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Eurasia Journal of Mathematics, Science and Technology Education (EJMSTE) is a monthly journal published online 12 times annually in **January, February, March, April, May, June, July, August, September, October, November, and December**.

EJMSTE is indexed and/or abstracted in **Cabell's Directory Index, EBSCO, SSCI® - Social Science Citation Index, SCOPUS, ERIC - Education Resources Information Center, PsycINFO, Current Contents - Social & Behavioral Sciences, EdNA Online Database, Education Research Index, Google Scholar, Higher Education Teaching and Learning Journals, Higher Education Research Data Collection, Index Copernicus, JournalSeek, MathDi, TOC Premier Database, Ulrich's Periodicals Directory and ZDB - Zeitschriftendatenbank**.

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Published by: **MODESTUM LIMITED**

Publication Office: Suite 124 Challenge House

616 Mitcham Road, CRO 3AA, Croydon,

London, UK Phone: + 44 (0) 208 936 7681

Email: [publications@modestum.co.uk](mailto:publications@modestum.co.uk)

Publisher: <http://modestum.co.uk>

Journal Web: <http://www.ejmste.com>

Twitter: <https://twitter.com/ejmste>

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ISSN 1305 - 8223

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## Enhancing Research Papers into Effective Teaching and Meaningful Learning in Mathematics, Science and Technology Education in Africa

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Ensuring the growth of effective science education across the African continent is of significant importance to addressing global issues in health, agriculture, economic development and environmental sustainability. There is now a significant number of researchers in science education for African contexts as universities proliferate across Africa and African postgraduate students study across the globe. While the challenges facing science education in Africa are many, an important strategy for supporting quality enhancement in teacher development and curriculum development is the provision of sound research into what works in the resource-restricted educational environments of Africa.

The ten papers in this Special Issue address a wide range of range of topics in Mathematics, Science and Technology Education (MSTE) in Africa. Several papers focus on teacher development so that teaching strategies can engage students in meaningful learning. As these studies show, learning activities for students of all ages need to be designed so that they immerse students in interactive, authentic scenarios. There can be no shortcuts. It is time that MSTE world-wide focused on this principle. Let me be quite clear: There is ample research evidence that a factory model of education is inefficient and minimally effective. If we want to use precious resources wisely, educational policy needs to focus on teacher development and curriculum development to produce learning environments where students are enthused by learning and can achieve the knowledge, skills and attitudes that will enable them to contribute to the myriad of problems facing countries in Africa and the entire globe. This requires a genuinely transformational approach to conceptualizing education systems, physical designs for schools, initial teacher education and ongoing teacher development. The world cannot afford to waste resources by perpetuating existing outmoded models for schooling and teacher education.

The small collection of papers in this Special Issue provides ample evidence that change is possible. These studies are on a micro scale; it is time to consider how to scale up our educational models so that all students can benefit from being in a meaningful and exciting educational environment. Let me briefly summarize some of the key contributions of these papers:

1. Clemence Chikiwa and Marc Schäfer explore the complex multilingual world that is ubiquitous across Africa. In multilingual mathematics classes, code-switching between English and local languages is common. In this complex linguistic environment, questions are often not phrased in higher-order cognitive terms. This highlights the need for close attention to language issues in teacher education.
2. Lydia Mavuru and Umesh Ramnarain tackle another complex aspect of African educational contexts. The interplay between socio-cultural beliefs and practices and conventional science is nicely illustrated in this study of three natural science teachers in township schools in South Africa. Recognizing and working with students' cultural beliefs about phenomena and practices can enhance student motivation and learning, and allow more active teaching strategies to take place.
3. Divan Jagals and Martie Van der Walt's paper focuses on how students can benefit from a design-based approach to planning their teaching. The paper highlights the need for teachers – both novices and experienced teachers – to consider theoretical principles in designing for learning. Iterative reflection on such design principles leads to better teaching strategies and a more nuanced theoretical understanding of teaching and learning.
4. James Ngugi and Leila Goosen's paper explores the complexity of individual innovative behaviour in undergraduate technology university students in Kenya, showing that both personal student attributes (exemplified in this study by self-regulated learning) and curriculum design contribute to the development of individual innovative behaviour. There is no 'one size fits all' recipe for higher education.
5. Vaughan van Appel and Rina Durandt focus on student attitudes in learning statistics. Student motivation in 'service' statistics courses is a global issue. This study provides clear evidence about this issue in higher

education in South Africa. In addition, there are attitudinal challenges with students who are in mainstream statistics courses. Indeed, food for thought and action.

6. Bernard Atsumbe, Samuel Owodunni, Emmanuel Raymond and Maxwell Uduafemhe compare scaffolding and collaborative teaching and learning strategies. They conclude that there is significant value in using collaborative work in teaching basic electronics in secondary schools in Nigeria. This is yet another study highlighting the need for students to discuss ideas and work together.
7. Hanti Kotze's study is in the area of mathematical modelling. Mathematics is often taught in an algorithmic fashion with an emphasis on set procedures and answers. In this study, the challenges that students have in applying mathematical models to real-world problems in biomedical technology are explored with obvious implications for classroom strategies and curriculum design.
8. Kgomotsego Samuel and Washington Dudu's paper offers a detailed look at the practice of four high-school science teachers as they begin to explore the value of role-playing in their classrooms. This is again evidence of the need for interactive and immersive teaching strategies.
9. Maria Catherine Kekana and Estelle Gaigher's study is another small-scale study exploring professional growth of four grade 7 science teachers, who need to negotiate challenges with resources and languages in their classrooms. For me, the key message is that a focus on teacher growth and development is more important than just decrying relatively poorly resourced environments.
10. Our final study by Sure Mupezeni and Jeanne Kriek has a poignant element. While out-of-school activities such as science fairs can motivate and enrich student learning and love of science, there is a stark contrast between support that urban and rural students receive in endeavouring to engage in such events. This finding is negative, but the positive aspect is that the infrastructure for science fairs exists and studies such as this one pinpoint strategies for the way forward.

It is of interest to explain how this Special Issue came into being. I have long been somewhat frustrated by the invisibility of the good work being done in Africa. MSTE research worldwide is dominated by research from the so-called developed nations, with the US, UK and Australasia being dominant players. My own background is varied with extended periods of time working in Africa, Asia and Australia, and several other shorter periods of time elsewhere. In many ways, my own career has straddled across the divide between the so-called developing and developed nations. I know there is significant MSTE research in Africa and this Special Issue highlights this nicely.

In collating the Special Issue, I took advantage of the ISTE International Conference on Mathematics, Science and Technology Education (MSTE) which provides a forum for practitioners from South Africa and other countries to interact and exchange ideas on issues relating to teaching and learning of mathematics, science and technology at all educational levels in South Africa and beyond. Since the inception of the conference in 2010, it has been hosted by the Institute for Science and Technology Education (ISTE) at the University of South Africa, the largest university on the African continent. The conference has hosted participants from all the continents of the world and has continued to reach out to a more diverse audience. Of the 200 abstracts received, about 100 are accepted for presentation (approximately 10% are from international participants), and about 50 papers are accepted after peer review for publication in the conference proceedings.

In selecting papers, I attended the 2017 ISTE conference. I went to the presentations of the papers that were ranked mostly highly during the peer-review process. I interviewed all the presenters, and finally selected ten papers on the understanding that authors would work with me to enhance their papers so that they would become a fresh contribution to the academic literature. All ten papers went through two rounds of review with me before they were sent out for peer review through the EJMSTE process. In several of the ten papers there is additional data, but all have much more strongly developed theoretical frameworks and discussion. Most are twice as long as the original conference paper. Eight of the studies are situated in South Africa; one in Nigeria and one in Kenya.

Many of the papers report research done during higher-degree studies, and hence one of the authors is an emerging scholar. One of my interests in the Special Issue relates to mentoring. How much investment is needed to support less-experienced academics gain skills in research and academic writing? I have had a long career as a Director of Teaching and Learning in universities in Australia and Hong Kong, during which time I have presented zillions of workshops on research, scholarship and academic writing that have been received well by participants. However, I have come to believe that much of my work has been 'edutainment' and I have seen insufficient evidence of follow-up in terms of real development in scholarship. The challenging and time-consuming process of individual mentoring does seem to have better pay-off.

I am grateful to colleagues world-wide who acted as peer reviewers for the Special Issue. This form of collegial service is often insufficiently recognized and yet it is the backbone of a global academic community. I am also deeply appreciative of the work of the editorial team of the *EURASIA Journal of Mathematics, Science and Technology Education* who have worked with the authors and myself to produce this Special Issue.

Finally, my heartfelt thanks to all the authors whose dedication to the refinement of their research has been done willingly and with diligence.

This collection is presented in the firm belief that it will be a useful resource for teachers, teacher educators and policy makers, as well as supporting further research on MSTE in Africa and elsewhere.

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# Promoting Critical Thinking in Multilingual Mathematics Classes through Questioning

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Received 30 January 2018 • Revised 16 April 2018 • Accepted 1 May 2018

## ABSTRACT

This study explores how teacher questioning was used to foster critical thinking in selected Grade 11 multilingual mathematics classes in the Eastern Cape Province. A mixed-method design was used to collect and analyse both qualitative and quantitative data through classroom observations and interviews of three purposively selected Grade 11 mathematics teachers during their teaching of trigonometry and analytical geometry. The study was guided by Bloom's revised taxonomy. The study found that teachers in these multilingual classes used lower-order levels of questioning during teaching. Higher-order questions, which research has shown have the potential of promoting critical thinking, were infrequently used during teaching. The paper concludes that, while all the categories of Bloom's taxonomy are important, the ones that are crucial in promoting critical and higher-order thinking required at Grade 11 were not adequately used. Suggestions for improving questioning in mathematics teaching are explored.

