the topic. Treagust, Chandrasegaran, Crowley, Yung, Cheong and Othman (2010)’s study revealed that learners’ responses to the test items showed that they have limited understanding of the particle theory concepts and find difficulties in applying the particulate theory to explain phase changes. Taber (2001, p. 131) argues that ‘one general problem that has widely been recognised in the learning of chemistry is the difficulty learners have with the relationship between the molecular and macroscopic’. He highlights reasons attributed to the difficulty among others that learners and amongst others the transfer changes in macroscopic properties to the sub-microscopic level. Boz and Boz (2008) investigated Turkish learners’ conceptions of the particulate nature of matter and found that learners of all age groups experienced difficulties in understanding the movement of particles in a solid substance.

METHODOLOGY

This study is located within a PDI and is based on a qualitative case study approach investigating how 16 novice unqualified teachers development and portrayal of their PCK. They hold science degrees, have done Chemistry for a minimum of one year during the course of their degree, mostly graduated within five years of the study and have no teaching qualifications. Table 1 provides a detailed description of the participants.
Table 1: Details of participants

<table>
<thead>
<tr>
<th>Teacher Pseudonym</th>
<th>Teaching grades allocated</th>
<th>Relevant Major subjects</th>
<th>Gender</th>
<th>Years since graduation</th>
<th>CoRes Group number</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS*</td>
<td>8 and 10</td>
<td>Biology</td>
<td>Male</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>MB</td>
<td>8</td>
<td>Biology</td>
<td>Female</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>TS</td>
<td>8 and 9</td>
<td>Biology</td>
<td>Female</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>DN*</td>
<td>9 and 10</td>
<td>Chemistry</td>
<td>Female</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>ZD*</td>
<td>9 and 10</td>
<td>Chemistry</td>
<td>Female</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>WM</td>
<td>8, 9, 11 and 12</td>
<td>Chemistry</td>
<td>Female</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>SR</td>
<td>8, 9 and 11</td>
<td>Chemistry</td>
<td>Male</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>TC</td>
<td>8 and 9</td>
<td>Chemistry</td>
<td>Male</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>KT</td>
<td>8</td>
<td>Chemistry</td>
<td>Female</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>LM</td>
<td>9, 11 and 12</td>
<td>Chemistry</td>
<td>Male</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>MJ</td>
<td>10 and 11 (but not particle nature)</td>
<td>Biology</td>
<td>Female</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>KK</td>
<td>9 and 11</td>
<td>Biology</td>
<td>Male</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>NN*</td>
<td>9 and 10</td>
<td>Physics</td>
<td>Male</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>AN</td>
<td>9 and 11</td>
<td>Physics</td>
<td>Male</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

*Case study teachers

The teachers are recruited by TSA working together with the Department of Education and expected to commit to teaching for a minimum of two years in some of South Africa’s most disadvantaged schools. Apart from representing the Physical science group and their willingness to participate in the study, these teachers were also in a position to teach the particulate nature of matter to the grade 10, a targeted Grade for this study. The particulate nature of matter was chosen not only because these inexperienced teachers were unlikely to teach physical science in higher grades but it is a widely researched topic underpinning basic chemistry concepts and presents challenges in teaching due to its abstract nature.

DATA SOURCES

Prior to being placed in schools, teachers participated in two weeks intensive training organized by TSA and conducted by experts from different universities and reputable teacher trainings private organisations in South. The first week covered generic teaching matters relating to classroom management and science curriculum and assessment in week two. The initial CoRe was constructed during first week for 1hour. Prior to CoRe construction, the author led in depth discussion on TSPCK and CoRes. The CoRe template used in this study was Mavhunga and Rollnick (2013) which accommodate the categories of TSPCK. Teachers were divided into three groups: two groups of five and one group of six and each group had a case study teachers (who had taught the topic) marked in asterisk in table 1. They had access to different science high school textbooks.
and curriculum guidelines to use during the CoRe construction. Due to time constraints and that the teachers had not taught before, a decision was taken to provide them with the big ideas. Each group was assigned a big idea as identified by Loughran et al. (2004) and had to complete its prompts.

Big idea 1 - Matter is made up of small bits called particles

Big idea 2 - There is nothing (empty space) between the particles that makes up matter

Big idea 3 - The particles are in constant motion

The author observed four case study teachers who were allocated to teach grade 10 learners. A fifth teacher MJ, only observed the topic but taught chemical bonding. The post-session workshop was held nine months later in the year where the same teachers with the exception of the TM, AN and DR worked in the same groups to produce a final CoRe. Teachers did not have access to the first CoRe when constructing the final CoRe during the post-session workshop. The author observed and video-recorded lessons, audio recorded interviews, kept field notes of the four case study teachers who taught grade. The lessons and interviews were transcribed for analysis.

ANALYSIS AND DISCUSSION

Prior to CoRe analysis, it is important to explain the criteria underpinning the analysis to follow. A decision to use the particle theory’s first 3 big ideas developed by Loughran et al. (2004) as an expert CoRe was taken. This CoRe was chosen because the topic is identical to the one under consideration and the experts’ CoRe was developed by a group of experienced high school science teachers working collaboratively, who have taught both General Education and Training (GET) and Further Education and Training (FET). Since the participants are unqualified, it was important to compare their CoRe responses with those of expert teachers. The responses to the prompts from the experts’ CoRe were used as a form of guidance in authenticating novice teachers’ responses where possible.

DEVELOPMENT OF TSPCK THROUGH THE CORE

The initial and final CoRes developed during the PDI are analysed. Analysis of each big idea is discussed according to the respective groups in the section to follow. The selection of the prompts analysed for each group below is based on the i) quality of the final CoRe responses relative to other groups, which translate into better portrayal of PCK and ii) availability of relevant analysed data from other data source which allowed triangulation.

Analysis of big idea 1 - Matter is made up of small bits called particles

Table 2 shows the group composition for big idea 1 and category curricular saliency is analysed.
Table 2: Composition of group for big idea 1

<table>
<thead>
<tr>
<th>Initial CoRe</th>
<th>Final CoRe</th>
</tr>
</thead>
<tbody>
<tr>
<td>DN*</td>
<td>DN*</td>
</tr>
<tr>
<td>SS*</td>
<td>SS*</td>
</tr>
<tr>
<td>DR</td>
<td>–</td>
</tr>
<tr>
<td>MB</td>
<td>MB</td>
</tr>
<tr>
<td>TS</td>
<td>TS</td>
</tr>
</tbody>
</table>

THE CATEGORY OF CURRICULAR SALIENCY

Evidence of emerging TSPCK is noticeable from the prompts ‘what concepts need to be taught before teaching this idea’ and ‘what else do you know about this idea that you do not intend learners to know yet’, which relates to the pre and post-concepts of the topic respectively. The prompt ‘what concepts need to be taught before teaching this big idea’ appeared to be difficult for this group as they indicated ‘none’ as the response in the initial CoRe. However, in the final CoRe teachers indicated that the understanding of what matter is, need to be grasped by the learners. This is an indication that they have acquired the knowledge of concepts still to be taught at a later stage for understanding this big idea.

Most responses (initial CoRe) to the prompt ‘what else do you know about this idea that you do not intend learners to know yet’ were not entirely acceptable as compared to experts’ CoRe, because the group gave big ideas 1 & 2 as answers instead of concepts or topics still to be taught. But the response ‘the behaviour of particles’ is acceptable, as it links to the experts’ response which indicates ‘at this stage particles is used in a general sense without discriminating between atoms and molecules’ Loughran et al. (2004). However, in the final CoRe the responses suggest that teachers have now acquired the
knowledge of concepts still to be taught at a later stage such as subatomic structure, phases of matter as well as explaining the kinetic energy and intermolecular forces. Teachers also gave acceptable responses in prompts ‘what do you intend the learners to know about this idea’ and ‘why is it important for learners to know about this big idea’ in the initial CoRe and better improved responses in the final CoRe. It is evident that there was a shift in the knowledge of curricular saliency prompts indicating developing TSPCK.

The last curricular saliency prompt ‘what concepts need to be taught before teaching this big idea’ is analysed in order to investigate evidence of emerging TSPCK from a case study teacher SS’s lesson. The response given by the group for this prompt in the initial CoRe illustrates the difficulty experienced by novice teachers in identifying concepts to be taught before teaching the big idea, as they indicated there are no pre-concepts, in figure 2. However, the response in the final CoRe response showed that the understanding of ‘what matter is’, needed to be grasped by the learners. Since this concept was not mentioned in the initial CoRe response as a response, it may be assumed that teachers who taught the topic might have had some influence prior to the development of the final CoRe.

Evidence from SS’s teaching experience to support growth in PCK is explicitly seen in the excerpt below, during the lesson on states of matter and kinetic molecular theory.

Teacher SS: today we are going to learn about the states of matter ok or matter just by itself. What are we talking about? (Asking learners to define matter)

Learners (chorusing): anything that occupies space and has a mass (Lesson Teacher SS)

The excerpt above shows that prior to teaching kinetic molecular theory, SS began the lesson by asking learners to define matter. It is expected of the learners to know this because the basic concepts of matter such as the particle model of matter are taught in both grades 8 & 9. Based on how SS introduced the lesson during the teaching of the topic; it is possible that his experience may have contributed to the improvement of the final CoRe in his group.

Analysis of big idea 2 - There is nothing (empty space) between the particles that make up matter

The group composition for this big idea consisted of teachers in table 3 and categories representations and conceptual teaching strategies are analysed.

<table>
<thead>
<tr>
<th>Initial CoRe</th>
<th>Final CoRe</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZD*</td>
<td>ZD*</td>
</tr>
<tr>
<td>TM</td>
<td>-</td>
</tr>
<tr>
<td>WM</td>
<td>WM</td>
</tr>
<tr>
<td>TC</td>
<td>TC</td>
</tr>
<tr>
<td>SR</td>
<td>SR</td>
</tr>
</tbody>
</table>
The categories of representations and conceptual teaching strategies

In the initial CoRe this group suggested the representations illustrated in figure 3 below but did not elaborate by giving examples and content on how these representations will be used.

<table>
<thead>
<tr>
<th>Initial CoRe</th>
<th>Final CoRe</th>
</tr>
</thead>
<tbody>
<tr>
<td>What...</td>
<td></td>
</tr>
<tr>
<td>Demonstration model</td>
<td>Diagrams (flow diagrams)</td>
</tr>
<tr>
<td>Flow diagrams</td>
<td>Demonstration models</td>
</tr>
<tr>
<td>Simulations</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 3: Representation prompt for big idea 2**

It is also not clear which representation is for macroscopic, sub-microscopic or symbolic representation. However, taking into consideration the response such as simulations documented in the final CoRe, one may assume that teachers might have had in mind the sub-microscopic representations. This is supported by what was documented by the author about teacher ZD’s lesson.

[From a lesson kinetic molecular theory] ZD used a simulations in an attempt to demonstrate both the arrangement and movement of particles in different phases (ZD field notes)


ZD used both the macroscopic and sub-microscopic representations. A macroscopic representation was represented by the block of ice to be heated. This is something that learners are able to see directly. The teacher further introduced the sub-microscopic representation of different phases of matter. Figure 4 indicates the distance between the solid particles. Learners are not able to see both the particles and forces in this regard, but might be able to imagine them based on the macroscopic representation

**Figure 4: ZD’s sub-microscopic representation of a solid**

In the first prompt for *conceptual teaching strategy* in figure 5, the group only showed the type of representations they would use without explaining how they intend to incorporate them in order to manifest effective strategy. In the initial CoRe’s first prompt, they gave answers that could be suitable for the category of *representation* with
no linking explanatory notes that includes content as the answer to the prompt ‘what effective strategies would you use to teach this idea’. The responses are not appropriate compared to the responses on the expert CoRe of expert teachers.

Initial CoRe

<table>
<thead>
<tr>
<th>Teaching Strategies</th>
<th>Final CoRe</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Simulation</td>
<td>- Have a demonstration using water and let the learners see how the different phases change</td>
</tr>
<tr>
<td>- Videos</td>
<td>- Have flow diagrams that illustrate how the particles behave in the different states</td>
</tr>
<tr>
<td>- Models</td>
<td>- How the particles of the different states are arranged?</td>
</tr>
<tr>
<td>- Drawings</td>
<td>- Explain what happens to the particles when phases change?</td>
</tr>
<tr>
<td></td>
<td>- Ask what's in the spaces? So as to see if they understood that there's an empty space</td>
</tr>
</tbody>
</table>

Figure 5: Conceptual teaching strategy prompts for big idea 2

However, this response in contrast with the final CoRe response where they elaborated on how to incorporate the representation in order to demonstrate specific concepts needed to be grasped by the learners as part of conceptual teaching strategy. The similar manner of responding is also seen on the experts’ CoRe. Although the expert teachers selected a ‘Predict-Observe-Explain (Kearney, 2004) procedure when squashing a syringe of air as teaching approach. This strategy involved a demonstration using water intended to show the learners how different phase change occurs which is acceptable-in the final CoRe.

Evidence of this strategy was observed and documented in the field notes during ZD’s lesson on the kinetic molecular theory. Although she did not literally bring liquid water, ice or boiling water, ZD used water as an example when explaining the concept of phase change.

[For example, ZD said to the learners, “If a block of ice is put on a stove that is switched on, what happens to the ice or the particles?”] (ZD field notes)

The group found the second prompt (questions considered important to ask) of this category challenging. The questions suggested in both CoRes were not conceptual compared to the expert teachers

Analysis of big idea 3 - The particles are in constant motion

Table 4 shows the group composition for big idea 3 and categories learners’ prior knowledge and what is difficult to teach are analysed.
Table 4: Composition of group for big idea 3

<table>
<thead>
<tr>
<th>Initial CoRe</th>
<th>Final CoRe</th>
</tr>
</thead>
<tbody>
<tr>
<td>NN*</td>
<td>NN*</td>
</tr>
<tr>
<td>MJ</td>
<td>MJ</td>
</tr>
<tr>
<td>LM</td>
<td>LM</td>
</tr>
<tr>
<td>AN</td>
<td>--</td>
</tr>
<tr>
<td>KT</td>
<td>KT</td>
</tr>
<tr>
<td>KK</td>
<td>KK</td>
</tr>
</tbody>
</table>

THE CATEGORY OF LEARNERS’ PRIOR KNOWLEDGE

Teachers were able to envisage correctly learners’ misconceptions associated with teaching this big idea. The particles in solids are envisaged to be the one that learners do not understand as suggested by the responses in figure 6 for both CoRes. The same response was also captured by the expert teachers in the expert CoRe.

Although not explicitly elaborated, the response in the initial CoRe ‘the molecules in liquid only move when you shake the container’ is a common misconception held by learners. It shows the learners’ inability to differentiate between macro and micro levels. An example related to this was documented by expert teachers as students’ thinking that influences the teaching of this idea.

Evidence relating to the difficulty in differentiating between macro and sub-microscopic levels was seen and documented in teacher NN’s field notes.

[From a lesson on kinetic molecular theory] The teacher NN asks learners to describe the motion of particles in liquids and gave an example of a glass of water. A learner indicated that the particles in liquid flow. It was clear from this response that the learner is unable to differentiate between the two levels.

(NN Field notes)

NN further elaborated on the misconception encountered in the lesson on kinetic molecular theory in the post observation interview excerpts below.

**Researcher:** How do you feel about the lesson today?

**Teacher NN:** I think I feel good. The lesson objectives were achieved. I wanted them to really understand the kinetic molecular theory and be able to apply it and explaining how the behaviour of matter under different situations. I think that was achieved to a bigger extent

**Researcher:** What do you consider the most effective teaching moment was in the lesson?
Teacher NN: I think the simulation was effective. It made them see particles moving in different phases, the particles vibrating and gaining energy from the heat. I think that was the most effective method. (Post lesson Interview NN)

The last part of the excerpt shows that NN emphasised the use of simulation in order to assist learners in conceptualising abstract concepts such as movement of particles in different phases.

**The category of what is difficult to teach**

Teachers were initially not aware of difficulties associated with teaching of this big idea. The response in the initial CoRe in figure 7 suggests they were not certain of exactly what is difficult. They response provided were generic and not clear on what exactly is difficult.

<table>
<thead>
<tr>
<th>Initial CoRe</th>
<th>Final CoRe</th>
</tr>
</thead>
<tbody>
<tr>
<td>What do you consider easy or difficult in teaching this big idea?</td>
<td>Hard to understand the idea that particles are always in constant motion when the object is stationary especially if the particles are in a Solid State.</td>
</tr>
<tr>
<td>Difficult that a lot of factors cause the molecules to move and not just energy. That there are also forces involved such as the average distance between solids and liquids is relatively the same but the major jump is in gases have a significant difference due to these forces.</td>
<td></td>
</tr>
</tbody>
</table>

The final CoRe showed improvement as it specified that learners may find it difficult to imagine particles in a solid moving. This concept was also identified in the CoRe by the expert teachers in Loughran et al. (2004). In order to instill the idea of ‘particles are always in constant motion’, in his lesson on kinetic molecular theory, NN made use of simulations representing the sub-microscopic representation.

**CONCLUSION**

The use of a CoRe enabled the novice unqualified teachers to engage with the PCK of particulate nature of matter. Teachers’ understanding of TSPCK revealed that category learner prior knowledge was easy before the PDI and they envisaged correctly that the misconception will be regarding motion of solid particles. Teachers produced better and refined responses in the final CoRe. The misconceptions identified regarding the solid particles by both case study teachers ZD’s lesson and NN’s post-interview has revealed the incapability of the learners in differentiating between macro and sub-microscopic levels (Jong et al., 2005). For curricular saliency and what is difficult to teach, teachers’ initial CoRe responses were generic. Prior to the PDI, teachers (i) identified pre-concepts consisted of either raw big ideas or not identified (ii) the post-concepts identified lacked an immediate link to the big ideas of the topic. Teachers gave acceptable responses for both the pre- and post-concepts for respective big ideas. This improvement indicates possible engagement in the teaching of the topic or its pre-requisite concepts. In terms of what is difficult to teach, teachers’ responses shifted from
generic to identifying the concepts considered difficult to teach and explanations in the final CoRe. Evidence from case study teachers’ lesson showed the utilization of simulations in order to make the abstract concept comprehensible.