**Keywords:** code-switching, critical thinking, multilingual, questioning

## INTRODUCTION

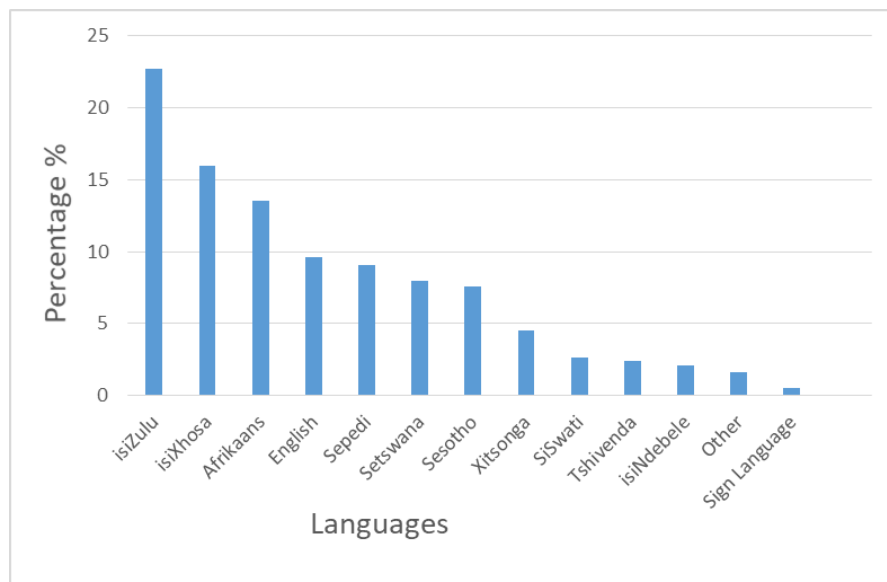
Oral questioning is crucial in the teaching and learning environment. Teacher questioning may be used as a teaching strategy in its own right, or as part of any other strategy, during instruction. Teacher questioning plays a critical role in mathematics classes for cultivating critical-thinking skills and thereby fostering deeper learning. The teaching of mathematics in South Africa's township and rural secondary school classrooms is usually conducted using the combination of languages spoken in a given community. This mix of the language of learning and teaching (LOLT) and indigenous languages occurs through code-switching which is an alternate use of two or more languages in a conversation or an utterance (Adler, 2001; Baker, 1993). Code-switching practices that incorporates indigenous languages are a feature of many South African classrooms where teachers and learners share a common home language, while the LOLT is English (Probyn, 2009). The use of an indigenous language by the teacher provides a communicative resource to facilitate learning when students lack proficiency in the LOLT (Then & Ting, 2011). Code-switching in this paper will refer to all the ways in which teachers orally use South Africa's indigenous languages during the teaching of mathematics.

The majority of learners in rural and township schools are taught mathematics in a language that is neither their first, nor one that is commonly spoken in the communities in which these learners live. This presents additional challenges associated with language uses during teaching. The LOLT is, in most cases, not developed to a level which these learners can comfortably use as a medium of instruction (Chikiwa & Schäfer, 2016). This presents teachers with a dual task of teaching mathematics in the LOLT and translating some concepts to the learners' first language in ensuring these learners grasp the mathematical concepts.

Teachers thus often ask questions in two or more languages through code-switching. In cases where the LOLT is not the learners' home language, many research studies in the field of mathematics education refute the assumption that the learners' home language is not necessary and should be ignored in multilingual classes (Setati, 2008). Some studies, for example Cummins (2000), proposed that learners who can converse in two or more

**Contribution of this paper to the literature**

- There are not many papers published in respected journals linking language use by teachers to critical thinking in multilingual classes.
- The benefits of code-switching as a potential teaching resource are discussed and suggestions made on how it can be used optimally in mathematics multilingual classes.
- This paper provides suggestions for improving questioning to promote critical thinking during mathematics instruction when teachers are teaching in neither their first nor the learners' first language.



**Figure 1.** Distribution of the South African population by the first language spoken (percentage) [Source: Statistics South Africa Census 2011]

languages and are permitted to use them during learning will perform better than their peers who do not. “The goal of education is for learners to ultimately think critically, learn, analyze, criticize and develop skills to solve familiar and unfamiliar problems. This implies that questions that encourage critical thinking should be part of the instructional repertoire of all teachers of mathematics” (Sullivan & Lilburn, 2002, p. 1). Thus, teachers’ language practices that provoke student thinking leading to deeper conceptual understanding of concepts are vital for promoting meaningful engagement and learning in mathematics classrooms.

The need to use learners’ home language to ask questions that promote deeper conceptual learning, long-lasting understanding and critical thinking, needs to be looked at more closely. Over the past three decades, research has increased on language-related factors and how they directly influence successful conceptual teaching and learning of mathematics in South Africa’s multilingual classes (Chikiwa & Schäfer, 2016; Setati, 2008). In an era where various societal and educational sectors are advocating visible transformation and quality decolonised education, language-related factors in teaching and learning at school level are paramount. Components that entail day-to-day functions of a mathematics class need to be investigated in promoting effective teaching and meaningful learning in mathematics in today’s secondary school mathematics classroom. Thus, in the light of teachers using pupils’ first language in South African’s mathematics classrooms, this paper focuses on how teacher questions posed in pupils’ home language through code-switching fostered critical thinking during teaching. We thus sought to address the following questions: **What teacher questions are prevalent in multilingual mathematics classroom? What forms of thinking do multilingual mathematics teacher questions promote? How can mathematics teachers use questions to promote critical-thinking during their teaching of multilingual classes?**

## BACKGROUND AND CONCEPTUAL FRAMING

### Language Landscape and Policy in the Eastern Cape Province

The advent of democracy in 1994 in South Africa led to the institution of 11 official languages (Figure 1), up from two (English and Afrikaans) that had official status during the apartheid era. While this was a positive initiative to ensure African languages are recognized and used for official purposes, it brought challenges.

Although all the 11 languages are official and equal under the constitution, their status in education is not equal. IsiXhosa, for instance, is spoken by around 80% of South Africans in the Eastern Cape Province (SA Statistics, 2012); this implies that isiXhosa is spoken as a first language by more than three-quarters of the population in this province, while English is spoken as a first language by only 5.6% of the total population in the province (SA Statistics, 2012). Therefore, the majority of rural and township schools in the Eastern Cape Province use the first language of the minority, which is English, as the LOLT at secondary school level. This can be seen in **Figure 1** which shows that only about 9% of South Africa's population speak English as their first language. We thus argue that the use of an unfamiliar language, English, continues to perpetuate inequalities through education. Owen-Smith (2010, p. 31) argued that "any child who cannot use the language which he/she is most familiar with (usually the home language), is disadvantaged and unlikely to perform to the best of his/her ability". The perpetuation of this unfortunate situation in South Africa is because of complex interactions of historical, political, economic and social factors over centuries of apartheid legacy.

The South African Language-in-Education Policy (LiEP) of 1997 mandates that schools can decide on their own language policies in consultation with parents. The LiEP of 1997, in essence, affords all students the right to be taught in the language of their choice. This legislative framework was enacted with an understanding that all indigenous African languages are capable of functioning as a LOLT. In most schools from Grade 4 in South Africa, the LOLT chosen by them is English despite the fact that the majority of learners have little exposure to English outside the classroom. This situation pertains in the Eastern Cape (Probyn, 2009); KwaZulu-Natal (Zuma & Dempster, 2008); Limpopo (Setati, 2005); and North-West (Carnoy et al., 2011). This implies that the official language policy of any region and the schools' position on the use of home languages through code-switching go a long way towards setting a context for the acceptance, rejection, systematic use or lack of use of African languages in educational settings (Mafela, 2009).

In the Eastern Cape, the empirical site of this study, most schools, including those identified for this study, have English as their LOLT despite the fact that the vast majority of the teachers and learners in these schools are isiXhosa first-language speakers. Alidou and Brock-Utne (2011, p. 160) identified that "studies related to language of instruction issues in post-colonial Africa unanimously suggest that the maintenance of languages such as English, French and Portuguese as dominant or exclusive languages of instruction creates teaching and learning problems in African schools". This is mainly because the majority of learners, and to some extent teachers in these communities, are not fluent in the LOLT resulting in communication, teaching and learning problems in mathematics classrooms.

The use of home languages as a medium for mathematics teaching and learning in South African schools is a much-debated topic. It has been observed that in general both parents and learners prefer English to be the LOLT (Probyn, 2009). This is driven by various factors from within and outside school settings. Probyn (2009) further suggested that English is likely to remain the chosen LOLT at school level and in teacher education institutions for the next foreseeable future. Setati (2008) argued that this is so because decisions on language policy in South Africa have to accommodate many competing historical, political, economic, social and educational factors. The result has been that the mathematics teachers' responses to the LOLT chosen by the school has been to use a combination of both the pupils' home language and the chosen LOLT through the medium of code-switching.

### Code-switching and Teacher Training in South Africa

Code-switching occurs when a teacher substitutes a word or phrase in one language with a phrase or word in a second language (Baker, 1993). It is defined as the use of more than one language in the same conversation or utterance (Adler, 2001; Choudhury & Bose, 2011). In South Africa, code-switching is now widely accepted and viewed as a legitimate resource for supporting school mathematics' teaching and learning in multilingual classes (Adler, 2001; Setati, 2008). It is considered as a practice in which teachers and their pupils who are learning mathematics in a second language can harness their main language as a learning resource (Setati, Adler, Reed, & Bapoo, 2002).

Wildsmith-Cromarty (2012), while acknowledging that teacher language practices such as code-switching in science and mathematics classrooms appears to be an already established practice, concluded that:

The challenge is, therefore, to understand how to harness this code-switching practice in a systematic way in order to enhance conceptual development in the mother or primary language. We need further research in order to ascertain whether the type of code-switching used by teachers truly builds an academic understanding of a concept, or whether it dilutes scientific meanings through the use of colloquial examples (p. 166).