The categories representations and conceptual teaching strategies were challenging for teachers, with conceptual teaching strategies being the most difficult before the PDI. Teachers gave generic responses regarding types of representations to be used, without linking them to specific concepts. Case study teachers’ utilization of multiple representations in their teaching such as: the macro and sub-microscopic representation including the simulation of solid phase, may have influence some of the acceptable response in the final CoRe though still need more refinement. Conceptual teaching strategy remained the most difficult as teachers struggled to elaborate and expand on suitable strategies to be used in most groups. However, there were some improvements in the final CoRe responses from group two of all chemistry majors engaging with big idea 2. Teachers attempted to elaborate further on how they would incorporate the representation in order to demonstrate specific concepts needed to be grasped by the learners as part of their teaching strategy which require a much more improvement as compared to the expert CoRe responses Loughran et al. (2004). This finding is not surprising considering that these teachers have no formal teachers’ qualification and possessed just under a year of teaching experience during the study. Generally, unlike expert teachers in Loughran et al. (2004) who had a full year to construct the CoRe, these teachers had a limited time of only 1 hour for developing a CoRe. Finally, I would argue that by engaging in a CoRe pushed novice teachers to start thinking about how to teach a particular topic. The same teachers portrayed better PCK on the particulate nature of matter after engaging in the teaching of that topic (Pitjeng, 2014). The findings suggest that teachers’ PCK of the particulate nature of matter was starting to develop during the PDI.

Sasol Inzalo Foundation and National Research Foundation is gratefully acknowledged.

REFERENCES


Pitjeng, P. (2014). Investigating the effect of an intervention on novice science teachers’ topic specific pedagogical content knowledge. (PhD), University of the Witwatersrand, Johannesburg.


### Important Science

<table>
<thead>
<tr>
<th></th>
<th>A: Matter is made up of small bits that are called particles.</th>
<th>B: There is empty space between particles.</th>
<th>C: Particles are in constant motion.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>What you intend the students to learn about this idea.</strong></td>
<td>If we break up substances, the smallest bit of substance we can get is a particle.</td>
<td>The relative distances between particles differs in solids, liquids and gases.</td>
<td>Particles of matter are always moving. The speed of particles can be changed (by heating/cooling, pressure change). The way particles are arranged can change when their speed changes.</td>
</tr>
<tr>
<td><strong>Why it is important for students to know this.</strong></td>
<td>Because it helps to explain the behaviour of everyday things e.g., diffusion.</td>
<td>Because it explains the ability to compress things and helps to explain events such as expansion and dissolving.</td>
<td>Because it explains what happens in phase changes, e.g., the need to contain gases is evidence the particles are moving.</td>
</tr>
<tr>
<td><strong>What else you know about this idea (that you do not intend students to know yet).</strong></td>
<td>At this stage ‘particles’ is used in a general sense without discriminating between atoms and molecules. Subatomic structure. Chemical reactions. Ions. More complex properties of materials. More complicated models of matter. Links to diffusion and thermal properties of matter.</td>
<td></td>
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<tr>
<td><strong>Difficulties/limitations connected with teaching this idea.</strong></td>
<td>Particles are too small to see. The use of particular science models is not necessary to comprehend science in everyday life. It is difficult to decide when to introduce the labels (i.e., atoms, molecules) for different kinds of particles. Substances seem to disappear when dissolved. What holds particles together? Why don’t substances automatically become a gas?</td>
<td>There is a big difference between macro (seen) and micro (unseen) levels, e.g., wood seems solid so it is hard to picture empty space between the ‘wood’ particles. Students don’t tend to think of gases as matter and therefore have difficulty thinking about empty spaces between gas particles.</td>
<td>That macro properties are a result of micro arrangements is hard to understand. The commonly used term ‘states of matter’ implies that all things can be discretely classified as solid, liquid or gas. It is difficult to imagine particles in a solid moving. There are problems with some textbook representations of liquid, e.g., particles are often shown as being much further apart than they are in solids. ‘Melt’ and ‘dissolve’ are often used interchangeably in everyday life.</td>
</tr>
<tr>
<td>IDEAS/CONCEPTS</td>
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<tr>
<td><strong>D:</strong> Particles of different substances are different.</td>
<td><strong>E:</strong> There are different types of small bits of substances.</td>
<td><strong>F:</strong> Atom particles don’t disappear or get created, but their arrangements may be changed.</td>
<td><strong>G:</strong> Models are used in science to help explain phenomena. All models have limitations.</td>
</tr>
</tbody>
</table>
| The characteristics of substances are related to the types of particles they contain. | There are two types of small bits of substance:  
- Atoms  
- Molecules.  
Molecules form when atoms combine. | Atoms don’t change but molecules can.  
New atoms can’t be made and atoms can’t be destroyed (Conservation of matter). | Particle theory is an idea constructed by scientists to help us understand some aspects of the behaviour of matter.  
There are limitations to what particle theory can explain.  
Constructions are modified over time.  
Breaking up all substances into categories of solids, liquids and gases can be problematic. |
| Because it explains the observable behaviours of different substances. | Because it explains why there are a limited number of elements, but many different kinds of compounds.  
Organise ideas that are later developed when studying ‘chemical reactions’. | Because in any reaction involving matter, all of that matter must be able to accounted for. | Because it helps students understand why the particle model is not perfect and because it gives some insights into how science works. |
| (As per Big Ideas A, B & C.) | Details about ionic and molecular structures.  
Fission and fusion reactions. | | |
| | Students can come to think that molecules ‘disassociate’ in boiling water (because of the confusion between atoms and molecules). | Atoms don’t change.  
It is difficult to understand that different substances with the same types of atoms have different properties.  
Generally students have never had any cause to consider the notion of conservation of matter on a microscopic scale. | |
<table>
<thead>
<tr>
<th>Knowledge about students’ thinking which influences your teaching of this idea.</th>
<th>A: Matter is made up of small bits that are called particles.</th>
<th>B: There is empty space between particles.</th>
<th>C: Particles are in constant motion.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Many students will use a continuous model (despite former teaching).</td>
<td>The notion of ‘space’ is very difficult to think about – most students propose there is other ‘stuff’ between the particles. Students think that particles get bigger during expansion.</td>
<td>Students have commonly encountered ‘states of matter’ but do not understand the ideas in terms of particle movement. Students can be confused by the notion of melting and think a particular particle melts.</td>
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<tr>
<th>Other factors that influence your teaching of this idea.</th>
<th>Probes of student understanding: e.g., students draw a flask containing air, then re-draw the same flask with some of the air removed. Probes promote student thinking and uncover individual’s views of situations. Analogies: Use of analogies to draw parallel between new ideas and specific/similar situations. For example, although something may appear to be made up of one thing – like a pipe is made up of one piece of metal – it is really the combination of lots of small things. This can be analogous to a jar of sand. From a distance it looks like one thing, but up close you can see the individual grains of sand.</th>
<th>Translation activities: e.g., role-play, modelling, drawing. For example, my life as a Carbon Atom; or, write about what you would see if you were inside a particle of water. Imaginative writing: Compare pieces with &amp; without misconceptions, i.e., share students’ work around the class and encourage students’ comments on aspects of understanding in them. Using models &amp; demonstrations: e.g., a jar of marbles as model: packed tight to illustrate a solid; remove one &amp; shake to demonstrate movement in a liquid. Observation: dry ice sublimating- what’s happening?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maturity – stage of psychological development, readiness to grapple with abstract ideas. Dealing with many different student conceptions at once. Knowledge of context (students’ and teacher’s). Using the term ‘phase’ suggests the idea of a continuum and may help to address the difficulties associated with the term ‘state’.</td>
<td>POE (Predict-Observe-Explain): e.g., squashing syringe of air (ask students to predict the outcome based on different models of matter – e.g., continuous vs. particle). Mixing activities: e.g., noting that the combined volume of methylated spirits and water or salt and water is less than the sum of individual volumes. (The outcome can be explained by empty space between the bits.) Comparing models: (e.g., continuous and particle.)</td>
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<td>D:</td>
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<td>Particles of different substances are different.</td>
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<td>Atom particles don’t disappear or get created, but their arrangements may be changed.</td>
</tr>
</tbody>
</table>

Students tend to internalise a model from textbooks that shows circles all of the same size, so they think all particles are the same.

Students use the terms ‘molecule’ and ‘atom’ without understanding the difference between these concepts. They simply adopt the language.

Students believe that new stuff can appear and that stuff can disappear (e.g., when water evaporates).

It’s hard for students to shift from thinking of science as ‘discovered’ to ‘constructed’.

(As per Big Ideas A, B & C.)

This is not traditionally addressed in science curricula.

MIXING ACTIVITIES:

It can be helpful to model the mixing of different substances by, for example, using different sized balls for the mixing of water and methylated spirits.

POE (Predict-Observe-Explain): e.g., What is the vapour above boiling water? Students predict what happens to hydrogen and oxygen molecules when water is boiled. Many students predict that H and O will separate. Teacher establishes test for each gas, and class explains outcome of POE using gas tests as required. (This can create a need for different kinds of smallest bits.)

Modelling with specific materials: e.g., explore the possible combinations of atoms and molecules in new things (e.g., using different sized blocks of plasticine).

[continued over]

HISTORICAL RESEARCH:

Students investigate history of ideas about atoms and atomic structure and how scientists observing nature came to different interpretations of it. Students can sequence a set of historical events including Dalton, Faraday, & Thompson’s inferences and observations (i.e., progressively building on models of matter and atoms.)

CLASSIFICATION AND INTERPRETIVE DISCUSSION:

Ask students to classify some substances as solid, liquid, gas. Include some problematic examples (e.g., ‘Oobleck’, honey, sand, foam, jelly, toothpaste.) Discuss aspects that are problematic in definitions.
### Matter is made up of small bits that are called particles.  
**Linking activities:**  
Behaviour of everyday things, e.g., putting a marshmallow in a gas jar and changing the pressure so the behaviour of the marshmallow is affected. This helps to illustrate the point that small bits move or act differently in response to changes in conditions. The marshmallow is good to use because it is an example of something they are familiar with – it links to their everyday experience.

### There is empty space between particles.  

### Particles are in constant motion.

### Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses).

- Questions such as, “Explain why popcorn pops”, “Why when popcorn is pierced does it not pop?” “Why can we smell onions being cooked when we are at a distance from them?”, “Why does a syringe containing NO₂ appear darker when it is compressed?” (Students deduce the gas particles have moved closer. Actually the gas is darker due to a chemical reaction – it is convenient to withhold this information.)

- Explaining thinking and defending views.
- Making predictions about new situations.
- Tracking one’s own learning, e.g., “I used to think …”
- Asking questions such as, “What is something that has been bothering you from yesterday’s lesson?”

### Concept Map using the terms: solid; liquid; gas; particles; air; nothing.

- Put on your ‘Magic Glasses’ (which are glasses that enable you to see the particles in substances) – What do you see? (i.e., discuss what might be seen through the magic glasses), OR, Draw what you see. Then compare and discuss these drawings.
A DIAGNOSTIC ASSESSMENT OF LEARNERS’ PRIOR ELECTRICITY KNOWLEDGE BEFORE LEARNING OHM’S LAW

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ABSTRACT

This study explored the effects of a diagnostic assessment of learners’ prior electricity knowledge before learning of Ohm’s law and its related concepts. An exploration of learners’ prior knowledge through diagnostic assessment administered prior to the presentation of a new topic provided some insights into what the learners already know or do not know. The study was underpinned by an interpretive paradigm, within which a mixed method case study approach was adopted. Quantitative data were obtained through a diagnostic test and post-intervention test from a focus group of twelve purposively selected Grade 11 Physical Sciences learners. On the other hand, qualitative data were gathered using stimulated recall interviews (SRIs) on six purposively sampled learners from the focus group. The findings from the grounded analysis of data revealed themes such as conceptions, misconceptions and content gaps. In light of our findings the study recommends that assessment should be viewed as an integral part of learning.

Keywords: Diagnostic assessment; prior knowledge; electric circuits; Ohm’s law; conceptions; misconceptions; constructivism

INTRODUCTION

Diagnostic assessment is defined as a unique form of evaluation used to surface precise areas of strengths and causes of weaknesses that learners might have (Cohen, Manion, & Morrison, 2011). Baghdady, Carnahan, Lam and Woods (2014) concur with Cohen et al.’s (2011) notion and further define diagnostic assessment as a mental process that measures engagement with content knowledge being tested, which positions it as an access tool into learners’ cognitive space. In the context of this study, a baseline or pre-diagnostic assessment referred herein is used interchangeably with diagnostic test as they share the same meaning and a post-intervention test was used at the end of the research process. The purpose of the diagnostic assessment was to access the prior knowledge and experiences that learners brought with them into the science class, specifically in relation to learning Ohm’s law. The diagnostic assessment might help both learners and educators because it provides understanding of prior learning (Lee & Coniam, 2013).

The assumption by most science teachers, however, is that learners are familiar with the expected prior knowledge on electric circuits since abstract concepts such as resistance
are dealt with from Grade 5, as stipulated in the South African Curriculum and Assessment Policy Statement for Natural Sciences and Technology in Grade 4 – 6 (CAPS) and Physical Sciences in Grades 10 – 12 (Department of Basic Education (DoBE), 2011). Such background knowledge is documented to constitute relevant prior knowledge. In addition, some of the topics in Grade 11 serve as main support for the learning of Ohm’s law, central to which graphicy is important. Graphicy is a form of communication, using symbols or diagrams, that is logically presented and which allows information to be easily interpreted (Wilmot, 1999). Such science skills may be abstract for most learners as they trigger a high level of reasoning and thinking. Graphicy skills, such as determining relationships between variables and sketching, as well as interpreting graphs based on the stated relationships, are studied in some Physics laws. Newton’s second law of motion, for instance, is typically dealt with in earlier chapters of Grade 11 content. We believe that integrating the same skills would be useful in establishing learning of Ohm’s law and so these graphicy skills need to be interpreted using science language.

It can be foregrounded that language usage and symbols are at the core of learning Ohm’s law which in part makes the topic on electric circuits abstract. It is for these reasons that the Examiners’ reports (2013 – 2016) recommend that revision of previous work can assist in mastery of the topic under study. These reports are intended to provide a detailed analysis on performance of Grade 12 learners’ summative assessment and they reveal that there is still an observed continuous decline in the quality of results specifically pertaining to electric circuits, a Physics section of Physical Sciences. It is against this backdrop that this study explored the effect of diagnostic assessment for learning of Ohm’s law by considering the following research sub-questions:

What prior knowledge in relation to Ohm’s law do Grade 11 Physical Sciences learners have?

How does Grade 11 Physical Sciences learners’ prior knowledge enable or constrain learning of Ohm’s law?

CONTEXT OF THE STUDY

Howie (2004) argues that South Africa consists of schools with different topographical orientations, of which about 50% are rural schools. He believes that this might in part contribute to the poor quality of science results. The research site for this study was a rural school in the Eastern Cape Province in South Africa. The research participants’ mother tongue or home language was isiXhosa and/or Sesotho; whereas English was the language of teaching and learning (LoLT). Taylor, Muller and Vinjevold (2003) argue that language literacy is a contributory factor to poor performance in Grade 12, especially if LoLT is different from the learners’ home language. Sibanda’s (2017) study on Grade 4 mathematics learners revealed the same language challenges. Sadly, such challenges are likely to carry-over from Grade 4 to Grade 12 in most science subjects.

The focus for this study was the Further Education and Training phase (FET), which is commonly known as a high school. Learners in the FET level are expected to have
acquired some science content knowledge from their previous grades as prescribed by the curriculum. This study thus explored learners’ prior knowledge for learning Ohm’s law and its related concepts. Such findings were taken into consideration from the planning stage as well as throughout the intervention stage until learners were later assessed to reveal their science content knowledge understanding.

**LITERATURE REVIEW**

The effects of a diagnostic assessment for learning Ohm’s law were explored and informed by the previous literature on prior knowledge, assessment, graphicy, mathematical skills and language. The first two aspects are interconnected and were viewed in unison. Diagnostic assessment is the key access tool for identifying prior knowledge and the level of understanding that learners have on the knowledge acquired through experiences (Harlem & James, 1997). According to Harlem and James (1997), diagnostic assessment is regarded as formative assessment because it draws from the current state of knowledge proficiency to inform future learning. This type of assessment entails detecting learners’ range of strengths, needs and weaknesses. The strengths are referred to as conceptions whereby connection with prior knowledge is established and weaknesses also are referred to as alternative conceptions or misconceptions were identified.

Misconceptions emanate from fragmented connection with prior knowledge resulting in learning barriers if not identified (Gurel, Eryilmaz, & McDermoll, 2015; Lee & Coniam, 2013). It could be argued that misconceptions might hint that the learners’ experiences are dominated by non-scientific concepts. The learner with a lot of misconceptions may experience learning barriers because of failure to make sense of concepts and this might hinder his/her abstract reasoning. Gurel et al. (2015) further argue that assessing prior knowledge through conventional methods of focusing on score rating does not necessarily reveal in-depth understanding of concepts. On the other hand, the understanding of learners’ thought processes through assessment helps to detect whether learning took place or not.

In Black and Wiliam’s (1998) terms, the purpose of assessment is to access learners’ thought processes and understanding. Diagnostic assessment serves as in-depth check on learners’ understanding of prior knowledge. It could be argued that assessment of prior knowledge has a strong element of providing value for learning and establish self-regulation of ideas (Harrison & Muthivhi, 2013). Such a state of self-regulation could be beneficial in that it ascertains doubts and empowers learners to develop understanding of concepts (Dann, 2014).