Research is needed to analyse code-switching practices of mathematics teachers and interrogate how such practices build and support critical thinking in learners. This is because the choice of unfamiliar languages such as English, as the LOLT in rural and township schools, has been observed to significantly encourage mathematics teaching practices and strategies such as rote learning (Setati & Adler, 2001); safe talk (Chick, 1996); and recall,

memorisation and chorus teaching (Alidou & Brock-Utne, 2011). In such classrooms, mathematics teachers do most of the talking, relying prevalently on traditional teaching strategies.

Legitimization and use of code switching in mathematics teaching has been done with little or no attention to whether teachers were trained to teach in any other language except English or Afrikaans in South Africa. Probyn (2015, p. 220) concluded that “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 the classroom in ways designed to enhance opportunities to learn”. In other words, while the use of indigenous languages through code-switching is now a common phenomenon in South Africa’s mathematics classrooms (Rose & van Dulm, 2006), teachers are left to make their own day-to-day decisions as to when, where and how to code switch during teaching.

Wildsmith-Cromarty (2012) noted that most teachers did not acquire their mathematical knowledge through an African language since such languages were (and still are) not available as the LOLT during their period of training. This then makes it difficult for most teachers to transfer mathematical knowledge from English to an indigenous African language. Pimm (1987) emphasised that knowing the mathematics register in one language (for example, second language) does not automatically mean that the same individual knows this mathematics in another language (say her/his first language). Essien (2013) also supported the idea that teachers would need to be trained to teach in indigenous African languages. Teachers should not be expected to automatically and correctly teach or transmit into an African language what they learn in English. This problem is compounded by the fact that, in the context of this study, there does not exist an agreed mathematics register in isiXhosa.

Prediger, Clarkson and Bose (2012) concluded that because empirical analysis has shown that code-switching can enhance teaching and learning, it is important “... to develop and promote teaching strategies that make more purposeful use of code-switching and other links between first and second languages” (p. 6214). This implies that the use of indigenous languages through code-switching cannot be left to chance or to occur unchecked. There needs to be deliberate steps towards promotion of the systematic and purposeful use of indigenous languages through code-switching during teaching. While this study embraces the notion of code-switching as a legitimate strategy employed by teachers during teaching, we specifically wish to analyse how code-switching, as a linguistic medium, promotes critical thinking through questioning.

### **Critical Thinking through Teacher Questioning**

Critical thinking is a way of making reasoned decisions or judgements about whether a claim, statement or any phenomenon posed is false, true or partially true. In the teaching of content subjects like mathematics, critical thinking enhances creative problem-solving options as it encourages learners to seek new strategies (Paul & Elder, 2008). Elder and Paul (1994: p. 34) stated that “critical thinking is best understood as the ability of thinkers to take charge of their own thinking”. Such a skill helps learners to think of adequate support to any claim, or belief they might have about mathematics. Students who are taught to think critically take charge of their own thinking and are able to monitor it. According to Paul (1990), critical thinking is “thinking about your thinking while you’re thinking, in order to make your thinking better” (p. 91). Presented with various mathematical situations, a critical-thinking learner will always monitor her/his own thinking, making sure that no premature conclusion or solution is provided.

As argued by Duron, Limbach and Waugh (2006), critical thinkers raise vital questions and problems, they formulate these questions clearly to gather and access relevant information they would use to base their judgements. Bloom’s work, as revised by Anderson and Krathwohl (2001), identified six levels within the cognitive domain that forms the primary base on which some critical-thinking theory rests. The last three levels, analysis, evaluating and creating focus specifically on what learners require to think critically.

One way to promote critical thinking is to ask appropriate questions framed at the right cognitive level in the teaching and learning of mathematics. Critical thinking is characterized by a readiness to question all assumptions, an ability to recognize when it is necessary to question, and an ability to evaluate and analyse (Duron, Limbach, & Waugh, 2006). Critical thinking has been widely recognized and encouraged in education for many years, and using questioning techniques is one way that teachers can inspire critical thinking.

Questioning is indispensable and all-important in the teaching and learning of mathematics. Thinking is largely driven by questions and not solutions. Questions are mostly essential for driving thinking during teaching and learning. Paul (2007, no page) argued that “if you have very few questions, you have very little to think about”. While there are many strategies mathematics teachers may use to influence learners’ thinking, Clasen and Bonk (1990) posited that teacher questions have the greatest impact. For learners to think through their work or rethink their solutions to given mathematics tasks, they must be asked questions that stimulate thought. The level of learners’ thinking was found by Clasen and Bonk (1990) to be directly proportional to the nature and level of questions teachers ask.

**Table 1.** Revised Bloom's Taxonomy Adapted from Anderson and Krathwohl (2001)

Category	Generic skills	Sample Verbs
Remembering	Questions posed require learners to recall and remember learned information.	Choose, Cite, Define, Enumerate, Group, Label, List, Match, Name, Outline, Repeat, Select, Sort, State, Underline
Understanding	Question posed seeks for evidence of grasp of meaning of information by interpreting or translating what has been learned.	Account for, Classify, Convert, Define, Describe, Discuss, Estimate, Explain, Identify, Indicate, Interpret, Report
Applying	Teacher questions require learners to make use of information in a new situation from the one in which it was learned.	Apply, Calculate, Change, Compute, Construct, Draw, Illustrate, Interpret, Make, Show, Sketch, Solve
Analysing	Teacher questions require learners to break learned information into its parts to best understand that information in an attempt to identify evidence for a conclusion.	Analyse, Arrange, Calculate, Categorise, Compare, Contrast, Diagram, Distinguish, Investigate, Order, Relate, Sequence, Subdivide
Evaluating	Questions that require learners to make decisions based on in-depth reflection, criticism and assessment.	Assess, Choose, Compare, Conclude, Deduce, Determine, Differentiate, Evaluate, Infer, Measure, Score, Select
Creating	Questions that require learners to create new ideas and information using what has been previously learned.	Combine, Construct, Create, Design, Develop, Formulate, Forecast, Hypothesize, Organise, Predict

Questions that demand critical thinking drive thought processes to look beneath the surface of things. In the context of the mathematics classroom, critical thinking encourages teachers and learners to delve beyond the surfaced definition of a mathematical concept. It encourages teachers and learners to interrogate the multitude of complexities of a mathematical concept or idea. Paul and Elder (2008) observed that, unfortunately, some teachers are themselves not generators of critical questions and answers of their own. This can result in superficial engagement, thinking and reflecting on their own teaching of mathematics. Paul and Elder (2008) asserted that many teachers are purveyors of questions and answers of others, usually those of a textbook and other materials developed by others, not themselves. This makes mathematics teaching and learning an impoverished exercise that may not result in intended objectives such as producing learners who are capable of thinking critically. This study focuses on how teacher questioning in the home language through code-switching was used to cultivate critical thinking in Grade 11 mathematics multilingual learners.

### Bloom's Taxonomy

In this study, we used the revised Bloom's taxonomy to analyse teacher language in questions. Bloom and others originally developed this classification in 1956, which has since been revised by a number of other authors. Below is Bloom's taxonomy as revised by Anderson and Krathwohl (2001) with modified terms and emphases. This adapted Bloom's model has changed *knowledge* to *remembering* and the highest level of development is *creating* (synthesis) rather than *evaluation*. Verbs (indicating activity) are used in preference to nouns. This change was necessitated by the need to better reflect the nature of thinking defined in each of the categories.

A strength of Bloom's Taxonomy, in our view, is its ability to distinguish between higher- and lower-order thinking skills. This has assisted in raising awareness of the need to foster critical thinking during teaching and learning. It must be emphasized that Bloom's categories are not in themselves independent from each other, but are decidedly interdependent (Paul & Elder, 2008). A close analysis of the South African mathematics curriculum's specification of content to be taught (Department of Basic education (DBE), 2011) shows that Bloom's revised taxonomy has informed the framing, designing and organisation of objectives and assessment tasks. This is because the taxonomy reflects different forms of thinking and thinking as an active engagement hence the use of action verbs to represent intended cognitive processes instead of nouns.

Dori and Herscovitz (1999) argued that the questions teachers ask reflect the level of thought required from the learner to answer them. They can therefore be ranked. Both Bloom's earlier and revised taxonomy of cognitive objectives is useful in formulating and planning questions that require low to high-level thinking. The levels include: remembering/ knowledge, understanding/ comprehending, applying, analyzing, evaluating and creating (Table 1). Teacher questions that elicit responses in the knowledge, understanding, and application domains are frequently considered lower-order questions, while questions that require learners to analyse, evaluate, and create are considered higher-order questions. Teachers who create learning environments in which learners interact in the upper three levels are exposing their learners to critical thinking (Limbach & Waugh, 2010). While lower-order questions are equally important, higher-order questions elicit deeper and critical thinking, thus, teachers are encouraged to ask questions in these domains as well.

**Table 2.** Summary of Participants and Data Collected

Participant	Gender	Qualifications	Mathematics teaching experience	Levels taught	Teacher's first language	Number of 1-hour lessons observed	Number of end-of-lesson interviews
A	Female	B Ed Honours Maths	20 Years	FET and Senior Phase	isiXhosa	5	5
B	Male	B Ed Maths	18 Years	FET	isiXhosa	5	5
C	Male	B Ed Maths	18 Years	FET and Senior Phase	isiXhosa	5	5

Using Bloom's taxonomy, the analysis level requires teachers to formulate questions that demonstrate an ability to determine internal relationships, ability to visualize patterns, to question, classify information, concepts and theories into component parts. Teacher questions at the synthesis level require students to demonstrate abilities to relate knowledge from several areas within and outside a given curriculum to create new or original concepts or ideas. Bloom's revised version provides a valuable framework for mathematics teachers and curriculum designers to use to focus on higher order thinking (Anderson, 2002).

In this study, we are not claiming that once teachers incorporate questions that call for analysis, synthesis and evaluation, then, they are teaching learners to think critically. Rather, we are suggesting that teachers who at least use such questions during teaching are to a significant extent promoting critical thinking more than those who do not. It is widely acknowledged that lower-order questions limit learners' critical thinking and deep understanding of any subject matter including mathematics (Qashoa, 2013; Schneider, 2001).

## SAMPLE AND RESEARCH PROCESS

This study used a case-study approach that enabled the researchers to gain detailed knowledge of teacher language used during questioning when they were teaching geometry in multilingual classrooms. Three Grade 11 mathematics teachers from three districts in the Eastern Cape Province of South Africa were purposively selected to participate in this study. As explained by Denzin and Lincoln (2000), purposive sampling groups participants according to pre-selected criteria relevant to a particular research question. The following criteria were used to select the sample of teachers for this study:

- Mathematics teachers who were fluent in isiXhosa, the language of the majority of learners in their classes.
- Mathematics teachers who were teaching at Further Education and Training phase (FET) of the South African curriculum and were willing to participate in this study.
- Teachers with at least five years' experience of teaching mathematics at secondary level and therefore are well experienced. This is to minimize the possibility that their language practices might be due to lack of teaching experience or recognized qualification. Each of the three teachers had more than 10 years' mathematics teaching experience.
- Teachers who teach at schools where code-switching is prevalent.

Participants' identity remained anonymous; hence the three teachers were identified as Teacher A, Teacher B and Teacher C. All appropriate ethical considerations were followed in this study. The LOLT of all the three classes was English and the home language of the majority of learners was isiXhosa. Each teacher and her/his class constituted a case. A summary of participants is given in [Table 2](#).

Each teacher was observed for five consecutive one-hour lessons in a week teaching trigonometry and analytical geometry. Lesson observations were used to identify teacher language used to formulate questions during teaching. Lessons were video-recorded, focusing only on the teacher and the language used. At the end of each lesson, each teacher was interviewed, following up on the language teachers had used during the lesson. Thus, multiple sources of data were used ([Table 3](#)). The use of mixed methods in the collection and analysis of data enhanced the validity of results.



**Table 3.** Data-collection Matrix

Descriptors	Explanation of descriptor	Data sources		
		Observations	Documents collected	Interviews
Materials used during teaching	Teaching materials used by teachers to plan for teaching and to conduct teaching	x	x	x
Teacher Questioning (TQ)	Forms of language used by the teacher to structure questions during teaching.	x	x	
Teacher Explanations (TE)	Words used by participants to explain mathematical concepts.	x		x
Classroom Management (CM)	Language used by participants to manage their classes during teaching.	x		x
Classroom Assessment (CA)	Language used by participants to assess their classes during teaching.	x		x
Responding to Student Contribution (RC)	Forms of language used by the teacher to respond to learners' contributions during teaching.	x		x
Evaluative Remarks (ER)	Language used by the teacher to praise and compliment learners.	x		x

The videos were transcribed and analysed in two stages. First, quantitative analysis was done to identify the frequency of the home language used across various lesson categories (**Table 3**). These lesson categories were developed from Gumperz's (1982) and Mercer's (1995) work. These lesson categories were responding to student contribution (RC), teacher questioning (TQ), teacher explanations (TE), classroom assessment (CA), evaluative remarks (ER) and classroom management (CM). This was followed by the qualitative analysis using the revised Bloom's taxonomy (Anderson & Krathwohl, 2001). Key isiXhosa words and phrases used by teachers to formulate their questions were considered and categorised guided by generic skills and sample verbs provided for in **Table 1**. Our categorisation of teacher questions using this taxonomy was not exclusive and as such decisions as to where to categorise a question was only arrived at taking the context in which the question was posed into account.

Trends and patterns emerged during the quantitative analysis relating to all lesson categories across participating teachers. In the second stage of analysis, teacher questioning (TQ) trends and patterns that emerged in the first stage were followed up during the qualitative data-analysis process. The qualitative analysis used two teacher code-switching practices that emerged during the quantitative analysis process. These were referred to as borrowing code-switching (BCS) and transparent code-switching (TCS).

Borrowing code-switching strategies (BCS) referred to where a teacher would borrow from the English language either by retaining the English spelling or by adapting the phonology of the borrowing language (Baker, 2011). Transparent code-switching strategies (TCS) referred to all code-switching where meaning of terms was not concealed but noticeable, self-evident and transparent to students (Meaney, Trinick, & Fairhill, 2012).

## DATA ANALYSIS AND DISCUSSION

In the lessons observed, the three teachers were teaching trigonometry and analytical geometry. They were dealing with different concepts of these topics in the week they were observed. This paper focuses only on how teacher questioning was used to foster critical thinking during instruction of these lessons.

Of the six lesson categories considered in this study, the participating teachers used the home language more frequently during questioning (TQ) and explaining (TE) (**Figure 2**). The high frequency of questioning was important as supported by Paul (2007, no page) who argued: "At every point in class, at every moment of instruction, there is a question on the floor. Because if there is no question on the floor there is nothing to think about". At least 22% of the questions asked by the teachers in this study were presented in the home language. The learners' first-language frequency used during questioning by these teachers is presented in **Figure 2** (A 33%; B 41%; C 22%). This implies that if such frequent use of home language is utilized in a manner that may not promote critical thinking, many opportunities are being missed by these teachers to encourage and develop this essential skill in learners. The following sections focus on the qualitative analysis of some of the questions teachers presented to their classes.

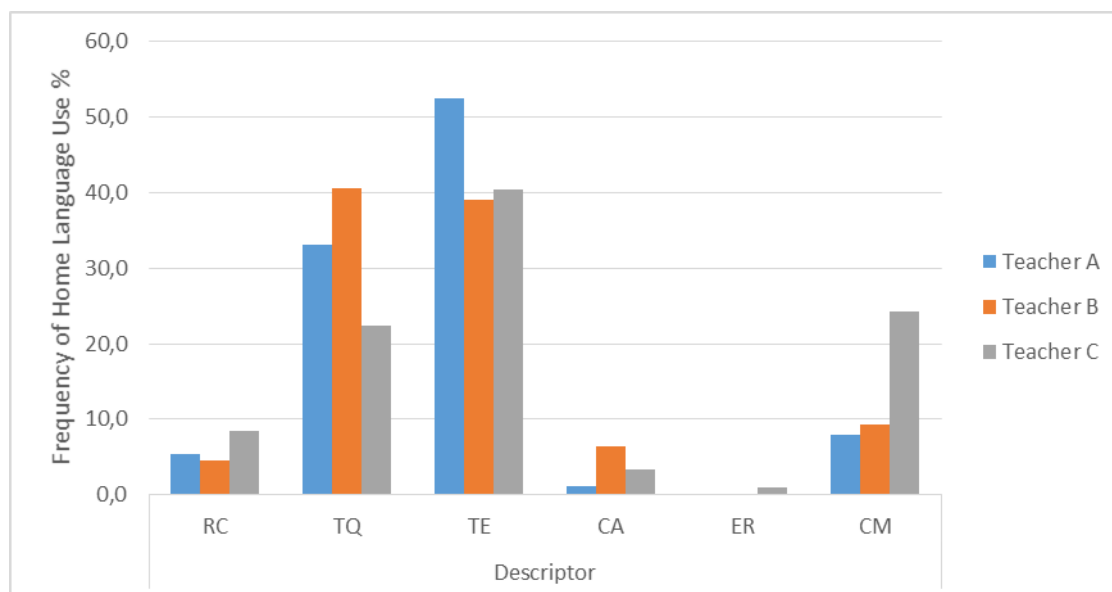


Figure 2. Teachers' Frequency of Home Language across Lesson Categories

Table 4. Excerpt 1

Teacher	Questions asked		Cognitive level of the questions
	Actual teacher language	English translation	
A	Sazintoni kanene nge-isosceles triangle?	What do we know about an isosceles triangle?	Remembering
A	U-BOD, can you see BOD, what type of an angle is BOD? / <i>Silence</i> / BOD siyambona u-BOD, uyintoni u-BOD pha kula-triangle? Niyambona u-triangle AOB, jonga kengoku u-BOD yena uyintoni kula-triangle?	BOD, can you see BOD, what type of an angle is BOD? /Silence/ BOD can you see BOD, what is BOD in that triangle? Can you see triangle AOB, now look at BOD, what is BOD in that triangle?	Remembering
B	Now we have a scalene triangle siyayibona? i-scalene triangle kuthwani?	Now we have a scalene triangle can you see it? What is it?	Remembering
A	Siyayazi i-arc? / <i>Yes</i> / Yintoni i-arc? Masijonge pha ebhodini, khanindi xelele i-arc pha? Yeyiphi i-arc?	Do we know an arc? / <i>Yes</i> / What is an arc? Let us look at the board, what is an arc? Which one is the arc?	Understanding
B	Nizibona ngantoni eza angles zi-equal kula triangle?	How can you identify the two equal angles in that triangle?	Applying
A	Uyintoni u-BOD pha kula-triangle? La-angle uyintoni pha kula-triangle? BOD uyintoni kula-triangle?	What is BOD in that triangle? That angle, what is it in relation to that triangle? What is BOD to that triangle?	Understanding
C	Singamfumana u-F lo, sisebenzisa eyiphi i-triangle?	We can find this F, which triangle can we use?	Understanding
C	Siyamfumana la-F using which triangle?	We can find this F using which triangle?	Applying

### Solving Triangles

Most of the questions Teacher A presented when solving triangles were those that required learners to recall information. In each case if the questions were phrased differently, they would have been classified in other domains of the taxonomy. An example is the third question in the extract below. If it was rephrased to "Why is this triangle a scalene?", then it would become an application question. Some examples are given in excerpt 1 (Table 4).