In light of the stated purpose of accessing prior knowledge for learning, Dega and Govender (2016) encourage that assessment should shift away from the fixed-mindedness approach of being score focused to the stimulation of sense-making from experiences through what Carless and Zhou (2016) refer to as ‘assessment change’. Assessment change is a method of valuing assessment as being qualitative by drifting away from associating it with rating scores (Carless & Zhou, 2016). This method encourages a strong connection between assessment and learning. While assessment is
about attaching meaning to the prior knowledge (Taylor, 1999), it is acknowledged that some teachers and learners might experience challenges in relation to assessment processes. For instance, teachers, mostly in South Africa, are faced with a congested curriculum with limited time for assessment.

On the other hand, learners might view assessment as a system that creates anxiety, especially if it is score focused (Dega & Govender, 2016). The study by Carless and Zhou (2016) highlighted that limitations on tensions between learning and score grading as well as increased workload elements of assessments still exist. Such limitations do not necessarily switch off the learning benefits of tapping into prior knowledge. Carless and Zhou (2016) argue that assessment points provide opportunities for learners to reflect and show readiness to learn new concepts. Learners also benefit from diagnostic assessment for their competency in skills such as mathematical skills.

In Grade 11, for instance, Physical Science learners are expected to master mathematical skills such as sketching and interpreting graphs as well as gradient calculations. Earlier research by Anagnostopoulou, Hatzinikita and Christidou (2015) in Greece, which has a low science performance, revealed that few learners were able to correctly use mathematical tools such as graph representations. Anagnostopoulou et al.’s (2015) study was informed by science international results as presented in the OECD focused programme for International Student Assessment (PISA) (OECD, 2013). Poor performance showed the incompetence in mathematics skills. Simayi’s (2014) findings based on a South African study revealed that the inability to accurately label graphs leads to loss of scientific meaning. Such incompetence on graphicacy skills opens up doors to challenges on meaningful understanding and presentation of correct science concepts. In addition to graphicacy, the language of learning and teaching (LoLT), which in most South African schools, especially historically disadvantaged and rural schools, is different from the home language of learners, may influence the processing and presentation of answers (Probyn, 2009; Setati, Chitera, & Essien, 2009).

Interchanging between languages in internalising concepts and verifying answers might promote language literacy to a certain extent which is a benefit of using a different language of instruction (Cummins, 2001, 2015). Participation in written work demands abstract thinking and proficiency in LoLT (Mestad & Kolsto, 2014). This may serve as self-assessment, as learners deeply engage their thoughts triggered by the nature of posed questions. Active learning is acquired as learners use language skills which involve reading and writing. According to Sibanda (2017), learners improve on the former language skills as they read and comprehend the questions when processing written responses. Whilst concurring with Probyn (2009) as well as Setati, Chitera and Essien’s (2009) notion that LoLT which is a second language brings language challenge within the abstract science language, she further argues that this might pose language as a barrier to learning and assessment.

**THEORETICAL FRAMEWORK**

This study was informed by Vygotsky’s (1978) social constructivism theory which was evident when stimulated recall interviews (SRIs) were done, especially focus group
Social constructivism provides an active and constructive engagement for collaborative learning through social interactions. Ideas stored in the individuals’ minds as a result of experiences and cultural context are referred to as the existing schema (Yilmaz, 2011). Yilmaz refers to schema as “a hypothetical mental structure for organising and representing generic events and abstract concepts stored in the mind in terms of their common patterns” (2011, p. 206). In the context of this study, learners’ individual schema may consist of well-developed concepts and/or poorly developed concepts on electricity as informed by prior learning. During SRIs, individual learners’ oral reflections were shared whereby learners further constructed knowledge in a social space.

Individual reflections encouraged all group members to critically think about their learning processes and that subsequently influenced how they thought about electricity concepts. Discussions and sharing of ideas promoted active construction of ideas and the use of different language skills such as written and oral forms. Learners used the language of learning and teaching (LoLT), English, in presenting their thoughts in both assessment tests but they also discussed in their home languages, for example, isiXhosa and Sesotho. During SRIs, learners were allowed to use their home languages because the focus was to access deeper thoughts and ensuring that all group members actively participated in the discussions. The active engagement in discussions helped to reveal the sources of strengths and weaknesses on the learning of Ohm’s law. This study embraced McRobbie and Tobin’s (1997) notion that individual and social construction of concepts occurred concurrently to support new learning.

**METHODOLOGY**

**Interpretive paradigm:** Construction of knowledge drawn from socio-cultural facets of learning was accessed through this qualitative study. The gist of the study was to get some insights into learners’ thoughts drawn from their experiences, hence underpinned by interpretive paradigm (Cohen, Manion, & Morrison, 2011). In Cohen et al.’s (2011) terms, the interpretive paradigm anticipates understanding the subjective world of individual experiences. The study thus sought to investigate how science learners made sense of knowledge acquired from the real world and the science world. Concurring with Cohen et al. (2011), Bertram and Christiansen (2015) argue that the interpretive paradigm focuses on individuals and understanding of human thoughts. The focus of the study was to access data on learners’ thoughts as they tapped into their prior knowledge on electric circuits and it took the form of a qualitative case study.

**Case study:** A mixed method case study was used to gather both qualitative and quantitative data. Quantitative data were obtained through a diagnostic test, whereas most of qualitative data were accessed through simulated recall interviews (SRIs). Transcripts from video-recordings of SRIs revealed rich data. From quantitative data, themes such as conceptions, misconceptions and content gaps were investigated further through SRI for the purpose of inquiring deeper into learners’ thoughts. The identified themes emerged out of data and that indicated an element of grounded approach of data analysis (Cohen et al., 2011).
Cohen et al. (2011) posit that grounded analysis, used in qualitative data, is inductive and the analysis depends on the emerged data. Thinking and conceptualising concepts by learners provided data which pointed to key elements that guided the qualitative grounded approach used. The categories emerging with interrelated patterns were grouped and coded into themes. The data from diagnostic test were used to develop a unit of work for intervention. The participants were reassessed and interviewed at the end of the research process to explore the effects of diagnostic assessment for learning of Ohms law. The participants were Grade 11 Physical Sciences learners.

85 learners at Lerato S.S.S. (pseudonym) in the Maluti district of the Eastern Cape wrote a moderated diagnostic test which was developed using the Examination Guidelines for Grade 11 and Grade 12 (DoBE, 2015, 2017), the CAPS document (DoBE, 2011) and Examiner’s reports (2013 – 2016). The type of questions used in a diagnostic test and post-intervention test demanded reasoning from lower order to higher order so as to precisely assess the actual learners’ cognitive level. Such questions included multiple-choice questions, questions that required explanations as well as graph interpretations. Multiple-choice questions with explanations to avoid guessing were included in the post-intervention test. A critical friend (Physical Sciences high school teacher) with good credentials in science education, from the same district assisted in the moderation of tests and marked scripts, verification of transcription of data from video-recordings, up to data analysis to check if all the processes had been fairly attended without bias. That served as validation of the research process because the researchers were also teachers in the same research site. According to Kember, Ha, Lam, Lee, Ng, Yan and Yum (1997), a critical friend plays an important role in ensuring that all research processes are followed. Thereafter, twelve learners from different achievement levels were sampled for in-depth analysis as informed by diagnostic test results, hence qualitative case study.

**Purposive sampling:** This sampling method assisted in narrowing the focus to explore the effects of diagnostic assessment for learning Ohm’s law. Four learners from each of the following achievement categories were sampled to form a heterogeneous research focus group where quantitative data were sourced, namely, from top category, middle category and lowest category. For gathering qualitative data through SRI, six learners were further sampled from the 12 pre-sampled learners as follows:

One learner from the top category and the other one from the lowest category were individually interviewed; and

Four learners from the middle category were interviewed as a group.

Interviews were used to access in-depth knowledge on how learners processed their diagnostic test answers. In addition, Gurel, Eryilmaz and McDermoll’s (2015) perception is that interviews provide in-depth diagnosis, which was the core of this study. For this study, stimulated recall interviews (SRIs) were used as a way of allowing participants to reflect on their thinking processes when responding to the assessment test questions. SRIs are usually associated with the watching of videos, but in this study they were innovatively used to get some insights into diagnostic test answers which
assisted to answer both of the research sub-questions stated earlier. Ethical issues were considered before and throughout the research process.

**Ethical considerations:** Initially, informed consent from the District Manager, principal and learners was sought. Informed consent to participate in tests and video-recorded interviews were sought as well as the right to non-participation or freedom to withdraw at any time during the research process. In addition, parents of the 12 pre-sampled learners were invited to school and their involvement with their children’s school activities ensured that ethics at rural settings were noted. They were invited for the purpose of discussing the outline of the research process. Lastly, a pseudonym for the school and learners were used to maintain anonymity and confidentiality.

**DATA ANALYSIS, VALIDITY AND TRUSTWORTHINESS:**

For validity and reliability, the participants were made aware of the topic to be assessed so as to prepare themselves. It was emphasised that explanations for or justification of the learners’ responses were more important than the scores. In accessing sense making of science concepts, stimulated recall interviews (SRI) were additionally used to source data from a different point of view. Cohen *et al.* (2011) refer to the process of using different data sources as triangulation. Triangulation has strong elements of validity and trustworthiness. Participants were allowed to use any language they were comfortable with during interview session. According to Cohen *et al.* (2011), recognition of participants’ language for accessing primary data is referred to as cultural validity. Cultural validity was recognised in this qualitative case study.

**FINDINGS AND DISCUSSIONS**

The main goal of this study was to explore the effects of diagnostic assessment for learning of Ohm’s law and its related concepts. Some quantitative data provided a brief overview on learners’ performance and pointed to specific questions where connection or disconnection to the prior knowledge was revealed. Themes such as conceptions, misconceptions and content gap which emerged from the data are discussed. The learners’ profiles in Table 1 below shows that the study took place in a multi-cultural classroom.

<table>
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<tr>
<th>PSEUDONYMS</th>
<th>Entle</th>
<th>Lizzy</th>
<th>Yolanda</th>
<th>Luyanda</th>
<th>Oyintando</th>
<th>Cozmo</th>
<th>Faith</th>
<th>Zoo</th>
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<td>Female</td>
<td>Male</td>
<td>Female</td>
<td>Female</td>
<td>Female</td>
<td>Female</td>
</tr>
<tr>
<td>Age</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>18</td>
<td>17</td>
<td>18</td>
<td>17</td>
<td>17</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>Ethnic group</td>
<td>Xhosa</td>
<td>Sotho</td>
<td>Xhosa</td>
<td>Sotho</td>
<td>Xhosa</td>
<td>Sotho</td>
<td>Xhosa</td>
<td>Sotho</td>
<td>Xhosa</td>
<td>Sotho</td>
<td>Sotho</td>
<td>Sotho</td>
</tr>
<tr>
<td>Mother tongue</td>
<td>IsiXhosa</td>
<td>Sesotho</td>
<td>IsiXhosa</td>
<td>Sesotho</td>
<td>IsiXhosa</td>
<td>Sesotho</td>
<td>IsiXhosa</td>
<td>Sesotho</td>
<td>Sesotho</td>
<td>Sesotho</td>
<td>Sesotho</td>
<td>IsiXhosa</td>
</tr>
</tbody>
</table>

Table 1: Selected learners’ profiles
Most of learners’ ethnic groups were similar to their mother tongue. Amazingly, all learners in this multicultural class were able to speak both IsiXhosa and Sesotho which made English their third language. However, when they discussed in their groups they switched from one language to another which is referred to as translanguaging in Probyn’s (2015) terms. Purposive sampling from the diagnostic assessment performance catered for diverse learning abilities as shown in Figure 1 below.

Figure 1: Diagnostic test results (Focus Group)

Figure 1 above, shows how a heterogeneous group consisting of four learners in three different achievement levels were sampled. The assessment composed of questions from different cognitive complexities. The frequency displaying the achievement of the assessed skills was detailed as shown in Table 2 below.

Table 2: A detailed analysis of diagnostic test results

<table>
<thead>
<tr>
<th>Pseudonyms</th>
<th>Frequency</th>
<th>Correct and Partially correct Explanations</th>
<th>Correct Graphacy</th>
<th>Partially correct graphacy</th>
<th>Wrong Graphacy</th>
<th>Correct Calculations</th>
<th>Partially correct Calculations</th>
<th>Wrong Calculations</th>
<th>Blank Spaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entle</td>
<td>6</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lizzy</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yolanda</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Luyanda</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Oyitando</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cozmo</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faith</td>
<td>7</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Zoo</td>
<td>8</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fiona</td>
<td>9</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Boithabiso</td>
<td>10</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rebahaae</td>
<td>11</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zodiac</td>
<td>12</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
From Table 2 above, it is revealed that learners were able to justify their answers to a certain extent. Learners also showed an ability to perform better in relation to graphicacy skills although they seemed to struggle with calculations. This revealed that poor application of mathematics skills in Physics could be an indication that some of the learners’ reasoning abilities were still fragmented or science language modes such as words, symbols, graphicacy and calculations seemed abstract (Gurel et al., 2015). Possibilities that such learners would underperform in the topic under study, electric circuits, were high if diagnostic assessment was not administered to reveal such weaknesses. Diagnostic test responses assisted in planning for the intervention on learning Ohm’s law and its concepts.

The qualitative data from the stimulated recall interviews were also inductively analysed based on similar patterns which emerged from the data gathered. Those identified similar patterns were later categorised into themes. The data which emerged from the interview transcripts also pointed to the previously identified themes. Each of the revealed themes is discussed below.

Table 3: Themes drawn from emerged data

<table>
<thead>
<tr>
<th>THEME</th>
<th>DIAGNOSTIC TEST DATA</th>
<th>POST-INTERVENTION TEST DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptions</td>
<td>Yolanda: “We did most of the work in Grade 10 so I was able to attend most of the questions”.</td>
<td>Faith: “Then masiphinda kwi-last test it was not that difficult to answer questions because we were taught”. (Translation from IsiXhosa: Coming back to the last test, it was not difficult to answer most questions because we were taught)</td>
</tr>
<tr>
<td></td>
<td>Faith: “I-test, we did not have much information about it. Besi-depende kwi-previous work. (Translation from IsiXhosa: The test, we did not have enough information about it”. We depended on previous work).</td>
<td>Layanda: “The way besifunda ngakhona made us to do better in the last test”. (Translation from IsiXhosa: The way teaching and learning took place made us to perform better in the last test).</td>
</tr>
<tr>
<td></td>
<td>Yolanda: “Yes. And to plot … and coming with the scale, That is where I had a problem”.</td>
<td>Oyintando: “I was able to draw correct a graph and do calculations but I made little mistakes ”.</td>
</tr>
<tr>
<td>Misconceptions</td>
<td>Yolanda: “Because .. I think I was never taught to … I was taught ... gradient [Shaking her head] .. e ne e le problem”. (Translation from Sesotho: Because.. I think I was never taught to … I was taught …gradient [shaking head] .. was a problem).</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Layanda: “There was misunderstanding ... ezinye ianswer ndizibhidanisile. Like kwi-potential difference and current”. (Translation from IsiXhosa: There was misunderstanding ... I exchanged some of the answers. Like with potential difference and current).</td>
<td></td>
</tr>
<tr>
<td>Content gap</td>
<td>Layanda: “Eish ... e ne e le thatanyana empa tulong tie ding e le bohle”. (Translation from Sesotho: It was difficult but easy at some parts).</td>
<td>Layanda: “there were no blank spaces because I remembered most of what I was taught”.</td>
</tr>
<tr>
<td></td>
<td>Layanda: “I did not know what to write. Yes, that is why there are some blank spaces”.</td>
<td></td>
</tr>
</tbody>
</table>
Conceptions:

Some learners were able to answer some questions with precise projected knowledge. In preparation for learning Ohm’s law, definition of concepts such as electric current, potential difference and resistance as well as understanding of relationships between variables was assessed to check if they were established or not. That understanding prepared learners to realise the connection between electricity concepts and graphicacy skills, for instance, correct graphs which started from the origin with uniform scale and correct labels. The graphicacy skills were modelled to a greater extent as shown in Figure 2 below.

Figure 2: An example of a Faith’s graph of potential difference versus electrical current (from diagnostic test)

Prior knowledge about graph skills pointed to the actual cognitive levels learners found in preparation for new learning. However, it can be depicted from Figure 2 that mathematical skills, such as understanding of ‘the line of best fit’, were still lacking; hence the graph is not a straight line throughout. Inability to correctly represent a correlation of variables might make it difficult to state the relationship between them. Incorrect labelling of graphs is also seen in Figure 2 and that corroborates with Simayi’s (2014) study that such labelling leads to misconceptions even if the required graph is accurately drawn.

Learners’ justification of the link between the assessed concepts and prior knowledge shows the degree of individual self-regulation of ideas which were previously internalised (see Table 3) (Harrison & Muthivhi, 2013; Dann 2014). The argument raised by Dann (2014) on confidence level is revealed through comparing the responses from Yolanda and Faith. Yolanda was sure that most of the examined work was linked to the previous grade content knowledge. In contrast, Faith struggled to make connection of the examined work with prior knowledge something which could possibly suggest that the previous work was learned without proper understanding. In her perspective, assessment of previous knowledge leads to less content knowledge to be
used in responding to the diagnostic test. The data drawn from Figure 2 and Table 3 revealed traces of misconceptions.

**Misconceptions:**

Most of the data revealed a number of misconceptions emanating from fragmented prior knowledge and lack of mathematics skills, such as gradient calculations (Anagnostopoulou, Hatzinikita, & Christidou, 2015). Studying Figure 3 below and the comments from Table 3, it was revealed that mathematics skills might hinder learning of Ohm’s law because learners cannot connect the gradient with interpretation of graphs. The findings were in line with Sibanda’s (2017) view on poor performance in mathematics. The challenge lies in drawing from prior knowledge that might have misconceptions (Taylor, 1999). An example of Luyanda’s gradient calculations shown in Figure 3 below and Yolanda’s misperceptions on gradient calculation (see Table 3) point to confusions which might lead to misconceptions.

![Figure 3: An example of Luyanda’s calculation of gradient (in diagnostic test)](image)

From Figure 3, Luyanda symbolised the gradient as ‘G’ instead of ‘m’ which is not scientifically correct (see Table 3). The use of wrong symbols brought a different scientific meaning and that resonated with Simayi’s (2014) claim that she was concerned with graph’s labels. The challenge of representing gradient quantities revealed that the concept ‘gradient’ was underdeveloped (see the position of change in both variables shown in Figure 3). The positive perception that Luyanda brought into this study is that he had an idea that gradient is represented in a form of a ratio between two quantities, but the correct representation of dependent versus independent variables is not well built (see Figure 3). Amazingly, the correct numerical values were substituted in the correct places although the gradient formula was incorrect.

In order to understand what Luyanda was thinking as he attended that question, he was invited to be part of interviewees. He explained that his answers were swopped due to poor connection between the formula and the substitution (see Table 3). The exact point of difficulty was identified and the learners’ strengths were embraced. Learners’ thoughts accessed through diagnostic assessment give an indication of the extent of meaning making they have on required prior knowledge (Black & William, 1998). Additionally, the effect of LoLT on processing of responses might negatively affect learners’ thoughts because some learners might have been challenged with LoLT and
abstract science language (Setati et al., 2009). For example, all learners were actively engaged in interviews whereas there were blank spaces in their scripts.

**Content gaps:**

In addition to misconceptions, blank spaces where learners did not provide answers revealed the content gaps learners had about electricity. Blank spaces triggered more attention because we were unable to gauge the degree of knowledge that learners brought into the science class. The SRI helped in gaining insight on the significance of blank spaces. Data from Table 2 indicated that some of the learners, such as *Faith* and *Luyanda*, might not have enough information in their schema to infer from. That pointed to the identification of content gap between the expected knowledge and the actual level of understanding. Drawing from the findings of this study, it is apparent that there is a necessity of examining learners’ prior knowledge to verify the scientific content knowledge brought into new learning as suggested by Cohen *et al.* (2011). Although Figure 1 is not as detailed as Table 2, it shows that learners’ interpretation of ideas improved during the research process.

After the intervention process the data from post-intervention test revealed that understanding of science concepts took place for most of learners as indicated by absence of blank answers (see Table 3). The study revealed that learners’ perceptions on mathematics skills and electricity concepts positively triggered connection to the prior learning although some learners were still having challenges, such as *Oyintando* (see Table 3). This challenge echoed what was suggested by Anagnostopoulou *et al.* (2015) and Sibanda (2017) on recurring calculation mistakes, such as gradient calculations from a graph. The findings of the study also revealed that learners were at different levels of understanding the topic on electric circuits. Notwithstanding this, the analysed data signalled the degree of readiness for learners to acquire new knowledge on Ohm’s law (Dann, 2014; Carless & Zhou, 2016).

**CONCLUDING REMARKS**

This study on assessment of learners’ prior electricity knowledge before learning new concepts on Ohm’s law served as a lens through which learners’ knowledge, understanding, thoughts and challenges were revealed. The purpose of recognising prior knowledge signified that learning is a process that is centred on understanding of relevant concepts or ideas. Learners’ perceptions of what they previously understood are revealed by their ability to conceptualise and connect new knowledge with the existing schema, hence cognitive levels of thinking increased. In this study, stimulated recall interviews were used as detectors for seeking deeper insight into learners’ thoughts or construction of knowledge. Their thoughts provided rich data which also revealed that mathematics content knowledge, for instance, the concept of gradient, might result in misconstructions if not integrated with Physical Sciences’ world.
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ABSTRACT
The purpose of this study is an investigation into research questions around e-schools in South Africa. The study is located within a relevant theoretical and conceptual framework around e-schools, and draws on the latest and most relevant research findings on the topic, in a literature review making the South African context in which the research questions are answered, explicit. The following section describes how the design and execution of the research methodology that was used is appropriate and adequate in relation to the research questions, considering issues related to reliability and validity for quantitative designs, and attention to the importance of dependability and interpretation issues for the qualitative part of the research design. Discussion of the results provides insight into demographic details in terms of the characteristics for the sample of participants from an applicable district. The author then details the extent to which the sample represented are characterised as e-schools. Importance is justified regarding contributing something new and original to the field. Implications are suggested and recommendations made that are applicable and useful to managers and teachers at e-schools across South Africa, the rest of the continent and even further afield. In the conclusion, the research questions are answered.

INTRODUCTION
Information and Communication Technologies (ICTs) are increasingly playing a significantly meaningful role at local, national and global levels, where the use of these is affecting everyday life (Terzoli, Dalvit, Murray, Mini & Zhao, 2005). ICTs generally affect government policies, as well as worldwide commercial and economic growth (Whelan, 2008). These are also specifically improving aspects of South African (SA) culture, together with citizens’ sense of democracy, employment and economic growth within an information society (Mpehle, 2011). In his capacity of Deputy Minister of Basic Education in South Africa, Surty (2010) pointed out that there appears to be “a deep grasp of the urgency, particularly for developing countries, to bridge the digital divide … to achieve developmental goals and improve people’s lives”.

As in many other countries, e-education has had a revolutionary effect on the development of the curriculum, and the delivery of school practice, in South Africa (Whelan, 2008). According to Evoh (2007), many policy makers tend to understand ICTs as being limited to only computer, satellite and Internet technologies. Evoh (2007),
however, also pointed out that more ‘traditional’ technologies, such as radio and television, also form part of the ICTs that can be used for supporting pedagogical curriculum delivery to improve effective and efficient teaching and e-education practices (Blignaut & Els, 2010).

An e-education policy has a key role in the effectiveness of educational reform (Evoh, 2007). Fortunately, South Africa developed an own structured and focused e-education policy, including strategies for using ICTs to transform teaching and e-education. These were set out in White Paper 7 on e-Education, appearing in 2004 (Surty, 2010). Although Blignaut and Els (2010) pointed out that this is currently the only e-education policy in South Africa, Wilson-Strydom, Thomson and Hodgkinson-Williams (2005) believe that the integration of e-education into teaching has ascended on the educational agenda in South Africa with the release of this White Paper.

In the White Paper on e-Education for transforming teaching and e-education through ICTs, the then South African national Department of Education (DoE, 2004:17) responded to the forces imposed by the information revolution on behalf of the education and training system by setting out the following e-education policy goal:

> Every South African learner in the General and Further Education and Training bands will be ICT capable (that is, use ICT confidently and creatively to help develop the skills and knowledge they need to achieve personal goals and to be full participants in the global community) by 2013.

Three research areas and related questions have been identified in this regard, with the purpose of the project reported on in this paper being to make a significant and substantial contribution towards solving:

More than ten years have passed since the publication of the White Paper on e-Education. Referring to Donner and Escobari, Heeks (2010) commented that it is important to note that the research reported in this paper takes place in an arena of fast-moving change. Assumptions and claims made in such an ‘old’ policy document in the fields of ICTs and e-education may very well be time-contingent - to what extent are these still valid and/or have continued relevance?

The ‘due date’ (2013) for the e-Education policy goal has come and gone. The research project reported on in this paper seeks to provide an evaluation of the progress being made on the implementation of the e-education policy in South African classrooms - to what extent has this goal been achieved?

Additionally, the continuing deficiencies regarding the associated research base also needs attention. What contribution can be made towards filling a major gap in knowledge identified in the literature?

The next section of this paper will locate the study within relevant theoretical and conceptual frameworks, regarding the details of this research around e.g. e-schools. Drawing on the latest and most relevant research findings on the topic, it will supply additional information in terms of discussions underpinning this study.
THEORETICAL AND CONCEPTUAL FRAMEWORKS FROM LITERATURE

The e-education policy document fairly abstractly and technically defines ICTs as representing “the convergence of information technology and communication technology. ICTs are the combination of networks, hardware and software, as well as the means of communication, collaboration and engagement that enable the processing, management and exchange of data, information and knowledge” (DoE, 2004:15).

Wilson-Strydom et al. (2005) believe that e-education is about integrating these technologies into teachers’ lessons in support of enhanced learning. In accord with the e-education policy document, they see e-education as being about more than just developing computer literacy and learning the skills needed to use different ICTs (DoE, 2004). The e-education policy further highlights tool(s) and communication aspects, by envisioning ICTs as communication and collaborative tools for teachers and managers to contribute to development.

In the White Paper on e-Education (DoE, 2004), e-schools are characterised as institutions having (1) learners using ICTs to enhance e-education; (2) qualified and competent managers using ICTs to plan, manage and administer; (3) qualified and competent teachers using ICTs to enhance their teaching and e-education; (4) access to ICT resources supporting curriculum delivery; (5) connections to ICT infrastructure and (6) connections to their communities.

The years since the advent of a new democracy in South Africa in 1994 has seen the development of dramatic changes all through education and training systems, as part of the process towards democratisation (Blignaut & Els, 2010). These aim to redress inequalities and provide access to new learning opportunities (DoE, 2004). Both Park and Van der Merwe (2009) and Surty (2010) therefore find it imperative to understand the contribution that advances in e-education could make towards demonstrating the unflinching commitment to transformation of the South African government.

Institutions “are creating new learning environments”, which model inclusiveness, “with learners who represent a wide array of cultures, languages and social backgrounds” (DoE, 2004:20). According to the DoE (2004:16), there is thus a shift towards inclusive “practice where learners work collaboratively … and develop creative thinking and problem-solving skills.” Information and communication technologies “embrace inclusive education by providing opportunities” for learners experiencing barriers to learning.

Mouyabi (2011) believes that the introduction of ICTs into the education community has necessitated new approaches, such as the creation and implementation of supple platforms and tools, being adopted as an alternate system towards pursuing sustainable and inclusive quality education. Sesemane (2007), however, also warned that the implementation of an e-education policy represents a highly contested field within the South African education landscape. Although the abstract of the article by Sesemane (2007) indicated that an analysis of the South African e-education policy and the impact thereof on education would be provided, that indication was not realised. The current
research project will therefore aim to provide an analysis of the progress being made on implementing the South African e-education policy.

The White Paper (DoE, 2004:35) indicates that the Medium Term Expenditure Framework will provide sustainable sources for implementing ICTs in education, and rollout “plans should be affordable, scalable and sustainable, based on generic activity-based design tools for teachers and learners.” Blignaut and Els (2010) also acknowledged the massive investment required, and due to the magnitude of the task of implementing the e-education policy goal, along with the White Paper (DoE, 2004), called for a long-term implementation strategy to provide a framework for specifically prioritising actions set out in a multi-year programme. Strategic objectives for using ICTs to turn schools into centres for sustainable and inclusive quality education was thus established.

ICT PROFESSIONAL DEVELOPMENT FOR MANAGEMENT, LEARNING AND TEACHING

In order for teachers to respond to their changing workplace requirements, they must develop the necessary skills for maximising the usefulness of ICTs for educational purposes (Dagada, 2004). It is therefore of the utmost importance that increased access to ICTs to learn and teach and the provision of software must go hand-in-hand with adequate professional development of teachers and the actual implementation of e-education (DoE, 2004). If teachers do not make use of e-education and/or are not trained to effectively handle the challenges that using e-education in their classrooms might present, it is highly unlikely that any significant improvements will be obtained. Thomen (2005) found that professional development was viewed by teachers as a broad concept, encompassing not only their practice, but also the teaching community and profession in a global context. All managers, teachers and administrators in e-schools should have access to the knowledge, skills and support needed for creating opportunities to integrate e-education into the curriculum (Surty, 2010). Thomen (2005) also warned that processes for the implementation of education change and improving the quality of professional development can be difficult. Higher Education Institutions (HEIs) are therefore encouraged to strengthen teacher training, and their participation in other events regarding pedagogy.

Electronic content resource development and distribution

The e-school curriculum should be supported effectively, engagingly and sustainably through software, electronic content and e-education resources (Mpehle, 2011). It is therefore crucial “that an education-industry partnership be developed to enhance innovative, effective and sustainable” e-learning resources (DoE, 2004:27). e-Learners, teachers, administrators and content developers should re-use, adapt and contribute effectively to such resources.

Accessing ICT infrastructure

One of the major challenges for the success of e-education involves institutions being able to allow all learners, teachers, managers and administrators to have increased
regular access to the reliable e-education infrastructure that they need, specifically suited to an African context (DoE, 2004). Accountability mechanisms, however, also have to be put in place to properly maintain such infrastructure (Evoh, 2007).

**Connectivity**

According to Surty (2010), a significant contribution towards pursuing sustainable and inclusive quality education needs to be made, by expanding the access of all teachers and learners to Internet “connectivity in both primary and secondary schools”.

**Community engagement**

HEIs are increasingly engaging more actively with communities to facilitate e-education to empower and benefit these communities. e-Schools should work in partnership with families and the wider community in ensuring shared knowledge about e-education and creating extended opportunities for community member e-education and development through ICTs (Mpehle, 2011).

**Research and development**

The best way to pursue sustainable and inclusive quality education is through research informed practice, evaluation and collaboration. To this end, the South African government aims to bring together teachers, researchers and the ICT industry in action-oriented research, to evaluate and develop leading-edge applications for e-education. Research and development communities, as specifically represented by HEIs, can support education departments by sharing the e-education knowledge and research produced at South African HEIs (Terzoli et al., 2005). This can be achieved by continuously assessing current practices, and exploring and experimenting with reliable emerging technologies, methodology and techniques, supporting teachers and administrators in e-education and e-administration (DoE, 2004). Research on e-education should not only be directly connected to other wide-ranging research on e-education, but also to practice. Since the education profession has a responsibility to play an significant role in producing ideas, testing examples and implementing strategies, they, in collaboration with the Departments of Basic Education, Communications, Higher Education and Training, and Science and Technology, HEIs and research agencies, will need to formulate an applicable research agenda on e-education.

**RESEARCH METHODOLOGY**

A mixed-methods study was decided upon, with a triangulation design being followed, combining both qualitative and quantitative modes of inquiry or approaches to research for collecting data (McMillan & Schumacher, 2010). Please note that although both quantitative and qualitative data were collected in the study reported on, only quantitative results will be discussed in this paper.

According to McMillan and Schumacher (2010), quantitative research designs put emphasis on objectivity in identifying, measuring and describing the characteristics of phenomena. One of the two sub-classifications with-in quantitative research is non-
experimental research designs, explaining events and observed relationships between various phenomena without directly influencing circumstances, which are experienced – two of these non-experimental designs will be applicable in this project: descriptive and survey. Research that uses a descriptive design offers a review of a current phenomenon that uses numbers to characterise, in the case of this project, particular schools, by assessing the features of current circumstances.

Quantitative research will mainly be used in a form of a survey questionnaire. When using a survey research design, investigators select a sample of participants for administering a questionnaire, to collect data about these participants’ opinions, attitudes, beliefs and other types of information, by asking them certain questions. Surveys are regularly used in educational research for describing attitudes and information as described in the previous sentence. Typically, research is designed in order to obtain information regarding a sizeable quantity of individuals (the population), by inferring based on the replies acquired from a reduced collection of subjects (the sample) (McMillan & Schumacher, 2010). In the structured (also termed reduced options) questions used, participants are provided with a suitable list of choices.

On the other hand, when using qualitative designs, most data take the form of words, as opposed to figures, and generally, researchers search through and explore these until they develop a deeper understanding (McMillan & Schumacher, 2010). A case study research design studies a restricted system (the so-called ‘case’), employing numerous sources of data located in the situation. In this project, each case is represented by a particular school, with a collection of persons limited by time and location, selected for use as an example of a particular instance. In this paper, the focus is on research sites consisting of several entities (schools) from a specific district in South Africa, making this a multi-site study. Aspects of an interactive qualitative research design is also used in the form of a phenomenological study, attempting to describe these respondents’ perceptions, perspectives and understandings of the integration of ICTs into their teaching. The importance of dependability refers to the extent to which readers are convinced that the data collection leading to the results did occur as indicated by the researcher.

The use of multi-method strategies could produce diverse insights regarding topics of interest and augment results’ credibility. These strategies also allow for data triangulation across inquiry techniques and provide the mechanisms for mutual support between qualitative and quantitative research - enabling researchers to verify the degree to which assumptions based on qualitative information are reinforced by quantitative perspectives, or the other way around. McMillan and Schumacher (2010) indicated such triangulation of the data as being critical for the facilitation of interpretation and validity, as well as ensuring reliability.

The use of a variety of strategies to enhance validity is required in especially qualitative research, since the validity of such designs include the extent to which perceptions and interpretations made had shared meaning between participants and the researcher. Several resources ought to be employed for comparing results with each other, for
ensuring the internal validity of qualitative research. As suggested by McMillan and Schumacher (2010), decisions were therefore made on how to ensure that the data collected was valid, for example by obtaining advice from expert researchers on the questions used, to ensure internal validity regarding causal inferences, and by obtaining detailed descriptions of participants and their environments for the facilitation of external validation and generalizability.

In agreement with suggestions by McMillan and Schumacher (2010), less experienced researchers can have their qualitative data analysed independently by another more experienced researcher, who had not been involved in obtaining the data - this provides another method for enhancing validity. Then, once agreement had been reached on the descriptive data collected, results can be analysed to obtain a full interpretation of the applicable participants and their environments.

Discussion of Results

With a survey sample made up of 23 (53.5%) female and 20 (46.5%) male respondents, the spread regarding gender fairly closely matches that obtained by Wilson-Strydom et al. (2005).

Table 1. These schools are located in ... areas

<table>
<thead>
<tr>
<th></th>
<th>Numbers</th>
<th>Percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Township</td>
<td>31</td>
<td>72%</td>
</tr>
<tr>
<td>Urban</td>
<td>12</td>
<td>28%</td>
</tr>
</tbody>
</table>

Although Wilson-Strydom et al. (2005:76) also reported that the majority of their “sample (43%) lived in township areas”, almost three-quarters of respondents in the survey reported on in this paper represented township areas. The percentage regarding urban areas were almost the same as that obtained by Wilson-Strydom et al. (2005:76), who had almost a third (31%) of respondents from urban areas. Whereas Wilson-Strydom et al. (2005), however, had a similar percentage regarding rural areas (26%), no respondents from rural areas were represented in the sample of the survey reported on in this paper.