We found that questions presented in the learners' home language during teaching were mainly reduced to recall. Very few were of the application level and other levels above. The words teachers used in some cases reduced the level of questions to just recall and remembering of facts. The teachers asked the "what" questions most of the time using words like *ngubani* (what is), *uyintoni* (what is), *yintoni* (what is), *sazintoni* (what do we know), *kuthwani* (what is it). Not much mathematical thinking was thus required of students due to the nature of questions teachers presented during the teaching of how to solve triangles. Considering that these teachers were teaching Grade 11 classes, questions that required more comprehending, applying, analyzing and synthesizing were



Table 5. Excerpt 2

Teacher	Questions Asked		Cognitive Level of the Questions
	Actual Teacher Language	English Translation	
A	BC intersect with DC at G, and DE niyabona? Iphi i-intersection idibanaphi? Zidibana apha let's say ngu-G siyabona, right?	BC intersect with DC at G, and DE can you see? Where is the intersection? Where do they meet? They intersect here, let's say its G can you see, right?	Remembering
B	Niyabona u-AC apho kudibana khona u-AC lo-FG, siyabona?	Can you see AC, where AC and FG intersect, can you see?	Remembering
A	U-B ngubani, usezantsi komgca?	What is B, it is below the line?	Remembering
B	I-scale sala straight line sithe ngubani?	What did we say the scale of the straight line is?	Remembering
A	Explain the relationship of BC to C. Uyintoni u-BC to C?	Explain the relationship of BC to C. What is BC to C?	Analysing/ Understanding
B	How do you solve for AD to be the subject of formula? Besithe senza njani kanene? Apha sifuna u-AD abe yedwa nhe?	How do you solve for AD to be the subject of formula? By the way, how did we say we do this? Here we want AD to be alone, right?	Applying/ Remembering
C	Describe with reasons what is AD is in that triangle? Yintoni u-AD?	Describe with reasons what is AD is in that triangle? What is AD?	Analysing/ Understanding

expected to be presented to these learners. In our observation, critical thinking was thus not adequately promoted in these classes due to how teachers used isiXhosa during the teaching of this concept. Students were thus provided with limited opportunities to think critically during their learning of how to solve triangles.

The questions asked in this section did not allow learners to come up with their own ideas. They were mostly required to remember what they did in the previous lessons or just extract information from the given diagrams without much depth to promote critical thinking. If teachers give themselves opportunities to think carefully before the lesson about their language practices, they could use home language through code-switching more productively formulating higher-order questions that will eventually lead to critical thinking. This will help curb overuse of remembering, recall and rhetoric questions that are less beneficial in aiding and promoting critical thinking.

### Transparent Code-switching and Critical Thinking

A form of code-switching termed transparent code-switching, used by Chikiwa and Schäfer (2016), emerged strongly in this study. This is where isiXhosa terms posed no translation problems because of their familiarity to both the teacher and the pupils to formulate questions. In this section, we focus on some of the questions in which transparent terms were used. Of interest in this section was to see if teachers provided opportunities for critical thinking when they code-switched transparently. These are discussed below.

In excerpt 2 (Table 5), 'intersection' used by Teacher A, is translated to *dibana* (intersect). Teacher B also used this translation in his questioning when referring to intersection. *Dibana* (intersect) is an everyday word, which teachers use to mean meet, intersect, or add. The use of *dibana* (intersect) was transparent in this case for both teachers. The only challenge was that teachers reduced their questions to recall by adding other words like *siyabona* (can we see), *niyabona* (can you see) and *nhee* (right), *sithe ngubani* (what did we say it is) among others. In some instances, eliminating these words would place the original questions in a different cognitive level. The last three sets of teacher questions in excerpt 2 (Table 5) presents examples of some occurrences where isiXhosa use by the teachers resulted in the lower cognitive level as compared to English version of the same question. Teacher B required learners to 'make AD the subject of formula' and the translation required learners to remember what they had done earlier. The teacher asked 'Besithe senza njani kanene?' (By the way, how did we say we do this?) Teacher C asked a question that required learners to analyse and provide reasons but on repeating the same question in isiXhosa, learners were only required to demonstrate understanding of what AD was in the given triangle. The same was noted for Teachers A and B. In this study, we attributed such reduction in the cognitive levels to lack of teacher language use planning, absence of a formal mathematics register in isiXhosa at secondary school and lack of mathematics teachers' training on how to use isiXhosa to teach highly technical and strongly bounded subjects like mathematics.

In the excerpt 3 (Table 6), the transparent word for 'calculate' that teachers used was *bala*. *Bala* (calculate) is an everyday word that teachers and pupils use in and outside the classroom. It is also a word that pupils are introduced to in their early years of learning mathematics. Teacher B formulated a question at the synthesis level using *bala* (calculate). The question requires learners to build up a solution using whatever way they deemed fit. It is not prescriptive of the method they are to use. Nevertheless, in the next question, the same teacher asked a recall question using the same word.

Table 6. Excerpt 3

Teacher	Questions Asked		Cognitive Level of the Questions
	Actual Teacher Language	English Translation	
B	Masiyibale kaloku, yibale ujonge uba uzawufumana bani. Nifumene bani?	Calculate it and then check what you will get as an answer. What did you get?	Analysing
B	Wabala i-gradient, yangubani?	You calculated the gradient, what did you get?	Remembering
C	The wabala i-value ka- $\alpha$ yangubani?	You calculated the value of $\alpha$ what did you get?	Remembering
B	Itheni i-gradient?	What is wrong with the gradient?	Analysing
B	Kutheni ingafumaneki ngoku? Kutheni ingafumaneki ngoku i-gradient?	Why can't you find it now? Why is it that you can't find the gradient now?	Analysing/ Understanding
C	Simfumene kengoku u-A, what else?	So now we have found A, what else?	Understanding
C	Yeyiphi esiyifunayo? Umfumene u-A, nabani omunye, nabani?	Which one are we looking for? We have found A and what else?	Remembering
B	I-tan ye-angle of inclination ilingana nantoni?	Tan of the angle of inclination is equal to what?	Remembering
B	U-DR ulingana nabani?	What is DR equal to?	Remembering
C	U-angle ACD ulingana nabani kula diagram?	Angle ACD is equal to what in that diagram?	Remembering

Teacher B asked two analysis questions about the gradient. Such a mix of questions is to be encouraged in the teaching of mathematics. We argue that questions that span across all domains/ categories are necessary for a quality teaching process. While synthesis and analysis questions were evident in some of the teachers' language, they were practiced at minimal levels. All the teachers in this study frequently asked questions that mainly required learners to remember information. Even in circumstances where these teachers could pose higher-order questions, the use of some home language terms like *siyavana*, *sisonke*, *niyabona*, *nhee*, in many cases unfortunately reduced their questions to lower-order ones.

While teachers used terms that were transparent to formulate questions of a higher-order, they also used some transparent terms to formulate lower-order questions. Opportunities to encourage critical thinking were thus limited in these circumstances.

### Borrowing Code-switching and Critical Thinking

While all forms of code-switching strategies were evident in teachers' language during questioning, borrowing was most frequent. In this section, we focus on some questions teachers formulated through using a borrowing code-switching strategy.

In all the extracts in excerpt 4 (Table 7), most key terms such as 'cosine rule', 'vertically opposite', 'subtend', 'co-interior', 'transpose', 'angle of inclination', and 'obtuse' were all in their borrowed forms. These are highly mathematical terms first encountered in Grade 10 and are not used in everyday life. Each of these terms were also used precisely to formulate questions during teaching. Most of the questions formulated through borrowing were of various cognitive levels including higher-order. Some opportunities were presented by for learners to think critically. Some words like 'concept', 'condition', and 'deduce' are used in day-to-day lives of both the teacher and the learners. The term 'concept' (*ingqiqo* according to Teacher B) is more technical even though it is used in everyday life. Its isiXhosa equivalent is not common especially with learners that were part of this study.

Table 7. Excerpt 4

Teacher	Questions Asked		Cognitive Level of the Questions
	Actual Teacher Language	English Translation	
A	Kutheni ningazukwazi i- vertically opposite angles? Sitheni enge- vertically opposite angles?	Why don't you know vertically opposite angles? What did we say about vertically opposite angles?	Remembering
A	Teacher A: Kwi- alternate angles, corresponding angles ne- co-interior angles sizibona ngantoni?	With the alternate angles, corresponding angles and co-interior angles, how can we identify them?	Understanding
B	Teacher B: Izawuba ndawoni i-angle of inclination pha ku-line 1? I-angle of inclination izawuba ndawoni?	Where will the angle of inclination on line 1? Where will our angle of inclination be?	Understanding
B	So sawuqale sithini phaya? Si-transpose nhe? Then u-y ibengu $y = 3/2x + 5$ so what will be the gradient there?	What are we going to do first? We're going to transpose right? Then y will be $y = 3/2x + 5$ so what will be the gradient there?	Applying
B	I-Cosine rule esizawuyi deducer pha izawuthini? Izawuthini i-Cosine rule yethu esizawuyi-deducer phaya?	What will be the Cosine rule that we are going to deduce? What will our Cosine rule say?	Understanding
C	Teacher C: Yeyiphi lo-concept ndiyi sebenzisayo if i-condition yam iya tshintja ngoku ndinikwa two sides and included angle? (Lesson 3).	Which concept do I now use if the condition changes and I'm given two sides and included angle?	Evaluating
C	Why sisithi yi- obtuse angle? Why iyi- obtuse angle?	Why do we say it's an obtuse angle? Why is it an obtuse angle?	Analysing/ Evaluating
C	Iphi le iyi-subtendayo?	Where is the line that subtends it?	Applying

In the interviews, Teachers B and C agreed that there are words used in geometry which do not have an isiXhosa equivalent. Teacher B explains that the best way to teach such words is to pick illustrations from everyday life where such concepts are used. This results in describing the words rather than translating them directly. We noted that for higher-order questions to be fruitfully formulated in this way, teachers would need to think of such illustrations beforehand and not during teaching. Teacher B went on to say that it is not easy to pick appropriate words in the home language to use as translations for these concepts when formulating questions.