Table 2. These are ... schools

<table>
<thead>
<tr>
<th></th>
<th>Numbers</th>
<th>Percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>33</td>
<td>77%</td>
</tr>
<tr>
<td>Secondary</td>
<td>7</td>
<td>16%</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
<td>7%</td>
</tr>
</tbody>
</table>

Of the sample reported on by Wilson-Strydom et al. (2005:76), “59% were General Education and Training (GET) educators and 41% Further Education and Training” teachers. Comparably, more than three-quarters of the respondents of the survey reported on in this paper were from primary schools and almost a fifth from secondary schools. Respondents indicating ‘Other’ included a district representative, a special school and a combined school.
Almost half of the respondents fell in the 40-49 years age category, followed by just
over a quarter in the 50-59 years group, with the 30-39 years and 60 years and above
categories accounting for 14% and 7% of respondents respectively (Wilson-Strydom et
al., 2005) - see Table 3.

<table>
<thead>
<tr>
<th>Ages</th>
<th>Numbers</th>
<th>Percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-29 years</td>
<td>2</td>
<td>5%</td>
</tr>
<tr>
<td>30-39 years</td>
<td>6</td>
<td>14%</td>
</tr>
<tr>
<td>40-49 years</td>
<td>21</td>
<td>49%</td>
</tr>
<tr>
<td>50-59 years</td>
<td>11</td>
<td>26%</td>
</tr>
<tr>
<td>60 years and above</td>
<td>3</td>
<td>7%</td>
</tr>
</tbody>
</table>

Table 3. Respondents’ Ages

More than a third of respondents had more than 20 years teaching experience. The
percentages regarding the number of years of teaching experience for the intervals
“between 11-15 years teaching experience” and 0 - 5 years was roughly equal to those
that had been obtained by Wilson-Strydom et al. (2005:76), while the categories 6 - 10
years and 16 - 20 years were comparably evenly distributed.

<table>
<thead>
<tr>
<th>Years of teaching experience</th>
<th>Numbers</th>
<th>Percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5 years</td>
<td>6</td>
<td>14%</td>
</tr>
<tr>
<td>6-10 years</td>
<td>5</td>
<td>12%</td>
</tr>
<tr>
<td>11-15 years</td>
<td>11</td>
<td>26%</td>
</tr>
<tr>
<td>16-20 years</td>
<td>5</td>
<td>12%</td>
</tr>
<tr>
<td>More than 20 years</td>
<td>15</td>
<td>36%</td>
</tr>
</tbody>
</table>

Table 4. Number of years teaching experience

In what could arguably be considered illustrative of the situation for schools across
Gauteng, more than three-quarters of schools represented by these respondents reported
having more than twenty computers at their schools.

<table>
<thead>
<tr>
<th>Computers at schools</th>
<th>Numbers</th>
<th>Percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 computers</td>
<td>2</td>
<td>5%</td>
</tr>
<tr>
<td>1-10 computers</td>
<td>3</td>
<td>7%</td>
</tr>
<tr>
<td>11-20 computers</td>
<td>5</td>
<td>12%</td>
</tr>
<tr>
<td>21 or more computers</td>
<td>33</td>
<td>77%</td>
</tr>
</tbody>
</table>

Table 5. Number of computers at the schools

In line with the results reported in Table 5, more than half of respondents reported that
computer laboratories are being used more than once a month. Although more than a
quarter of respondents indicated that computer laboratories are being used less than once
a month, incidences where computer laboratories are being used about once a month or
never are significantly lower.
Table 6. Regularity of computer laboratory use

<table>
<thead>
<tr>
<th></th>
<th>Numbers</th>
<th>Percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td>More than once per month</td>
<td>23</td>
<td>53%</td>
</tr>
<tr>
<td>About once per month</td>
<td>3</td>
<td>7%</td>
</tr>
<tr>
<td>Less than once per month</td>
<td>12</td>
<td>28%</td>
</tr>
<tr>
<td>Never</td>
<td>5</td>
<td>12%</td>
</tr>
</tbody>
</table>

Table 7. I am participating in my role as a/the

<table>
<thead>
<tr>
<th>Role</th>
<th>Numbers</th>
<th>Percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal</td>
<td>10</td>
<td>23%</td>
</tr>
<tr>
<td>Deputy Principal</td>
<td>5</td>
<td>12%</td>
</tr>
<tr>
<td>Head of Department</td>
<td>9</td>
<td>21%</td>
</tr>
<tr>
<td>Teacher</td>
<td>16</td>
<td>37%</td>
</tr>
<tr>
<td>Administrator</td>
<td>1</td>
<td>2%</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>5%</td>
</tr>
</tbody>
</table>

The largest segment of respondents were teachers (more than a third), with principals and Heads of Department each making up almost a quarter each. Of the two persons who selected ‘Other’, one specified herself as an ICT-coordinator. Although the other person did not select ‘Provincial official’, she did indicate that she was from the district office. Please note that various options that were available, but not selected by respondents, are not shown in this table.

Please note that full details relating to the data that follows, including tables, can be accessed in Goosen (2016).

Just less than three-quarters of respondents (22; 52%) agreed or (8; 19%) strongly agreed that learners at their institutions responded to ICT-integrated lessons by helping each other, compared to 91% of respondents in the study by Wilson-Strydom et al. (2005) agreeing with a similar statement. Almost two-thirds (25; 60%) of respondents agreed or strongly agreed that learners at their institutions responded to ICT-integrated lessons by producing work that is more creative, with two-fifths (17; 40%) of them agreeing with this statement. More than half of respondents (23; 55%) agreed that learners at their institutions responded to ICT-integrated lessons by working together, compared to 88% of respondents in the study by Wilson-Strydom et al. (2005) agreeing with a similar statement. In the study by Wilson-Strydom et al. (2005), 94% of respondents agreed with a statement relating to learners at their institutions responding to ICT-integrated lessons by becoming actively involved - in the study reported here, almost three-quarters of respondents (21; 50%) agreed or (10; 24%) strongly agreed with this statement. Respondents’ opinions regarding learner activities at their institutions changing towards increasingly working on group projects show that almost two-thirds of them (20; 50%) agreed or (4; 10%) strongly agreed - very close to the 61% of respondents in the study by Wilson-Strydom et al. (2005) agreeing with a similar statement. Although the largest segment of respondents (21; 55%) agreed that learner activities at their institutions were changing towards increasingly presenting their work to the class, two-fifths of respondents either (12; 32%) disagreed or (3; 8%) strongly disagreed with this statement. In line with the progression regarding e-education
indicated in the White Paper (DoE, 2004:19), more than half of respondents (18; 47%) agreed or (6; 16%) strongly agreed that learners at these institutions are learning about ICTs (exploring what can be done with ICTs), 18 (45%) agreed or five (13%) strongly agreed that learners at these institutions are learning with ICTs (using ICTs to supplement normal processes or resources), and 17 (45%) agreed or five (13%) strongly agreed that learners at these institutions are learning through the use of ICTs (using ICTs to support new ways of learning and teaching). Regarding achievement of the e-Education policy goal, respondents in this study were split exactly down the middle: half each either (14; 37%) agreed and (5; 13%) strongly agreed vs. (14; 37%) disagreeing and (5; 13%) strongly disagreeing that the institutions they represented had learners who are ICT capable.

More than half of respondents (22; 54%) agreed that every manager had the means to obtain a personal computer for personal use, administration and preparation of lessons, 22 (54%) agreed that institutional managers have access to in-service training on how to integrate ICTs in management and administration, 23 (56%) agreed that all institutional managers integrate ICTs in management and administration, 22 (56%) agreed that the DoE uses ICTs seamlessly in planning, management, communication and monitoring and evaluation and 20 (54%) agreed that provincial managers are trained in ICT integration to offer support to institutions. For two statements, regarding ongoing support to managers being provided at different levels of the system (15; 37%), and every manager having access to basic training in the use of e-education (16; 39%), the percentage of respondents who agreed vs. disagreed with each of these statements were exactly equal; debunking respondents’ seeming ambivalence, however, for each of the latter two statements, eight (20%) of the respondents strongly agreed. Finally, although the largest segment of respondents (19; 46%) disagreed with the item relating to a set of case studies and examples being available to managers on how to integrate ICTs in management, teaching and e-education, almost half of respondents (18; 44%) agreed or (1; 2%) strongly agreed with this statement.

While more than half of respondents (24; 57%) agreed that these institutions had a dedicated teacher to manage the facility and to champion the use of e-education in these institutions, almost two-thirds of respondents (20; 49%) agreed or (6; 15%) strongly agreed that every teacher has access to basic training in the use of e-education and (19; 45%) agreed or (6; 14%) strongly agreed that teachers have access to in-service training on how to integrate ICTs into teaching and e-education. More than half of respondents (21; 55%) disagreed that technology incentives for institutions and teachers to use e-education are installed through the “Most Improved Schools Award” program and other schemes, 24 (57%) disagreed that all teachers integrate ICTs into the curriculum, and 24 (59%) also disagreed that all teachers are ICT capable. Almost half of the respondents (20; 48%) disagreed that every teacher has the means to obtain a personal computer for personal use, administration and preparation of lessons, while just slightly less (17; 44%) disagreed that teachers have access to ICT technical support training, 18 (43%) disagreed that all teachers are trained in basic ICT integration into learning and teaching,
and 17 (43%) disagreed that a set of case studies and examples is available to teachers on how to integrate ICTs in management, learning and teaching.

More than half of respondents (22; 58%) agreed that these institutions are using educational content that was developed according to set national norms and standards, and 21 (53%) agreed that these institutions have access to educational content on the Educational Portal “Thutong”, while exactly half of respondents (20; 50%) agreed that the Educational Portal “Thutong” provides access to resources in all learning areas in the GET phase and all subjects in the FET phase. Just less than half of respondents (19; 48%) agreed that these institutions use educational software of high quality, while slightly less (17; 44%) agreed that these institutions have access to an updated database of evaluated content resources and is able to select content for their usage. Two-thirds of respondents (26; 67%) disagreed that teachers are producing digital content of high quality and making it available to other teachers, while the same number of respondents (26; 65%) disagreed that these institutions have access to digital libraries. Just more than half of respondents (20; 54%) disagreed that these institutions use the Educational Portal to communicate, collaborate and access content, while just less than half of respondents (18; 49%) disagreed that the province is collaborating and pools ICT resources where appropriate. Although the largest segment of respondents (16; 41%) disagreed that these institutions use the Educational Portal for learning and teaching in an outcomes-based education fashion, only one less respondent (15; 38%) agreed with this statement.

In excess of half of respondents (22; 54%) agreed that these institutions use electronic means to communicate with provincial offices, 22 (54%) agreed that these institutions have a computer and software for administrative purposes and 21 (51%) agreed that these institutions have legal software and use the software. Just less than half of respondents (20; 49%) agreed that these institutions have access to a networked computer facility for learning and teaching that is safe, effective, designed to facilitate ICT integration into learning and teaching, and in working condition, and 18 (45%) agreed that these institutions’ ICT facilities are safe. Although just over two-fifths of respondents (17; 41%) agreed that ICT facilities are being used effectively to facilitate ICT integration into learning and teaching, and that these institutions’ ICT facilities are safe, effective, designed to facilitate ICT integration into learning and teaching, and in working condition, almost identical numbers of respondents (16; 39%) disagreed with these two statements. Almost two-thirds of respondents (21; 62%) disagreed that these institutions have access to an e-Rate. Although just more than two-fifths of respondents (18; 44%) disagreed that these institutions are connected to the Educational Network, and 17 (43%) disagreed that networks are safe and information security is monitored, again almost identical numbers of respondents (17; 41%) and (16; 40%) respectively agreed with these two statements.

Almost two-thirds of respondents (26; 63%) disagreed that these institutions serve as a venue for business advisory services and training for community-based small computer and repair businesses, 25 (61%) disagreed that Small, Medium and Micro Enterprises (SMMEs) have been developed and trained to provide technical support to these
institutions, and 21 (57%) disagreed that SMMEs provide technical support to the institutions. More than half of respondents (19; 53%) disagreed that communities are integrally involved in these institutions and 20 (51%) disagreed that these institutions have access to computer facilities and services after hours. Finally, just less than half of respondents (17; 47%) disagreed that community involvement supports these institutions to sustain ICT facilities.

CONCLUSION

With regard to answering the first research question, the validity and continued relevance of some of the assumptions and claims made in the White Paper on e-Education are affirmed by the following results:

The majority of respondents agreed with ninety percent of statements on the survey relating to learners using ICTs to enhance their learning; for five of these statements, 50% or more of respondents agreed.

More than half of respondents agreed with five out of eight statements regarding these institutions having qualified and competent managers that were able to use ICTs for planning, management and administration purposes. For two statements, regarding ongoing support to managers being provided at different levels of the system and every manager having access to basic training in the use of e-education, the percentage of respondents who agreed vs. disagreed with each of these statements were exactly equal.

Finally, although a total of 46% of respondents agreed or strongly agreed with the item relating to a set of case studies and examples being available to managers on how to integrate Information and Communication Technologies in management, teaching and e-education, the largest segment of respondents disagreed with this statement.

For eight of the statements concerning these institutions having ICT infrastructure and connectivity, the majority of respondents agreed, with three of these representing more than half of respondents. Although the majority of respondents therefore only disagreed with only three of these statements, one of the latter, relating to these institutions having access to an e-Rate, represent almost two-thirds of respondents.

In terms of the implications for existing theory, these results therefore could suggest that, at least for the concepts related to these specific aspects of e-schools, the status quo is acceptable.

When it comes to answering the second research question, however, regarding the achievement of the e-Education policy goal, the results reflected that respondents in the survey reported on in this paper were split down the middle: exactly half of each either agreed or strongly agreed vs. disagreeing or strongly disagreeing that the institutions they represented had learners who are ICT capable.

This result with regard to the achievement of the e-Education policy goal is underscored by results indicating that

Although respondents agreed with half of the statements with regard to access to ICT resources supporting curriculum delivery (three of which 50% or more of the
respondents agreed with), the majority of respondents disagreed with the other five statements, with up to two-third of all respondents disagreeing with the statement that teachers are producing digital content of high quality and making it available to others.

Most respondents also disagreed with almost three-quarters (70%) of statements in terms of having qualified and competent teachers using ICTs to enhance their teaching and learning.

Unfortunately, the majority of respondents disagreed with all six of the statements related to these e-schools’ community engagement.

Although some of the results as reported on in this paper might be disappointing, with regard to the deficiencies in terms of the associated research base pointed to by the third research question, the importance of this paper is none-the-less justified regarding contributing something new and original towards scholarly debates in the field, by filling a major gap in knowledge identified in the literature.

In terms of identifying future implementation directions, this paper illustrated positive directions that can serve as recommendations, which are applicable and have practical usefulness to managers and teachers at e-schools across SA, the rest of the continent and even further afield. Further research should, however, also be conducted with regard to those aspects of implementation that have not been as successful (yet), in order to ensure that the further implementation of this policy, towards pursuing sustainable and inclusive quality education, is eventually successful - through research informed practice.

Acknowledgement

This paper represents non-trivial extensions of the conference papers (Goosen, 2015) and (Goosen & Van der Merwe, 2015), with more than 50% of the data presented being new, compared to especially the latter. Finally, the content has also been re-worked significantly to provide various perspectives on ICTs in education, especially to fit in with the conference theme.

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CREATING ONLINE VIDEOS FOR A FIRST YEAR ENGINEERING COURSE

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ABSTRACT

Due to improvements in technology, online video is becoming a significant contributor towards trends in higher education. Based on this, the aims of this study were to 1) find a cost effective way to create videos and provide them to students, 2) use analytics from the videos to determine which areas of the course material students needed most help with and 3) determine the effect of the supplementary videos on exam results. A cost effective way was found to create the videos. A mobile phone and flexible phone holder were used for recording the videos which were uploaded onto a YouTube channel to be accessed by the students. Two YouTube channel metrics called total watch time, TWT, and average percentage viewed, APV, were used to determine which areas of the work students required most help with. Those videos with the highest TWT indicate the topics that the students were most interested in (i.e. needed most help in). Two chapters were identified as most important to the students. Third, to assess the impact of the videos on student results, a survey was carried out on 378 students asking them what percentage videos they watched and what were their exam results. Compared with the exam average of those that watched no videos, there was a slight increase in exam average for those that watched more than 75% of the videos.

INTRODUCTION

Education is currently undergoing major changes. Young people of today are learning in a different way (Woolfitt, 2015). Mobile device use and access to the internet are increasing rapidly and video is becoming a significant contributor to trends in education (Greenberg & Zanetis, 2012).

Video usage currently dominates internet bandwidth (Woolfitt, 2015). According to Cisco, internet video traffic in 2021 will be four times that of 2016 and video traffic will be 78% of all internet traffic in 2021, up from 67% in 2016 (CISCO, 2016). Current statistics show that YouTube has 300 hours of videos uploaded per minute and 5 billion video views per day (Donchev, 2017). It is clear from these statistics that the world is moving online and online content is moving towards video.

Seeing as society is rapidly moving online and towards video, higher education needs to follow suit. Seeing as young people access information differently from decades past, how do academic institutions remain up to speed in this changing environment? How is technology shifting education? This paper aims to investigate these questions.
LITERATURE REVIEW

It is clear that the use of technology, with the emphasis on video, promises much in education. But how is video being used, what appear to be future trends, and how effective are they?

Educational video has been recorded in various ways. One way is to record the instructor as they are lecturing a class and to make these videos available to the class at the institution or even publish them online. This has been done extensively by Massachusetts Institute of Technology (MIT). Another method is to record shorter videos covering the course material and to similarly provide them to local students or make it available online. There are abundant examples of this found on YouTube.