During the interviews, Teacher B was asked why he borrowed terms like gradient or cosine rule all the time when asking questions and he said: *"I was struggling to find the name for gradient, as a result most of the time I just borrow the word and just say i-gradient. I do not know any particular word that is used for gradient in isiXhosa."* Teacher A admitted that it was very difficult to find some appropriate mathematical words in isiXhosa to ask questions and hence her resorting to borrowing. In this study, we found that the borrowing strategy was prevalent during questioning because of, firstly, lack of directly translated mathematical terms in isiXhosa and, secondly, teachers used it to avoid lengthy illustrations of concepts, and lastly inadequate learner language competencies in these classes.

All participating teachers indicated that they do not plan for when and how they use isiXhosa for questioning. Teacher A said: *"I do not plan questions in Xhosa before my lessons. I just switch from English to home language whenever I find necessary."* This explains the prevalent use of the borrowing strategy observed. Teachers also indicated the lack of materials in isiXhosa. Teacher C mentioned: *"I do not use any materials in isiXhosa, I actually do not have any such materials. I rely on my own understanding of mathematics and my Xhosa knowledge."* Such lack of materials in the home language explains the high frequency of borrowing done by these teachers during questioning. While borrowing helped teachers formulate some higher-order questions, such terms remained essentially in English except for the prefix.

### Leading Teacher Questions

One aspect that became very evident in teacher questioning was the use of leading questions. These are questions phrased by participating teachers that suggested, prompted or encouraged the answer intended or desired by these teachers.

Teacher A used leading question during her teaching to seek confirmation of progress. The commonly used phrases were *'siyavana sonke'* (do you all understand), *'siyayibona sonke'* (can we all see), *'nhe'* (right) and this is shown in excerpt 5 (Table 8).

Table 8. Excerpt 5

Teacher	Questions Asked		Cognitive Level of the Questions
	Actual Teacher Language	English Translation	
A	So this is a right angle isosceles triangle siyavana sonke nhe?	So this is a right angle isosceles triangle do you all understand?	Remembering
A	Siyabona mos i-vertex ka-angle C? It lies on the circle, siyabona sonke nhe?	Can we all see the vertex of angle C? It lies on the circle, can we all see it?	Remembering
A	Nanku u-Z shape siyabona sonke? This angle C2 siyayibona sonke? Therefore angle A is equal to C2 siyijongile?	Here is your Z-shape, can you see? This angle C2, can we all see it? Therefore angle A is equal to C2 are paying attention?	Remembering
B	Siyayibona nhe? Siyibambile nhe?	Can you see that? Do you understand?	Remembering
B	Niyayibona nhe? Niyibambile nhe?	Can you see that? Do you understand?	Remembering
B	Iyavakala?	Do you understand?	Remembering
C	Arc AD niyabona mos? La-A lowana siyabona nhe?	Can you see arc AD? That A, can you see?	Remembering
C	We are told that this angle is 22 degrees, akunjalo?	We are told that this angle is 22 degrees, isn't that so?	Remembering

During Teacher B's teaching, commonly occurring words that he used to formulate leading questions included '*siyibambile*' (do you understand), '*niyibambile*' (do you understand), '*siyayibona*' (can you see), '*iyavakala*' (do you understand). In all these cases, questions phrased using these words solicited chorus answers. The pupils' chorus responses in these particular cases were then interpreted by the teacher as confirming students' understanding of the concepts. This is also evident in some of the other extracts taken from his lessons as given above. Teacher C did not use these terms as frequently as Teachers A and B. He used his own term '*akunjalo*' (isn't that so) together with '*niyabona*' (can you see) and '*siyabona*' (can we see) that other teachers also used.

Teacher B used statements like 'We all got the same thing, right?' In response to this, the class would give a chorus 'yes' except in very few cases where some students were brave enough to respond differently. Teachers A and B used '*nhe*' (right) and '*mos*' (right) in their questions and to end some of their questions changing these words, or omitting them would transform the question to a higher-order questions (see Tables 5 and 8). While these questions might have been meant to serve other purposes, they did not, in our analysis help much in improving and enhancing critical thinking during the teaching, in this case of analytical geometry and trigonometry.

## SUMMARY OF FINDINGS AND CONCLUSIONS

In this study, teachers spent 20% of their teaching time asking questions in isiXhosa, the learners' home language. The majority of the questions were of the lower-order level according to the revised Bloom's taxonomy. Such questions did not allow learners in these multilingual classes to come up with their own ideas that they could analyse and evaluate during learning. Thus, opportunities were missed to provide for learners in these classes to think critically.

Teachers in this study mostly asked recall and leading questions that did not give learners enough opportunities to think critically and find solutions on their own. A few questions that required comprehension and application, that is, those that required understanding and ability to use learned materials, were least asked in this study. Questions that only required remembering and application were responded to correctly without thinking and understanding. These questions ultimately promoted critical thinking the least during our observations. Questions that encourage learners to do more than just remembering and recalling known facts have a potential of stimulating critical thinking and deeper reasoning (Sullivan & Lilburn, 2002). Students should not be taught mathematics to only recite mathematical formulas or following algorithms and procedures, but to think critically and mathematically.

In this study, teachers formulated questions using some transparently code-switched terms that were familiar with their learners. While this practice is commendable, it was not widely practiced. In some cases, it was used in such a way that it reduced the level of questions to a lower level, which did not encourage learners to think critically. Teachers are encouraged to plan their questions in advance to ask those questions that will help learners to think deeply and critically about mathematical concepts presented to them. This study recommends careful planning of how and when specialised mathematical terms will be code switched during teaching. Collier (2011) advised that the use of two languages when teaching, if not carefully planned, may lead to pedagogically random code-switching which may not meet instructional objectives. Such planning can be aided by available teaching materials in learners' home language such as a multilingual learning and teaching resource book in English, isiXhosa, isiZulu and Afrikaans volumes 1 and 2 by Young et al. (2005, 2009) and multilingual mathematics dictionaries (for example, Wababa, Welman & Press, 2010).

During planning, teachers need to consider some thoughtful ways of introducing and integrating home-language mathematical vocabulary in their questions. Teachers should identify and highlight key words required to formulate questions of different cognitive levels. They should consider especially terms that are likely to recur, those with multiple meaning and those that may be problematic. Slavit and Ernst-Slavit (2007) advised that “identifying and carefully planning the use of any such words in a lesson can support students’ efforts to follow the subsequent line of discourse” (p. 8). Examples in this study include words like *bala* that could be interpreted to mean *calculate*, *find* and *solve*; *fumana* that also could be used to mean *find* or *solve*. We thus recommend that teachers’ code-switching should provide explicit, meaningful and well-timed language support to students for the enhancement of conceptual teaching in mathematics. Teachers should also be trained to plan how to formulate questions in their home language that will encourage critical and deeper thinking. Such training should be encouraged and incorporated in all structured pre-service and in-service teacher professional development programs.

The main advantage of questions that seek critical thinking is that they in themselves present an invitation to learners to engage in thinking. They cannot be successfully answered without one being largely involved in focused and deeper thinking. Critical-thinking skills are essential to every aspect of mathematics learning, this is because a learner who can think critically will be a better reader, writer, test-taker, and student inside and outside of the classroom (Schneider, 2001). Teachers are thus encouraged to use words in both languages that encourage critical thinking in multilingual classrooms. Huinker and Freckmann (2004, p. 355) acknowledged that “[b]y choosing our words carefully and using intentionally designed questions, we can engage and transform another person’s thinking and perspective”.

While all the three teachers in this study used borrowing code-switching in the formulation of questions of various cognitive levels during teaching, this was achieved because there was not much effort on the teacher’s part to find more transparent terms. They used the ‘easy way-out method’ of adding an isiXhosa prefix to an English term. Any group of people, like teachers in their classrooms, who regularly talk about mathematical concepts and ideas will have specific ways to succinctly convey their meanings (Meaney, Fairhill & Trinick, 2008). While these teachers felt the need for, and importance of, home-language use, their strategy was mostly through borrowing. Prevalent use of borrowing which is not transparent suggests the need for intellectualisation of indigenous African languages for them to meaningfully function as the LOLT at secondary school level. The only isiXhosa terms that were transparently used for mathematical purposes were those that teachers and the learners use in everyday life, and those mathematical terms that students were exposed to in the early years of their learning, that is, the Foundation Phase of the South African curriculum where the mathematics register is well developed.

This study concludes that if teachers of mathematics multilingual classes in township and rural schools continue to use predominantly lower-order questions in their pupils’ first language, they are depriving their learners of opportunities for meaningful and beneficial engagement with mathematical concepts. In the process, they unintentionally and unconsciously, perpetuate inequalities associated with use of the second language in the teaching and learning of mathematics. Teachers are thus urged and prompted to ask and incorporate a multitude of higher-order questions in isiXhosa that require learners to analyze, evaluate and create their own thinking and procedures whilst code-switching. This can be achieved through careful prior planning of questions in consultation with mathematical materials available in learners’ home language. Such practices will create rich teaching and learning environments that fosters critical thinking in multilingual mathematics classrooms.

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# Relationship between Teaching Context and Teachers' Orientations to Science Teaching

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Received 25 January 2018 • Revised 16 April 2018 • Accepted 1 May 2018

## ABSTRACT

The social context available to science teachers is known to influence their classroom practices or pedagogical orientation. This study investigated how social context influences pedagogical orientations at three township schools in South Africa. The study employed a qualitative case-study design involving three Grade 9 Natural Sciences teachers. Data collection involved pre-lesson interviews; lesson observations using the Reformed Teaching Observation Protocol (RTOP); post-lesson interviews; and analysis of documents. Data were analysed using a constant comparative method. Findings revealed that learners' socio-cultural practices, experiences and beliefs influenced teachers' pedagogical orientations in two important ways. Firstly, their teaching became more process- and activity-driven. Secondly, teachers' views about the goals of science teaching changed. Rather than a focus purely on curriculum coverage and exam preparation, building learner confidence, stimulating appreciation for the relevance of science, and motivating learners also became important. Implications drawn for in-service and pre-service teacher development programmes are discussed.