Videos have either been used in an enhancing or a self-study manner (Albo, Hernandez-Leo, Barcelo, & Sanabria-Russo, 2015). Videos used in an enhancing manner means that the instructor either uses video during the lecture or in addition to the lecture. Self-study means the instructor plays more of a supporting role in the education process. An example of self-study is the flipped classroom where the instructor uses video as the primary means for communicating the knowledge and then acts as a guide to the students (Albo, Hernandez-Leo, Barcelo, & Sanabria-Russo, 2015) (Bishop & Verleger, 2013). Pre-recorded video lectures are provided for the students to view as homework and the normal class time with the lecturer is then designated not for presenting the material but for having interactive sessions with the students to discuss any questions they might have from the video content and also to cover various problems. The lecturer can then interact more deeply with the students during class time. The first known case of the flipped classroom was in 2007 (Albert & Beatty, 2014).

Another increasing popular self-study example is the Massive Online Open Course, or MOOC, which was first introduced in 2008 (De Corte, Engwall, & Teichler, 2016). Similarly to the flipped classroom, MOOC content is made available to the student to study at their own pace and in their own time. The flipped classroom applies mainly within a single institution between a lecturer and the local students, whereas the MOOC is open to students globally. Another difference is that MOOCs do not necessarily allow for direct student-instructor interaction since MOOC attendance can be very large, even up to 150,000 students globally (Pappano, 2012). Examples of MOOCs are Coursera, Khan Academy, Udacity and edX. It seems that the lecturer/teacher role is changing to a more supervisory or guiding role for the student and away from the traditional lecturing role. Pre-recorded video lectures appear to be the way higher education is moving.

With regard to technology in higher education, another trend is learning analytics. This is not necessarily related to online video but is related to how data can be used to improve the learning of the students. Learning analytics is essentially a data mining technique that is already being used to personalize the experience of users in commercial spheres. The idea is that these techniques could also be used to personalize the experience of the student in the educational sphere (The New Media Consortium, 2014). A higher education analytics project called Predictive Analytics Reporting Framework
has compiled records of over 1.7 million students in order to better understand student failure and success (The New Media Consortium, 2014). A company called X-Ray Research is conducting research to determine behavioural variables that best predict student performance and detect early warning signs (The New Media Consortium, 2014). Learning analytics can provide information to teachers regarding the quality of education they are delivering. The data can also provide teachers with feedback regarding how the students are doing in the course and what sections of the material the students are struggling with (Nial Sclater, 2016). Although data analytics in higher education is becoming more important, no literature was found that uses video data analytics to understand students’ learning.

Although video and technology appear to be affecting higher education substantially, what is the effect it has had on learning? Just because video is popular and being adopted on a large scale, is it effecting learning in a positive way? Nashash & Gunn (Al Nashash & Gunn, 2013) state that students consider being able to view video lecturers online as an effective means to help them since the material is available 24 hours a day and can be reviewed multiple times. Muller (Muller, Eklund, & Sharma, 2005) states that “it seems reasonable to expect that technology and video would have a positive impact on education” but there doesn’t seem to be a significant body of research researching the value of multimedia systems in higher education. Hansch et al. (Hansch, Hillers, McConachie, Newman, Schildhauer, & Schmidt, 2015) states that there is little evidence to show that video is effective in online learning. Some have however, measured the effectiveness to a certain extent. The use of videos as supplementary material to traditional teaching has shown to improve results as shown by Boster et al. (Boster, Meyer, Roberto, Inge, & Strom, 2007), Traphagan et al. (Traphagan, Kucsera, & Kishi, 2010) and Chtouki et al. (Chtouki, Harroud, Khalidi, & Bennani, 2012). Wieling & Hofman (Wieling & Hofman, 2010) also show improvement in grades after using enhanced video lectures.

Based on the above literature, three questions were asked:

- How can we incorporate video into our courses in a simple, cost effective manner?
- How can we use analytics from the videos to understand student learning?
- Are the videos effective in improving student results?

The following sections aim to answer these questions.

**INCORPORATING VIDEO IN A COST EFFECTIVE WAY**

There was the desire to incorporate video into a first year engineering mechanics course in a cost effective way. In order to do this, the first step was to determine what software could be used. Panopto™, which is software that provides lecture recording and video content management software, was considered first since it was already being used in the authors’ institution. Panopto™ is a very powerful video content manager that provides many useful capabilities, but due to licensing issues it was not used. YouTube
was then chosen as an obvious alternative since it is free and all the students would have easy access to the video content.

The next challenge was to determine which hardware would be used to record the videos. One option that was strongly considered was the use of a portable document camera which could be placed on a desk and the lecture could be recorded using pen and paper. But due to the high cost of the document camera, (~ R12,000), this was not a viable option. Another solution was to make use of an iPad as a recording device and in some manner mount it above the desk and focus the camera onto the desk. But this too was challenging since no iPad mounting products were found online and a custom made mount would need to be made. It was finally decided to make use of the author’s Sony Experia smartphone since the camera and recording capacity was of relatively high quality and the phone did not need to be purchased. The next challenge was to find a stand that the phone could be mounted on. After some research it was found that there are devices such as mobile phone holders that would serve as a mobile phone mount. A flexible mobile phone holder was purchased from Takealot.com (cost approximately R70) (see Error! Reference source not found.). The one end of the holder is able to clamp to a structure nearby and the other end clamps onto the phone (see Figure).

![Flexible mobile phone holder.](image)

Because the holder is flexible, the mobile phone could be manoeuvred into position so that the phone camera is directly above the work area. Videos were recorded using notepad and pen. Video content covered material from Engineering Mechanics by Hibbeler (Hibbeler, 2010). The length of the videos were between 5 minutes and 30 minutes and were uploaded onto a YouTube channel dedicated to hosting engineering mechanics videos for the author’s specific course.

The first video was uploaded to the YouTube channel on 18 January 2017 and during the 1st semester 2017 (February – June), 78 videos were uploaded covering Chapters 1, 2, 3, 4, 5, 8 and 9 of Engineering Mechanics by Hibbeler (Hibbeler, 2010). Currently the channel has 407 subscribers and almost 46,000 views. Students were then able to view the videos online at their own convenience and as many times as they chose to. It is believed that a cost effective way was found to incorporate videos into the course.
USING YOUTUBE ANALYTICS TO UNDERSTAND STUDENT LEARNING

This section aims to investigate the second question regarding using video analytics to understand how the students are learning. Specifically, we can use the YouTube analytics to determine which sections of the course material students are struggling in the most. YouTube provides a few metrics for each video as shown in an example in Figure 3. From left to right it shows the name of the video, the total watch time (TWT), the total number of views, the average view duration and average percentage viewed (APV). These will be described below.

<table>
<thead>
<tr>
<th>Video</th>
<th>Watch time [minutes]</th>
<th>Views</th>
<th>Average view duration</th>
<th>Average percentage viewed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chap 4.1 Moment of a Force - Scalar Formulas...</td>
<td>9.724 (4.7%)</td>
<td>1,216</td>
<td>7.59</td>
<td>28%</td>
</tr>
<tr>
<td>Chap 4.6 Moment of a Couple</td>
<td>7.909 (3.6%)</td>
<td>1,088</td>
<td>6.45</td>
<td>31%</td>
</tr>
</tbody>
</table>

The *total watch time*, or TWT, indicates the total number of minutes a video has been watched. It can also be measured as a percentage of the total watch time for all 78 videos, as shown in brackets next to the number of minutes. *Number of views* indicates the total number of times a video has been viewed. These two metrics may indicate how popular a video is but they don’t give the entire picture. For example, there may be a high watch time and high number of views but the viewers may begin watching the video and find that it is not helping and then cancel the video. This is where the metric called *average percentage viewed*, or APV, is valuable. This metric gives the average percentage of the video that has been watched, and is perhaps a better indicator of the video usefulness. The higher the APV, the more valuable the video was to the viewers. So to briefly summarize, the total watch time and total views may indicate how interested the viewers are in a specific video but the average percentage viewed indicates how useful the viewers considered the video. If a video has both high TWT and APV,
then it is considered to be a useful video from the viewers’ perspective. Basically from here on we will only consider the TWT and APV since it is felt these two metrics are the most valuable in answering the questions.

In total, 1058 students began the engineering mechanics course in 2017. To determine which sections of the course the students require the most help in we begin by finding the videos with the highest total watch time, TWT.

The top twenty total watch time (TWT) videos are presented in Table 1 ranked in descending order. As indicated above, the TWT for each video is measured as a percentage of TWT for all 78 videos. For example, the top TWT video garnered 4.7% of the TWT for all videos. This table shows the video title in the left, the TWT in the middle column and the average percentage viewed (APV) in the right most column. As an initial observation, it looks like Chapters 4 and 9 received the highest TWT.

<table>
<thead>
<tr>
<th>Video title</th>
<th>Total watch time [ %]</th>
<th>Average percentage viewed [ %]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chap 4.1 Moment of a Force - Scalar Formulation</td>
<td>4.7</td>
<td>28.0</td>
</tr>
<tr>
<td>Chap 4.6 Moment of a Couple</td>
<td>3.6</td>
<td>31.4</td>
</tr>
<tr>
<td>Chap 4.3 Moment of a Force - Vector Formulation</td>
<td>3.3</td>
<td>30.2</td>
</tr>
<tr>
<td>Chap 9 (a) - Introduction to Center of Gravity (Mass), Centroid</td>
<td>2.5</td>
<td>45.7</td>
</tr>
<tr>
<td>Chap 9 (b) - Using moments to calculate the centers</td>
<td>2.5</td>
<td>42.0</td>
</tr>
<tr>
<td>Chap 9 (c) - Centroid of an Area (Example 9.5)</td>
<td>2.4</td>
<td>40.5</td>
</tr>
<tr>
<td>Chap 4.2 Cross Product</td>
<td>2.4</td>
<td>28.6</td>
</tr>
<tr>
<td>Chap 2.9(a) Example 2.16</td>
<td>2.3</td>
<td>28.8</td>
</tr>
<tr>
<td>Chap 4.8 Further simplification of a force and couple system</td>
<td>2.3</td>
<td>38.3</td>
</tr>
<tr>
<td>Chap 4.4 Examples 4.5 &amp; 4.6</td>
<td>2.1</td>
<td>24.2</td>
</tr>
<tr>
<td>Chap 2.5 Cartesian Vectors (b): Coordinate Direction Angles</td>
<td>2.1</td>
<td>31.5</td>
</tr>
<tr>
<td>Chap 3.3 Problem 3-18 (14th ed), 3-21(13th)</td>
<td>2.0</td>
<td>26.1</td>
</tr>
<tr>
<td>Chap 4.9 Problem 4-151 (13th Ed)</td>
<td>2.0</td>
<td>33.9</td>
</tr>
<tr>
<td>Chap 8 (b) - Equilibrium</td>
<td>1.9</td>
<td>53.7</td>
</tr>
<tr>
<td>Chap 5 Problem 5-14 (13th Ed.)</td>
<td>1.9</td>
<td>35.1</td>
</tr>
<tr>
<td>Chap 5 - A quick overview</td>
<td>1.8</td>
<td>43.5</td>
</tr>
<tr>
<td>Chap 4.7 (a) Simplification of a force and couple system</td>
<td>1.8</td>
<td>45.7</td>
</tr>
<tr>
<td>Chap 4.3 Example 4.3</td>
<td>1.8</td>
<td>34.6</td>
</tr>
<tr>
<td>Chap 8 (c) - Impending motion</td>
<td>1.8</td>
<td>52.6</td>
</tr>
<tr>
<td>Chap 8 - Example 8.4 (Impending motion at some points)</td>
<td>1.7</td>
<td>38.3</td>
</tr>
</tbody>
</table>
To further analyse the content in Table 1, Table 2 presents the number of times videos from each chapter appear in the top twenty TWT. The data shows that the most requested videos were on Chapter 4 which had 9 videos in the top twenty TWT and the second is Chapter 9 with 3 videos. This suggests that the students felt that Chapter 4 was more challenging than the other chapters and therefore watched a considerable number more videos on Chapter 4. In Chapter 4 of the Engineering Mechanics textbook by Hibbeler (Hibbeler, 2010), the difficulty level jumps from Chapter 3 since it begins to deal not only with particles but with rigid bodies and the rotation of bodies. This therefore confirms the difficulty level of the different chapters as an initial analysis.

Table 2. Number of videos per chapter that appear in the top twenty TWT.

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Number of videos</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

However, Table 3 may present a slightly different picture. In this table we see the Chapter number in the left-most column, the number of videos that created for each chapter in the second column, and the average video length for each chapter. A significantly higher number of videos, namely 23 and 25, were created for Chapters 2 and 4, respectively. Also, Chapter 2 and Chapter 4 have the highest average video length.

Table 3. Number of videos and average video length per chapter.

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Number of videos</th>
<th>Average video length [min:sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>11:59</td>
</tr>
<tr>
<td>2</td>
<td>23</td>
<td>16:31</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>10:33</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
<td>14:14</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>11:26</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>10:08</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>13:36</td>
</tr>
</tbody>
</table>

It could be argued that because there are so many Chapter 4 videos compared with other chapters, students would naturally watch more from this chapter. Although this may be true, Chapter 2 had 23 videos and only appeared twice in the top twenty TWT in Table 2. This suggests that the Chapter 4 videos were the most requested and give us further confidence that Chapter 4 is potentially the most challenging chapter.
The chapter with the next highest number of videos appearing in the top twenty TWT is Chapter 9 which covers centers of gravity, mass and centroids. This chapter also proved to be quite challenging to the students because of the conceptual ideas of centres as well as the math skills that are required to solve the integrals.

We have thus far looked at the *absolute* number of chapter videos appearing in the top twenty TWT and we found Chapter 4 and Chapter 9 as the top two chapters. But if we look at what percentage of chapter videos appear in the top twenty TWT it may give us more insight. For example, if we divide the number of Chapter 4 videos in the TWT (9) by the total number of Chapter 4 videos we would obtain \(9/25 \times 100 = 36\%\). This means that 36\% of all Chapter 4 videos appeared in the top twenty TWT. If we carry out this exercise for the rest of the videos, we obtain the data in Table 4. We can now look at the video impact by considering not only the absolute number, but the percentage of chapter videos. We can see that Chapter 9 had 60\% of its videos appearing in the top twenty TWT, almost double that of Chapter 4 (36\%) and Chapter 5 (33\%). Therefore as a percentage, the data now suggests that Chapter 9 videos were more requested than Chapter 4 videos. Chapter 4 nevertheless was still the second most requested. What is interesting to note is that Chapter 2 which had 23 total videos had the lowest percentage (8.7\%). Therefore in an *absolute* sense, Chapter 4 is most requested but when compared with the number of available videos per chapter, Chapter 9 was seen as most requested. The results in Table 4 suggests that the students view Chapters 9, 4, 5, 8, 3 & 2 in descending level of difficulty.

<table>
<thead>
<tr>
<th>Chapter</th>
<th>% videos</th>
<th>Total videos per chapter</th>
<th>TWT impact [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>9</td>
<td>25</td>
<td>36</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
<td>5</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>23</td>
<td>8.7</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>6</td>
<td>33</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>8</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>8</td>
<td>12.5</td>
</tr>
</tbody>
</table>

The above analysis is an indication of the areas that the students find most challenging. This is also supported by the author’s own experience as well as an exam analysis that was carried out in 2013 (Smith, 2013). In that paper it was shown that students found Chapter 4 material the most challenging. Although these results may have been expected based on prior experience, no similar work has been found in the literature and it is believed that this technique may provide instructors with a diagnostic tool to identify what areas of the work the students struggle in most and may contribute toward understanding student learning.
EFFECT OF VIDEO LENGTH

This section continues the analysis of the YouTube metrics in an attempt to understand student learning. Table 5 presents a new top twenty video list, ranked according to the average percentage viewed. It is interesting to note that Chapter 8 videos now rank highest on this list with the top three videos all being Chapter 8 and all with higher than 50% APV. The reason for Chapter 8 ranking the highest is most likely due to having the shortest average video length of 10:08 min, as shown in Table 3.

Table 5. Top twenty videos with respect to average percentage viewed.