**Keywords:** pedagogical orientations, teaching and learning context, natural sciences

## INTRODUCTION

This paper reports on how teachers' knowledge of their teaching context influences their pedagogical orientations to science teaching. It is part of a larger study which explored the role contextual knowledge plays in the pedagogical content knowledge (PCK) of selected Grade 9 Natural Sciences (NS) teachers in township schools. Contextual knowledge referred to learners' Indigenous Knowledge Systems (IKS), which Odora-Hoppers (2001) defined as being characterised by its 'embeddedness in the cultural web and history of a people including their civilization and forms the backbone of social, economic and technological identity' (p. 74). As such, learners' IKS is expressed through their socio-cultural practices, experiences and beliefs. 'Township school' refers to an institution of learning which is located in the then underdeveloped urban areas allocated for Blacks during the era of apartheid in South Africa. It should be noted that in spite of the integration process that took place in the education sector after achieving democracy in 1994, schools which were previously reserved for a particular race still remain highly populated by that group (Chisholm & Sujee, 2006). As a result, township schools are populated with Black learners and are characterised by poor socio-economic status which Bush and Heystek (2003) condemned as perpetuating racial segregation. Because most parents are not gainfully employed or unemployed, they contribute minimally through school fees; hence, most schools are generally under-resourced and overcrowded (Onwu & Stoffels, 2005). In some cases, learners are constantly fearful of crime and violence (Hammett, 2008; Prinsloo, 2005).

Research has indicated that science teachers' practices are influenced by factors such as the social context of their work environment (Little, 2003), which is herein referred to as teachers' knowledge of the teaching context; their subject matter knowledge (Abell, 2007); general pedagogical knowledge (Çimer, 2007); their beliefs about teaching or orientations (Jones & Carter, 2007); and their PCK (Abell, 2007). In the study the relationship and interaction between teachers' knowledge of their teaching context and teachers' beliefs about the goals and purposes of science teaching and learning (teachers' orientations) was explored. The current paper does not focus

### Contribution of this paper to the literature

- In a science-classroom situation, science teachers face daunting challenges which: firstly, include recognising and understanding diverse learners' socio-cultural backgrounds in the classroom; and, secondly, finding the most suitable ways to manage these differences for effective engagement of learners with science concepts.
- Information on the role of context in shaping the pedagogical orientations of teachers towards science teaching informs teachers about appropriate pedagogical approaches in science teaching by presenting strong descriptions of dynamic features of teaching in socio-culturally diverse environments.
- In this way, the paper contributes information that empowers teachers who strive to meet the challenges of making science more comprehensible to socio-economically and culturally diverse learners.

on teachers' subject matter, pedagogical knowledge and PCK per se but they are inherent in the teachers' classroom practices.

## Teachers' Orientations towards Science Teaching

Teaching is a complex process that requires teachers to transform and apply knowledge from multiple domains; science teaching orientations have been found to be a critical component within the PCK of science teachers (Abell, Park Rogers, Hanuscin, & Gagnon, 2009). There are various conceptions of science teachers' orientations or teachers' beliefs about science and science teaching and learning. Some of these conceptions include pedagogical orientation (Ramnarain & Schuster, 2014); teaching orientation (Magnusson, Krajcik, & Borko, 1999); teaching approach (Anderson & Smith, 1987); conceptions of science teaching (Grossman, 1990; Hewson & Hewson, 1988); functional paradigms (Lantz & Kass, 1987); world images (Wubbels, 1992); preconceptions of teaching (Weinstein, 1989); and approaches to teaching (Trigwell, Prosser, & Taylor, 1994).

Teaching orientations are teachers' knowledge and beliefs about the purposes and goals of teaching science at a particular grade level; or simply a general way of viewing or conceptualising science teaching (Magnusson et al., 1999). In elaborating this definition, Friedrichsen, van Driel, and Abell (2011) conceptualised teaching orientations as beliefs that characterise goals, purposes of science teaching, and views about science teaching and learning, which include the nature of science and the nature of teaching and learning science. As a way of combining these definitions, Anderson and Smith (1987) referred to science teachers' orientation as a combination of teachers' cognition and action. Drawing on the different definitions above, the study conceived teachers' orientations as teachers' beliefs about the nature, goals and purposes of science, and how science teaching and learning occur in a particular learning environment such as a township school.

Magnusson et al. (1999) proposed nine different orientations to science teaching, namely:

- Process, where teachers engage learners in activities to develop thinking process
- Academic rigour, where teachers challenge learners with difficult problems and activities
- Didactical teaching through lecture or discussion, and questions directed to learners
- Conceptual change, where teachers engage learners in discussion and debate so that learners can construct valid knowledge claims
- Activity-driven teaching, where learners are involved in hands-on activities
- Discovery, where learners explore their thought process and interest
- Project-based science, where learners engage in investigative work to generate new information
- Guided inquiry, and open inquiry where learners are involved in identifying problems and solving them through investigations with and without teachers' guidance respectively.

These pedagogical orientations were used in analysing teachers' orientations in the study.

## Teaching Context in the Science Classroom

The study conceptualised teaching context as the social environment portrayed in the science classroom due to learners' socio-cultural practices, experiences and beliefs that develop as a result of learners belonging to specific cultural groups and living within specific environmental and social settings. These are aspects of IKS. It is necessary for science teachers to recognise diversity in their classrooms, meaning the differences in ethnicity, home language, socio-economic status and culture among learners (Lee & Luykx, 2006). Different cultures hold different norms, values and expectations which present strong influential guidelines on educational practices (Ho, Holmes, & Cooper, 2004). In this regard, socio-cultural factors which include language used in the teaching and learning

process; the learners' prior experiences; and their behaviour, attitudes and cultural values have been found to either facilitate or hinder learner interaction and active participation in class (Appleton & Harrison, 2001; Wellington & Osborne, 2001). As a result, science teachers face daunting challenges which, firstly, include recognising and understanding diverse learners' socio-cultural backgrounds in the classroom and, secondly, finding the most suitable ways to manage these differences for effective engagement of learners with science concepts.

Social context shapes the teachers' practice in terms of the kind of questions they ask, the ideas they reinforce, the tasks they assign to their learners and, most importantly, the teaching methods they will employ. Such a practice brings knowledge to the learners and assists them in understanding some of the problems in their communities or even explaining some of the issues or challenges they encounter in everyday experience. This is in accordance with the South African amended National Curriculum Statement (NCS) Grades R-12: Curriculum and Assessment Policy (CAPS) for Natural Sciences (DBE, 2011) which, in one of its aims, seeks to ensure that learners acquire and apply knowledge and skills in ways that are meaningful to their own lives. Specifically, the curriculum aims to equip learners irrespective of their socio-economic background with knowledge, skills and values that enable them to participate fully in society. In addition, as one of its principles, NCS values indigenous knowledge systems (IKS), acknowledging the rich history and heritage of the country, as important contributors to nurturing values. Such a stance brings to the fore aspects in science teaching which include the importance of NS teachers being knowledgeable about their learners' socio-cultural backgrounds and employing instructional strategies that engage learners in meaningful understanding. In addition, science teachers should always strive to gain skills to manage classroom discourse whereby learners' socio-cultural background is considered in teaching NS.

### Interaction of Context and Pedagogical Orientations

Teachers' pedagogical orientations are an important teacher knowledge domain, particularly in this study because teachers' beliefs about science and science teaching have a strong bearing on the kind of learning experiences and activities they select when considering their teaching and learning context (Magnusson et al., 1999). Teachers' consideration of the teaching and learning environment entail integrating learners' socio-cultural practices, experiences and beliefs when teaching particular NS topics. Teachers' recognition of the teaching and learning environment (context) is a key requirement for meaningful presentation of science to Grade 9 township learners. Mavuru and Ramnarain (2017) noted that science teachers' knowledge of the teaching and learning context enables teachers to engage in multiple pedagogical and instructional strategies which make science more relevant to the learners.

Arguably, science reforms fail to cater for the unique situations within specific classroom contexts characterised by learners' diverse socio-cultural backgrounds (Sarrason, 1996; Windschitl, 2002) since they disregard the influence of particular institutional contexts and the role of individual classroom teachers. Smith and Southerland (2007) found that the effectiveness of reform efforts is largely dependent on teachers' ability or inability to modify their fundamental or central beliefs about what it means to teach and to learn science. Teachers' beliefs shape them as to who they are as science teachers; and therefore influence their instructional decisions (Smith, 2005). Some researchers also noted that teachers' beliefs or personal theories about teaching and learning inform the decisions they make concerning teaching methods and strategies as well as the content they select for their learners in a science classroom (Brickhouse & Bodner, 1992; Smith, 2005).

Consequently, the success of any science reform programme depends on the teachers' ability to think differently about teaching and learning. This is because changing beliefs is thought to be a long-term sustained change in practice (Richardson, 1996). Because teachers invest emotionally and intellectually in their beliefs, they maintain their beliefs unless something challenges the existing beliefs the individual teacher holds (Pajares, 1992). There is also substantial evidence that deeply held subject-matter beliefs constrain science and mathematics teachers from adopting practices that conflict with their notions of what is appropriate science instruction (Fennema & Franke, 1992; Laplante, 1997).