<table>
<thead>
<tr>
<th>Video Title</th>
<th>Watch time [%]</th>
<th>Average percentage viewed [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chap 8 (a) - Introduction</td>
<td>1.1</td>
<td>54.6</td>
</tr>
<tr>
<td>Chap 8 (b) - Equilibrium</td>
<td>1.9</td>
<td>53.7</td>
</tr>
<tr>
<td>Chap 8 (c) - Impending motion</td>
<td>1.8</td>
<td>52.6</td>
</tr>
<tr>
<td>Chap 4.9 (b) Reduction of a simple distributed loading</td>
<td>1.1</td>
<td>50.7</td>
</tr>
<tr>
<td>Chap 3.2 Free Body Diagram (a) - Introduction</td>
<td>0.4</td>
<td>49.9</td>
</tr>
<tr>
<td>Chap 3.1 Conditions for the equilibrium of a particle</td>
<td>0.3</td>
<td>49.6</td>
</tr>
<tr>
<td>Chap 4.9 (a) Reduction of a simple distributed load</td>
<td>1.2</td>
<td>49.2</td>
</tr>
<tr>
<td>Chap 8 (e) Types of friction problems</td>
<td>1.2</td>
<td>48.8</td>
</tr>
<tr>
<td>Chap 4.9 (c) Reduction of a simple distributed load</td>
<td>1.3</td>
<td>46.2</td>
</tr>
<tr>
<td>Chap 4.7 (b) Simplification of a force and couple system</td>
<td>1.3</td>
<td>45.8</td>
</tr>
<tr>
<td>Chap 9 (a) - Introduction to Center of Gravity (Mass), Centroid</td>
<td>2.5</td>
<td>45.7</td>
</tr>
<tr>
<td>Chap 4.7 (a) Simplification of a force and couple system</td>
<td>1.8</td>
<td>45.7</td>
</tr>
<tr>
<td>Chap 4.9 F4-42 (13th &amp; 14th ed) - Springs</td>
<td>1.3</td>
<td>45.5</td>
</tr>
<tr>
<td>Chap 3.2 Free Body Diagram (b) - Springs</td>
<td>0.8</td>
<td>44.9</td>
</tr>
<tr>
<td>Chap 3.2 Free Body Diagram (c) - Cables &amp; Smooth Contact</td>
<td>0.4</td>
<td>43.7</td>
</tr>
<tr>
<td>Chap 5 - A quick overview</td>
<td>1.8</td>
<td>43.5</td>
</tr>
<tr>
<td>Chap 2.3 (a) - Vector addition of forces, Part (a)</td>
<td>0.4</td>
<td>42.6</td>
</tr>
<tr>
<td>Chap 9 (b) - Using moments to calculate the centers</td>
<td>2.5</td>
<td>42.0</td>
</tr>
<tr>
<td>Chap 3 (a) Equilibrium of a Particle - Background</td>
<td>0.4</td>
<td>41.8</td>
</tr>
<tr>
<td>Chap 9 (c) - Centroid of an Area (Example 9.5)</td>
<td>2.4</td>
<td>40.5</td>
</tr>
</tbody>
</table>

Table 6 presents the number of videos per chapter when measured according to the APV. A couple of points can be learned from this new information. Firstly, Table 6 shows that Chapter 4 still has the largest number of videos (6) and secondly, the top twenty APV list is different from the top twenty TWT list. Different chapter videos appear on the two lists. This suggests that students view the top twenty TWT videos as important but they don’t end up watching those videos all the way through. It is important to find out why the students did not watch the TWT videos for longer times.
Table 6. Number of chapter videos appearing in the top twenty average percentage viewed (APV).

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Number of videos</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

To recap, the TWT is a measure of which chapter videos the students watched the most (indicating which chapters were most requested), and the APV is a measure of the percentage viewed for each video (indicating whether those videos were considered helpful). Why are the top twenty videos for TWT and APV different, and what can we learn from them? To answer this question let us compare average video lengths for the top twenty TWT and APV lists. The average lengths for the top twenty TWT and APV videos are 17:36 and 8:33, respectively. It can be seen that the average time of top twenty TWT videos is more than double that of the top twenty APV videos. This indicates that the shorter views will naturally have a higher APV simply because of being shorter in length.

The following can be concluded. The students may perceive the highest total watch time video material to be more important that the other material but the videos may simply be too long for them to watch through to the end. This may cause the students to miss crucial information that is at a later stage in these videos. The data suggests that future videos should be approximately 8 minutes or less in order to have a high average percentage viewed (> 40%). Even in the author’s own experience, watching an educational video that is longer than 10 minutes seems to have a negative psychological effect regarding that video. Therefore if shorter videos are made, the more important content will receive a higher percentage viewed. This compares well with the literature where a study by MIT recommends that videos should be shorter than six minutes in length (Guo, Kim, & Rubin, 2014) and another study states that videos should be kept to less than 15 minutes in length (Berg, Brand, Kirk, & Zimmerman).

EFFECTIVENESS OF THE VIDEOS ON THE RESULTS

This section aims to answer the third question regarding how effective the videos were on the students’ results. In order to answer this question, a survey was carried out with 378 students which are approximately 36% of the total student population taking the engineering mechanics course. A survey was required since YouTube does not give the statistics of each student attending the course. Two simple questions were asked: 1) estimate the percentage of total videos that you watched (out of 78 videos) and 2) indicate what your June 2017 exam results were (as a percentage). With respect to the
1st question students could choose the following values, 0%, 25%, 50%, 75% and 100%. According to the survey results, 8.1% watched no videos, 17.6% watched 25%, 26.2% watched 50%, 37.3% watched 75% and 14.2% watched 100%.

The average mark for each group was then calculated and compared with the percentage videos watched as shown in Figure 4. It can be seen that for the group that watched no videos, i.e. the control group, the average mark was 59%. For the 25% and 50% groups, the average marks actually decrease to 58% and 56% respectively. The 75% and 100% groups showed an increase to 60% and 65% respectively. Were the videos effective in improving student results? If we look at the 25% and 50% group we would say no. But perhaps these students would not have received those results without the aid of those videos. However it does seem that for the students that watched all the videos, there was a noticeable increase in the average mark, from 59% to 65%. As an initial analysis, the results suggest that in order to have a significant improvement over the control group, almost all the videos need to be watched.

![Figure 4. Average exam results per percentage videos viewed.](image)

**LIMITATIONS OF STUDY AND FURTHER WORK**

With regards to determining which areas of the work the students struggle in most, only the chapter numbers were looked at and not the subsections within the chapters which could provide more detail.

This study did not look into the impact of conceptual vs problem type videos. Did students watch more conceptual (theoretical) type videos or problem (example) videos? Do conceptual or problem type videos have a larger impact student results?

This study on the effectiveness of the videos on the results has limitations. The first is that it was carried out via survey where it is reasonable to assume that the exam results provided by the students are accurate but it is more difficult to assume the percentage
videos watched are as accurate. For example, how do the students really know if they watched 25% or 50% of the videos? Therefore as indicated above, the only two data points that the author feels might carry some weight are the results from the 0% and 100% groups. In order to try to answer this question more accurately, we require accurate measures of video watching activity of each student individually.

Furthermore, it may be that the students that watched more videos are simply more diligent students and would on average tend to obtain higher results. This requires further study. The statistics provided by YouTube were not ideal since the author was not able to extract the video viewing statistics per student enrolled in the course. This will be modified in future studies by hosting all videos on the Panopto™ platform.

This study did not investigate different teaching methods within the video which is a topic for future work.

CONCLUSION

Video is becoming a significant contributor towards trends in education. Based on this, 78 short videos were recorded covering the course material in a first year engineering mechanics course. These were provided as a supplementary resource to the students to use at their own time. This study asked three questions regarding the use of supplementary videos for this course:

How can we incorporate video into our courses in a simple, cost effective manner?

How can we use analytics from the videos to understand student learning?

Are the videos effective in improving student results?

To answer the first question, a cost effective method was used to create online videos. This method included recording the videos using a mobile phone mounted above a workspace using a flexible mobile phone holder. Videos were then uploaded onto a YouTube channel created specifically for this course and easily accessed by the students.

The second question was answered using YouTube video analytics to determine which sections of the work the students found most challenging. Chapters 4 and 9 of the course textbook were found to have the highest YouTube metric total watch time, TWT, that may indicate which areas the students needed most help with. These results correspond to a previous study as well as the author’s own experience lecturing this course.

The second YouTube metric of importance was the average percentage viewed, APV. This metric indicates how much (percentage) of the video a user has watched. This metric helped us to understand that although a video (or videos) may have a high TWT, if the APV is relatively low then perhaps the video lengths were too long or the content was not helpful. Therefore the students may identify the videos as important but because of long video lengths, the TWT will be high but the students may not, on average, watch that much of the video. This could be detrimental since important information could be stored in the later stages of the video. The average video lengths of the top twenty TWT videos and the top APV videos were calculated to be 17:36 min and 8:33 min respectively. This is clear evidence that the top APV had less than half the average
length of the top TWT videos. This shows that in order to keep the students watching the videos for longer periods, we need to reduce the lengths to approximately 8 minutes. Finally, the effectiveness of the videos on student learning was measured using a survey. It was found that for those that watched 75% or more, there is a positive effect on the results.

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PHYSICAL SCIENCES TEACHERS’ BELIEFS ABOUT TECHNOLOGY FOR TEACHING AND FACTORS INFLUENCING THEIR UPTAKE OF A SPECIFIC TECHNOLOGY

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ABSTRACT

In this article I use the Theory of Planned Behaviour (TPB) to measure South African physical sciences (SA PS) teachers’ general beliefs about Information and Communication Technology (ICT) usage in teaching. I investigate correlation between these beliefs and the teachers’ use of a specific ICT resource and how this is moderated by having attended a workshop related to the resource. Data were collected by surveying 127 SA PS teachers about their beliefs and behaviour regarding usage of ICT in general and of a particular ICT they had received. A subset (n = 68) had attended a workshop the previous year about this ICT. The findings suggest that a high proportion of the teachers hold beliefs favourable to general usage of ICT in teaching when the ICT is used by the teachers themselves rather than by the learners. The findings also highlight the importance of workshop attendance as a moderator to these general beliefs in influencing uptake of a specific ICT.

Keywords: Information and communication technologies (ICT), teachers, Theory of Planned Behaviour (TPB), uptake, workshop

INTRODUCTION

The South African Department of Basic Education has put much hope in ICT to improve learning, particularly for mathematics and physical sciences (Department of Education, 2004). However, the efficacy of such efforts is obviously dependent on whether the teachers do actually use these resources, with low uptake levels reported throughout the world (Kreijns, Vermeulen, Kirschner, Buuren, & Acker, 2013; Utterberg, Lundin, & Lindström, 2017).

When the Theory of Planned Behaviour (TPB) (Ajzen, 2011) is applied to teachers’ beliefs about a specific ICT it predicts the likelihood of teachers’ uptake of that specific ICT with a high degree of accuracy (Lee, Cerreto, & Lee, 2010). However, the generic application of such specific belief indices is limited. I hypothesise that a favourable general belief about ICT usage in teaching facilitates, but does not determine, uptake of a specific ICT, and so measuring these beliefs is useful to predict uptake of any ICT provided it meets whatever other criteria are relevant.

Teacher education regarding ICT usage is known to affect uptake. For example, Arikoo (2010) found that Ugandan teachers, and Khoali and Sanders (2008) found that South African teachers, who had attended teacher training workshops, were more likely to use
a resource than teachers who had not. Similarly, Kabakci Yurdakul and Çoklar (2014) found that ICT training improved Turkish teachers’ ICT-usage and improved Technological Pedagogical Content Knowledge (TPACK), a requirement for effective use of ICTs in education (Herring, Koehler, & Mishra, 2016). However, the efficacy of various kinds of ICT education is not fully understood (Cradler, Freeman, Cradler, & McNabb, 2002), and some of the findings in this area, for example the superiority of extended mentoring programs (Jones & Carter, 2007), are difficult to implement in practice (Galanouli, Murphy, & Gardner, 2004). Constraints of time, logistics, funding and educational policies about access to teachers, make once-off, short duration workshops held in the afternoon after the teaching day, an attractive and feasible option for in-service teacher education. However, some research (e.g. Rudduck, 1986) suggests that such workshops are too shallow and transitory to have significant effects. Other research acknowledges the superiority of more extended support programs, but shows that one-time workshops are not without any efficacy (e.g. Stott & Case, 2014), including enhancing ICT uptake (Cradler et al., 2002), for some teachers.

This research was guided by existing literature on the Theory of Planned Behaviour (TPB), particularly in the context of ICT uptake by South African teachers, and by the questions “What are South African physical sciences teachers’ general beliefs about using ICT in teaching?”, “Do general beliefs about using ICT in teaching have predictive value regarding a teacher’s uptake of a specific ICT?” and “Does attendance of a once-off short duration workshop about a specific ICT have predictive value regarding a teacher’s uptake of that ICT?”. The research has implications for those involved in developing and providing ICT to teachers.

THE THEORY OF PLANNED BEHAVIOUR AS A PREDICTOR OF ICT UPTAKE

The generic and parsimonious natures of the Theory of Planned Behaviour (TPB), its firm establishment (Ajzen, 2011), including as a tool for predicting ICT usage with a high level of accuracy (Teo & Tan, 2012) and its provision of specific guidance to developers (Lee et al., 2010), make it an attractive choice as a theoretical framework for this study. According to the TPB, an actual behaviour is determined by a person’s intention to perform the behaviour, moderated by their perception of behavioural control (PBC). Behavioural intention is determined by the person’s attitude beliefs (AB), perception of subjective norms (SN) and perceived behavioural control (PBC) regarding the behaviour. In the context of ICT uptake, AB refers to the teacher’s affective response to, and beliefs concerning the consequences of, using ICT in the classroom, SN includes pressure placed on the teacher to use ICT by the school’s principal and the learners the teacher teaches, and PBC is affected by the access the teacher has to ICT both in terms of resource and time availabilities (Mumtaz, 2000), the teacher’s confidence in using ICT (Pelgrum, 2001), curricular constraints and the availability of technical and administrative support (Afshari, Bakar, Luan, Samah, & Fooi, 2009).

In qualitative studies of South African teachers, Miller, Naidoo, van Belle, and Chigona (2006) investigated teachers’ general usage of ICT in teaching, and Khoali and Sanders
investigated teachers’ uptake of a specific resource. Both found the TPB useful for describing the likelihood of uptake. Kriek and Stols (2010) were able to predict SA PS teachers’ uptake of a specific ICT with a 71% accuracy, based on the index of behavioural intention, largely informed by the TPB. The mismatch between intention and actual behaviour arose from limited resource access (limited PBC), as predicted by TPB. Hart and Laher (2015) and Govender (2012) found that SA teachers tend to have positive attitudes and normative beliefs favourable towards ICT usage in education, however Govender (2012) found that these teachers display lower levels of perceived behavioural control, resulting from limited access, and time for use, of ICT. This study extends such research by reporting on the general beliefs about using ICT in teaching of one subgroup of SA teachers, namely PS teachers, and by exploring the relationship between these beliefs and teachers’ uptake of a specific ICT. This study therefore has some overlap to that by Kriek and Stols (2010), but is larger in scale, and additionally focusses on the contribution of short-duration once-off teacher workshops to uptake.

**METHOD**

**Sample**

The convenience sample (Merriam, 1988) surveyed consists of 127 grade 12 PS teachers from throughout South Africa. The surveys were conducted approximately a year after distributing 6 000 Chemical Industries Resource Packs, developed by the University of Cape Town’s Chemical Engineering Department’s (UCT ChemEng) School’s Project, to grade 12 PS teachers throughout the country. This resource pack included electronic material on a disc, i.e. ICT, in the forms of animations, videos and printable material. This is referred to as the *provided ICT*. Approximately 2 000 of the teachers who received a pack attended a workshop about it. Presentation at these workshops was conducted by an experienced teacher and focussed on both technical and pedagogical aspects of usage of the resource as recommended in literature (Herring et al., 2016). The following year, the UCT ChemEng School’s Project ran similar workshops throughout South Africa during distribution of another resource pack. Where time allowed, and if the teachers voluntarily gave informed consent, they anonymously completed a survey in the last few minutes of the workshop. Both sets of workshops were hosted at willing schools and all the PS teachers of the surrounding schools were invited. Attendance was free and motivated by reception of resource packs. The 382-strong data set were filtered to include only the 127 teachers who indicated they were teaching grade 12 PS, had received the provided ICT and answered enough of the survey to enable valid calculation of the indices used. As shown in Table 1, the sample is not representative of SA grade 12 PS teachers, having too high a proportion of teachers with BSc degrees and who teach at high quintile schools (Stott, 2013).

The characteristics of the teachers who had (referred to as the *workshop group*) and who had not (referred to as the *non-workshop group*) attended one of the workshops about the provided ICT, differ somewhat. If anything, these differences seem to favour ICT uptake by the non-workshop group, since higher quintile (a mean of 3.6 compared to the workshop group’s 3.0) and non-township (81% compared to 67%) schools tend to
be better resourced and the teachers better supported (Shalem & Hoadley, 2009). Holding a BSc degree (55% for the non-workshop group and 44% for the workshop group) tends to be associated with stronger content knowledge (Stott, 2013), which is related to an epistemology conducive to pedagogical reflection and change (Abell, 2007). Less experienced teachers (10.3, compared to 11.3, years) are known to be more open to ICT integration than more experienced teachers (Ariko, 2010; Jones & Carter, 2007; Miller et al., 2006).

**Table 1 Characteristics of the sample of SA grade 12 PS teachers**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total</th>
<th>Workshop group</th>
<th>Non-workshop group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quintile</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number teachers from low (1-3) quintile</td>
<td>64 (54%)</td>
<td>38 (61%)</td>
<td>26 (46%)</td>
</tr>
<tr>
<td>schools</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number teachers from high (4-5) quintile</td>
<td>54 (46%)</td>
<td>24 (39%)</td>
<td>30 (54%)</td>
</tr>
<tr>
<td>schools</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean quintile rating</td>
<td>3.3</td>
<td>3.0</td>
<td>3.6</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>1.5</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Grade 12 PS teaching experience</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inexperienced (≤ 5 years)</td>
<td>39 (31%)</td>
<td>19 (28%)</td>
<td>20 (34%)</td>
</tr>
<tr>
<td>Experienced (&gt; 5 years)</td>
<td>87 (69%)</td>
<td>49 (72%)</td>
<td>38 (66%)</td>
</tr>
<tr>
<td>Mean number of years</td>
<td>10.8</td>
<td>11.3</td>
<td>10.3</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>7.7</td>
<td>7.9</td>
<td>7.8</td>
</tr>
<tr>
<td>School’s location</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rural</td>
<td>41 (33%)</td>
<td>21 (31%)</td>
<td>20 (35%)</td>
</tr>
<tr>
<td>Urban</td>
<td>50 (40%)</td>
<td>24 (36%)</td>
<td>26 (46%)</td>
</tr>
<tr>
<td>Township</td>
<td>33 (27%)</td>
<td>22 (33%)</td>
<td>11 (19%)</td>
</tr>
<tr>
<td>Number of computers for learner</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>usage at school</td>
<td>None</td>
<td>18 (15%)</td>
<td>11 (17%)</td>
</tr>
<tr>
<td>Low (1 to 10)</td>
<td>9 (7%)</td>
<td>4 (6%)</td>
<td>5 (9%)</td>
</tr>
<tr>
<td>Moderate (11 to 30)</td>
<td>36 (29%)</td>
<td>18 (27%)</td>
<td>18 (32%)</td>
</tr>
<tr>
<td>High (&gt;30)</td>
<td>60 (49%)</td>
<td>33 (50%)</td>
<td>27 (47%)</td>
</tr>
<tr>
<td>Science qualification</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have a BSc degree</td>
<td>50%</td>
<td>44%</td>
<td>55%</td>
</tr>
</tbody>
</table>

**DATA COLLECTION**

The self-report survey used (see Appendix 1 and 2) probed the teachers’: General usage of ICT within the classroom, administratively and personally; specific use of the provided ICT; beliefs regarding general usage of ICT in teaching, according to the TPB. Creation of the survey was informed by literature on the TPB and the pragmatic constraints of access frequency and time. Francis et al. (2004)’s steps for design of TPB surveys were followed, except it was not possible to administer the survey to the same group of people at a two-week interval. Instead, the 34 PS teachers who answered the pilot survey did this in a once-off session. In response to feedback given by these teachers I made slight modifications to the survey to improve its clarity. Multiple versions of questions measuring the same construct using direct and indirect measures were avoided due to time constraints. Consequently, the internal consistency of the responses cannot be determined. However, the high correlation (explaining 63.9% of the variance) between the measured indices and the teachers’ self-reported ICT class usage is taken as support for a high degree of validity of the survey.
DATA ANALYSIS

Data were analysed using descriptive data, multiple regression analysis, correlation analysis and by using unpaired t-tests assuming equal variance. Significant differences between groups were inferred from p values of less than 0.05 (i.e. 95% chance or greater of difference).

RESULTS

General beliefs about using ICT in teaching

The teachers’ responses to each of the TPB-related questions regarding general beliefs about using ICT in teaching (see Appendix 1) yielded high scores, in general. Every average value was found to be above the mid-point (4), and the mode for each question was 7 (very much), with particularly high values for each component of attitude to ICT (5.7 to 6.2) and personal access to a computer (6.0). The lowest ratings were found for access to computers for learners (4.5) and principals expecting teachers to use ICT (4.8).

The teachers’ responses regarding their usage of ICT in teaching in general (see Appendix 2) also yielded high scores for every value except getting learners to use computers during teaching, with an average value of only 3.7 and a mode of 1 (not at all). This was the only item with an average below the mid-point and not having a mode of 7. Particularly high values were recorded for teachers using computers for administration (6.1) and the use of email (5.7) and the internet (5.6).

Workshop attendance, beliefs and uptake of a particular ICT

Table 1 shows the teachers’ responses regarding their use of the provided ICT. Clearly a higher proportion of teachers who had attended a workshop used the provided ICT, and used it to a greater extent, than teachers who had not attended a workshop.

<table>
<thead>
<tr>
<th>Question: Have you used each of these?:</th>
<th>Group</th>
<th>Number of responses</th>
<th>Response frequency (number and %)</th>
<th>Average rating (/2)</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>The practical movies</td>
<td>Workshop</td>
<td>63</td>
<td>39 (62%)</td>
<td>6 (10%)</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>Non-workshop</td>
<td>52</td>
<td>23 (44%)</td>
<td>9 (17%)</td>
<td>1.06</td>
</tr>
<tr>
<td>animations</td>
<td>Workshop</td>
<td>65</td>
<td>48 (74%)</td>
<td>9 (14%)</td>
<td>1.62</td>
</tr>
<tr>
<td></td>
<td>Non-workshop</td>
<td>55</td>
<td>27 (49%)</td>
<td>5 (9%)</td>
<td>1.07</td>
</tr>
<tr>
<td>pack</td>
<td>Workshop</td>
<td>68</td>
<td>55 (81%)</td>
<td>8 (12%)</td>
<td>1.74</td>
</tr>
<tr>
<td></td>
<td>Non-workshop</td>
<td>58</td>
<td>40 (69%)</td>
<td>6 (10%)</td>
<td>1.48</td>
</tr>
</tbody>
</table>

Table 7 SA PS teachers’ use of the provided ICT
Figure 1 shows the average ratings for the teachers’ responses to the 7-point Likert-scale items regarding beliefs and usage of ICT in general, as well as of the provided ICT, converted to a 7-point index. Error bars indicate standard deviation. According to t-tests, the workshop and non-workshop groups do not differ significantly regarding any of the indices related to the TPB and to the general ICT usage practises surveyed: \( t(124) = -0.4, p = ns \); \( t(124) = 1.1, p = ns \); \( t(124) = -5.4, p = ns \); \( t(124) = -0.5, p = ns \); \( t(124) = -0.6, p = ns \); \( t(124) = -0.4, p = ns \); \( t(124) = -0.8, p = ns \). However, the workshop group’s mean rating was significantly higher for use of the provided ICT: \( t(124) = -2.6, p < 0.05 \).

Figure 1: SA PS teachers’ beliefs and usage of ICT in general and of the provided ICT

**GENERAL ICT BELIEFS AND UPTAKE OF A PARTICULAR ICT**

As shown in Table 2, the results of a multiple regression analysis indicates that the three indices of TPB for beliefs about ICT usage in teaching in general explain 63.9% of the variance of teachers’ behaviour regarding general ICT usage in teaching. PBC is the most influential and AB is insignificant. Correlation statistics do, however, yield a moderate correlation for AB, and give strong correlations for SN and PBC (Table 3). These findings suggest that the survey used and indices calculated are sufficiently valid to provide meaningful data. The efficacy of the calculated indices for predicting general ICT class usage is demonstrated by the close fit of the data points to the trend line in Figure 2. The general ICT belief index used in Figure 2 was calculated as the average of the TPB indices.

The results of a multiple regression analysis (Table 2) show that the TPB indices for general ICT usage account for 22% of the variance in the data regarding specific use of the provided ICT for the workshop group and virtually none for the non-workshop group. As shown in Table 3, moderate correlations were found between each TPB index
and the index for use of the provided ICT for the workshop group, but no correlation was found for the non-workshop group. This is illustrated graphically in Figure 3.

Table 8 Results of multiple regression analyses for components of the TPB and ICT usage

<table>
<thead>
<tr>
<th>Regression statistic</th>
<th>TPB and general ICT class usage</th>
<th>TPB and use of the provided ICT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Workshop group</td>
<td>Non-workshop group</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.639</td>
<td>0.22</td>
</tr>
<tr>
<td>F</td>
<td>3.119</td>
<td>6.97</td>
</tr>
<tr>
<td>Degrees of freedom</td>
<td>72.86</td>
<td>3.61</td>
</tr>
<tr>
<td>p</td>
<td>8.1 x 10^{-27}**</td>
<td>0.0004**</td>
</tr>
<tr>
<td>β . p</td>
<td>AB -0.05, 0.73</td>
<td>0.09, 0.35</td>
</tr>
<tr>
<td></td>
<td>SN 0.31, 0.00068**</td>
<td>0.13, 0.04*</td>
</tr>
<tr>
<td></td>
<td>PBC 0.87, 5.6 x 10^{-16}**</td>
<td>0.08, 0.21</td>
</tr>
</tbody>
</table>

** p<0.01; *p<0.05

Table 9 Correlations between components of the TPB and SA PS teachers’ use of the provided ICT and general ICT class usage

<table>
<thead>
<tr>
<th>Component of the theory of planned behaviour, regarding general ICT class usage</th>
<th>Correlation to use of the provided ICT</th>
<th>Correlation to general ICT class usage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Workshop group</td>
<td>Non-workshop group</td>
</tr>
<tr>
<td></td>
<td>r(65) =</td>
<td>r(56) =</td>
</tr>
<tr>
<td>Attitude (AB)</td>
<td>0.33, p &lt; 0.05</td>
<td>0.01, p = n.s</td>
</tr>
<tr>
<td>Subjective norms (SN)</td>
<td>0.47, p &lt; 0.05</td>
<td>-0.09, p = n.s</td>
</tr>
<tr>
<td>Perceived behavioural control (PBC)</td>
<td>0.53, p &lt; 0.05</td>
<td>0.03, p = n.s</td>
</tr>
<tr>
<td></td>
<td>Internal control (confidence)</td>
<td>0.31, p &lt; 0.05</td>
</tr>
<tr>
<td></td>
<td>External control (access)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>0.41, p &lt; 0.05</td>
</tr>
</tbody>
</table>

** 0.78, p < 0.05; *p<0.05
Those teachers whose data points are plotted in the upper right-hand area of Figure 3 can be called predictable users, since their uptake of the provided ICT is expected by their high general ICT belief index, according to the TPB. The teachers represented in the lower left can be called predictable non-users. Teachers represented in the lower right can be called pioneers, since they show high uptake levels of the provided ICT despite not seeming to be well predisposed to ICT uptake. Teachers represented in the upper left of Figure 3 can be called problems, since although they appear to be well
predisposed to using ICT in teaching, they show little or no uptake of the provided ICT. Using the arbitrary cut-off values of the mid-points of each index to delineate these categories, little difference was found between the proportion of pioneers in the workshop (7%), and non-workshop (9%) groups. However, only 4% of the workshop group can be classified as problems whereas this statistic is 29% for the non-workshop group.

DISCUSSION

General beliefs about using ICT in teaching and ICT usage

The teachers in the sample have favourable attitudes towards general usage of ICT in their teaching. This corresponds to Govender (2012)’s and Hart and Laher (2015)’s findings to the same effect. However, this high AB appears to have less relevance to the teachers’ behavioural choices regarding ICT-usage in teaching than do their beliefs regarding SN and PBC. This is inconsistent with findings that AB is the main predictor of ICT-usage (e.g. Almusalam & Adviser-Stein, 2001; Sugar, Crawley, & Fine, 2004; Teo & Tan, 2012) and that PBC has little to no behavioural predictive value (e.g. Salleh & Albion, 2004; Teo & Lee, 2010). It is, however, consistent with other South African research showing that PBC is the strongest predictor of South African teachers’ ICT classroom usage (Govender, 2012; Kriek & Stols, 2010; Miller et al., 2006). The more limiting the control that teachers have over ICT usage, the less accurately AB and SN predict behaviour (Ajzen, 1991). In environments where ICT confidence and access are low, such as in many South African classrooms (Shalem & Hoadley, 2009), it is therefore not surprising that the teacher’s attitude towards ICT predicts their actual ICT classroom usage to a lesser extent than the other components of the TPB do, and then AB indices for teachers in better ICT-resourced environments do. However, at least for the sample reported on here, this explanation appears to be inadequate since the teachers reported high ICT confidence and access levels, with the mean scores for each aspect of PBC and of ICT usage in teaching, except regarding learner ICT-usage, being above the mid-point and the mode for each question being 7/7.

The teachers reported very high levels of personal access to a computer and usage of computers for administration, email and the internet. Stols (2008) explains that teachers more easily adopt practises such as these than they do ICT integration into teaching, since such practises require no pedagogical change. However, teachers with greater individual access to computers are more likely to be confident in using technology and in their instructional ability (Falba, Grove, Anderson, & Putney, 2001, in Sugar et al., 2004) and more interested in using technology in teaching (Germann & Sasse, 1997, in Sugar et al., 2004). Maddux and Johnson (2011) point out that educational uptake is particularly strong when an ICT has developed a high cultural momentum so that the ICT is so widely used in everyday life that it may be expected to be used in the classroom too. Therefore, it is possible that high levels of personal access to, and usage of, computers, could impact, or may already have impacted, ICT confidence levels and ICT classroom usage. The far lower classroom, relative to administrative and personal, ICT usage measured, shows that in many cases this transition has not yet occurred, though.
Nevertheless, ratings for classroom ICT usage are high for a large number of the teachers, except regarding getting learners to use computers in teaching. The low level of learner hands-on ICT usage is not completely explainable in terms of limited access, since the teachers’ responses to the question about having easy access to computers for their learners are more favourable (mean = 4.5, mode = 7) than their responses to the question about getting their learners to use computers in their teaching (mean = 3.7, mode = 1). This may be because getting learners to use computers hands-on is perceived as being too time consuming, given curriculum constraints (Govender, 2012), and requires a greater change in pedagogy, and therefore is less likely to be adopted, than teacher demonstration using ICT, does (Stols, 2008). There is a wide range in the data for classroom ICT usage, with considerable numbers of teachers giving each of the possible responses.

The teachers in the sample appear to experience considerable pressure from their learners to use ICT in their teaching. There is a wide range of perceptions of principal expectations. In many cases the principal both encourages and expects the teachers to use ICT in teaching, but a number of principals neither expect nor encourage this. This is consistent with Blignaut, Hinostroza, Els, and Brun (2010)’s findings that fewer than half of SA principals prioritise ICT-integration. The high predictive value of the SN index corresponds to findings that principals’ attitudes towards ICT integration are strong predictors of teachers’ ICT usage in the classroom (Law, Lee, & Chan, 2010; Miller et al., 2006).

**Workshop attendance, beliefs and uptake of a particular ICT**

The TPB indices measured for teachers’ beliefs about ICT usage in general has some predictive value regarding use of the provided ICT for those teachers who had attended a workshop about this ICT, but not for those who had not. This supports the hypothesis that a favourable general belief about ICT usage in teaching facilitates, but does not determine, uptake of a specific ICT. The workshop group shows significantly greater use of the provided ICT than the non-workshop group. This may be because the workshop enhanced the teachers’ AB and PBC regarding the provided ICT, since the ICT’s positive pedagogical aspects were highlighted to promote positive attitudes towards it and the teachers engaged with the ICT in a supportive environment to enhance confidence and hence perception of behavioural control. Additionally, principals and heads of departments may have expected the teachers to use the provided resource if they knew a teacher had attended a workshop on it, further contributing to the teacher’s behaviour.

**CONCLUSION, LIMITATIONS AND IMPLICATIONS**

The results of this study, and discussion arising from these results, can be summarised in three assertions, which answer the research questions:

- Most of the SA PS teachers surveyed have favourable general beliefs about using ICT in teaching regarding their own usage of ICT, rather than learners’ usage of ICT in class time.
• Both general beliefs about using ICT in teaching and workshop attendance about a specific ICT have some predictive value regarding uptake of a specific ICT.

• Attending a once-off short duration workshop about a specific ICT increases the likelihood that a teacher’s general ICT belief is a good predictor of usage of that specific ICT.

The logistics of collecting data at teacher education workshops of limited time duration and mostly voluntary attendance imposed various limitations on the research. These include convenience, rather than representative, sampling, the need for a relatively short survey with consequent sacrifices of checks of internal consistency, some teachers omitting some questions in the survey, and reliance on self-reporting. These limitations are reduced by the facts that the workshop presenter was always on hand to clarify instructions and the teachers had little motivation for false reporting since participation was anonymous and voluntary.

The lack of representivity of the sample of SA PS teachers reduces generalizability of these conclusions to the entire population, particularly regarding the extent of general beliefs about using ICT in teaching of SA PS teachers. Multiple regression analysis was used to test the extent to which biographical characteristics significantly predict participants' general classroom ICT usage. The results of the regression indicate that the four characteristics tested for explain only 6% of the variance ($R^2=0.06, F(4,110)=2.86, p<0.05$). None of the characteristics tested for was found significant. These are: Holding a BSc ($\beta = 0.48, p=n.s$), number of years of grade 12 PS teaching experience ($\beta = -0.05, p=n.s$), number of years of teaching experience ($\beta = 0.07, p=n.s$) and school’s quintile ($\beta = 0.22, p=n.s$). These findings suggest an increased possibility of generalizability to the larger population. It is believed, however, that even without generalizability, valuable insights can be learnt from the sample.

The findings of this study suggest that designers and distributors of relevant, quality ICT for SA PS teachers can be optimistic that a reasonably large number of SA PS teachers will use these resources, particularly those resources which do not require hands-on learner usage in class, provided that the teachers attend a well-conducted workshop about the resource. This is because many SA PS teachers are well predisposed towards ICT uptake. In other words, many have favourable attitudes towards, and perceptions of subjective norms and behavioural control regarding, ICT usage in teaching. This study also suggests that short-duration, once-off teacher workshops, which are logistically and financially much more viable than more extended teacher education programs, are not without efficacy in encouraging ICT uptake. However, this claim is largely limited to those teachers who are already predisposed to ICT usage by having positive attitudes, perceptions of subjective norms, and perceived behavioural control, regarding general ICT usage in teaching. Possibly teachers who are less well predisposed to ICT usage in teaching need engagement in more extended teacher education programs before they will use an ICT in their teaching. This suggests that different ICT teacher education strategies may be needed dependent on a teacher’s general beliefs about using ICT in teaching.
ACKNOWLEDGEMENTS

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REFERENCES


## APPENDIX 1

### Table 10 SA PS teachers’ general beliefs about using ICT in teaching

<table>
<thead>
<tr>
<th>Item in TPB</th>
<th>Question</th>
<th>Responses per option</th>
<th>Average rating (/7)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Very much: 7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>I don’t know / neutral: 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not at all: 1</td>
<td></td>
</tr>
<tr>
<td>Attitude beliefs (AB)</td>
<td>Using ICT will/has improve(d) my teaching</td>
<td>63</td>
<td>6.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>32</td>
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<td>I have easy access to a computer everyday</td>
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<td>I have easy access to a data projector / Smartboard</td>
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<td>I have easy access to computers for learner use in my teaching</td>
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<td>I have easy access to someone at school who can help me with ICT-problems</td>
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## APPENDIX 2

Table 11 SA PS teachers’ general usage of ICT in teaching

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<th>ICT general usage context</th>
<th>Question</th>
<th>Responses per option</th>
<th>Average rating (7)</th>
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<td>Very much: 7 6 5 I don’t know / neutral: 4 3 2 Not at all: 1</td>
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<td>classroom</td>
<td>I use ICT in my lesson preparation</td>
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<td>I use a computer in my teaching</td>
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<td>I use a data projector / Smart board in my teaching</td>
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<td>administrative and personal</td>
<td>I use email</td>
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<td>I use the internet</td>
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<td>I use my cell phone to go on the internet</td>
<td>I get learners to use computers in my teaching.</td>
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<td>I always use a computer for admin (e.g. entering marks / setting tests)</td>
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