Knowing how to teach specific content to learners of various abilities and in various contexts is a complex process (Abell, 2007). This study did not disregard this complexity. Instead, it sought to examine what science teachers knew about their learners' socio-cultural practices, experiences and beliefs; and how best they could use such knowledge to make science more relevant, thereby engaging their learners for improved understanding. In addition, teachers' orientations to science teaching and learning were envisaged as an important teacher knowledge domain. Hence, the study explored how teachers' integration of the learners' socio-cultural practices, experiences and beliefs shapes teachers' pedagogical orientations to science teaching. The researchers' argument is that teachers' knowledge of learners' socio-cultural background (context) should enable them to teach science concepts in a more comprehensive manner that enhances learners' understanding of science concepts. By taking the stance of focusing on the social context, the understanding was that science teachers' knowledge about their learners' socio-cultural backgrounds lays a foundation upon which teachers may understand the learners' expectations,

**Table 1.** Structure of teacher professional development

Stage	Activities	Resources
Before interviews	<ul style="list-style-type: none"> <li>Discussing the study's conception of learners' socio-cultural background.</li> <li>Brainstorming on the aspects of learners' socio-cultural practices, experiences and beliefs</li> </ul>	Concept map showing the aspects of learners' socio-cultural background
Before lesson observations	<ul style="list-style-type: none"> <li>Identifying learners' socio-cultural practices, experiences and beliefs suitable for incorporation in some NS topics</li> <li>Identifying suitable methods and activities for integrating learners' socio-cultural practices, experiences and beliefs in NS teaching and practise using them</li> <li>Planning lessons that incorporate learners' socio-cultural background in some NS topics</li> </ul>	Curriculum documents, lesson plans, learners' textbook
After lesson presentations.	<ul style="list-style-type: none"> <li>Identifying the successes and failures of the previous lessons</li> <li>Evaluating the teaching strategies and activities used in the previous lessons</li> <li>Identifying ways of improving the upcoming lessons</li> </ul>	Video clips of lessons observed

beliefs, attitudes, languages, systems and values that influence science teaching and the learning process (Suh, 2005).

This study, therefore, sought to answer the question: How does social context influence Grade 9 Natural Sciences (NS) teachers' pedagogical orientations at three township schools in South Africa?

## METHODOLOGY

### Research Design

The study employed a qualitative case-study research design, which allows an in-depth exploration of classroom practices, using multiple forms of data collection (Creswell, 2005). The emphasis in qualitative research is the key concept, idea, or process studied (Creswell, 2014). Using Yin (2003), a case-study design was suitable for the study because the focus was on answering how context influences Grade 9 NS teachers' pedagogical orientations to science teaching without manipulating their behaviour or the contextual conditions within the science classroom. The researchers sought to understand phenomena in context-specific settings (township schools), without manipulating the phenomenon of interest (Patton, 2002), but probed for deeper understanding rather than examining surface features (Johnson, 1995).

### Selection of Participants

Using Patton's (2002) notion of purposeful sampling, three Grade 9 NS teachers (one female and two males), each from three different township schools, were selected for this study. The logic and power of this type of purposive sampling lay in selecting information-rich cases for in-depth study, yielding insights and in-depth understanding rather than empirical generalisations. This enabled the researchers to generate meaningful and relevant data that answered the research question (Patton, 2002). The teachers had each taught Grade 9 NS in the same school for at least three continuous years, in which time they had an opportunity to interact and familiarise themselves with the community. The teachers (pseudonyms: Tembi, Thobile and Nyiko) were of different ethnic backgrounds and spoke different home languages (Sipedi, IsiZulu and Tsonga respectively). Their teaching experience and ages ranged from 4 to 33 years, and from 26 to 58 years respectively, and all had a professional teaching qualification (BEd degree or higher diploma in Education) from different universities in South Africa. They had also been trained on how to integrate learners' socio-cultural background in their teaching in a five-day professional-development programme previously organised by the researchers as shown in **Table 1**. Hence, they had an interest in the study. Most importantly, their learners came from diverse backgrounds, in terms of ethnic origin, home languages (IsiZulu, IsiXhosa, Sesotho, Setswana and Sipedi) and socio-economic background as explained earlier; all this formed a rich backdrop for the exploration of the influence of context on teachers' pedagogical orientations.

The three selected schools are located in a township south-west of Johannesburg and are within a radius of approximately five kilometres from each other. Therefore, the schools are located in almost the same community and generally enroll learners from township and informal settlements, all of which are poor. The schools were all non-fee-paying schools and hence depended on government support in terms of resources. It is important to understand the nature of the schools and communities in which the study took place. This is because the influence of schools and communities is difficult to separate as there is often an overlap between the school's socio-economic profile and that of the community in which the learners reside (Masondo, 2013).

**Table 2.** Description of the role of each subscale

Subscale Name	Description
1 Lesson design and implementation	Examined how the design and application of a lesson supported learner understanding by determining how the teacher organised the lesson to address learners' preconceptions from other classes and everyday experiences as opportunities to explore the topic or concepts
2 Propositional pedagogical knowledge	Measured what the teachers knew, and how well they organised and presented material in a learner-oriented setting
3 Procedural pedagogical knowledge	Measured the level at which learners were involved in scientific ways of thinking (predicting, estimating, hypothesising, negotiating ideas, and alternative ways of reasoning) as this is vital for developing critical-thinking skills in learners
4 Learner-learner interaction	Assessed the level at which learners actively communicated with one another as they explained their ideas and evaluated the ideas of others, which develops learners' critical-thinking skills
5 Learner-teacher interaction	Examined how the teacher fostered a culture where learners were comfortable to ask questions and had control over their own learning process

### Data Collection

For each teacher, three pre-lesson and three post-lesson interviews were conducted using a semi-structured interview schedule. Five lessons were observed for each teacher using the Reformed Teaching Observation Protocol (RTOP) (Sawada, Piburn, Falconer, Turley, Benford, & Bloom, 2000). This protocol is an observational instrument used by mathematics and science evaluators of professional-development projects to observe classroom content implementation, classroom culture and learner participation (Sawada et al., 2000). The instrument has five subscales and is calibrated with five indicators from 0, which means 'never occurred', to 4, which means 'very descriptive'. **Table 1** shows the description of each subscale.

A non-participant observation method was used to capture real classroom practices hence providing a complete picture. Each teacher was observed whilst teaching concepts on reproduction, blood circulation, nutrition and energy. Only some aspects of the concepts taught on reproduction and other different topics had been discussed during professional development but the rest were simply according to the schools' work plan. Thus, there were a total of nine pre-lesson interviews, 15 lesson observations and nine post-lesson interviews for the three teachers. Teachers' reflections provided a means through which researchers could determine teachers' thinking in terms of their pedagogical orientations and practice.

### Data Analysis

Video and audio recordings of the lessons, as well as the pre- and post-lesson interviews, were analysed using the constant comparative method (Merriam, 1998), which allowed for themes and patterns to emerge from the multiple sources of evidence. Analysis involved identifying evidence of any of Magnusson et al.'s (1999) nine different orientations. Data collection and analysis occurred concurrently to enable collection of adequate and relevant data (Baxter & Jack, 2008), to answer the research question: How does social context influence Grade 9 NS teachers' pedagogical orientations at three township schools in South Africa? This also enabled the researchers to build coherence during the data-interpretation process (McMillan & Schumacher, 2001).

Analysis began with the first interviews and observations and field notes as they were made; this occurred daily throughout the research process. This included the writing of conceptual memos which gave theoretical insights that emerged from the researcher's interpretation of the field notes. After repeatedly reading the interview transcripts and field notes, and reviewing the videotaped classroom observations, emergent patterns or trends were identified, coded using Saldana's (2009) manual coding system and then linked to representative quotes or incidences. These themes or 'recurring regularities' were first identified separately for each teacher for the lessons taught and interviews. The three cases (teachers), Tembi, Thobile and Nyiko, were later compared in a cross-case analysis. Similar codes and categories from one data set were merged with those from other data sets. Any discrepancies identified required that the researcher recode the data or even engage the participants to ascertain what they meant if it were interview data, or what they intended to do if it were data from lesson observations. As a result, two common themes were identified.

**Table 3.** Coding and analysis of data from lesson observations

Codes	Categories	Emerging themes
i) Value alternative ways of solving problems ii) Use of learners' prior knowledge and experiences iii) Exploring learners' belief systems iv) Use of learners' involvement v) Community involvement vi) Use of different representations vii) Prediction of results of investigations	i) Investigations involving classifying sources of energy learners use at home ii) Constructing models and different ways to present concepts and results iii) Peer coaching among the learners iv) Involving learners in an activities to identify positions of structures struck by lightning. v) Performing food tests using traditional food items from different ethnic groups.	Teacher involvement of learners in <b>hands-on activities</b>
i) Exploring the use of different strategies ii) Outlining procedural instructions in some cases iii) Involving learners in enacting their thought processes iv) Learners constructing knowledge v) Teacher enhancing learner investigations vi) Teachers listening to learners' ideas vii) Content integration with other disciplines viii) Learners trying different ways to understand concepts	i) Exploring beliefs on lightning, witchcraft, curses and ancestral spirits when teaching concepts on reproduction such as fertility and surrogacy. ii) Employing argumentation as a strategy when teaching male reproductive system and circumcision iii) Using authentic problems and learners' everyday life experiences for discussion in class iv) Providing opportunities for learners to reflect and evaluate their original ideas based on the newly acquired knowledge v) Teacher using prompts and open-ended questions vi) Knowledge construction involved negotiation between different ideas	Teachers involving learners in reflecting and evaluating the relationship between their socio-cultural practices, experiences and beliefs and scientific knowledge. Teachers involving learners in <b>process-oriented learning</b>

**Table 4.** Coding and analysis of data from interviews

Codes	Categories	Emerging themes
i) Plan authentic problems ii) Teachers plan content beyond the level of the grade iii) Thought-provoking activities iv) Questions requiring critical thinking	i) Content and activities that consider learner involvement and use of the socio-cultural knowledge, experiences and practices ii) Teacher preparation of higher-level content in anticipation to explain learners' ideas. iii) Engaging learners in thought-provoking discussions and promoting critical thinking	Planning authentic teaching and learning experiences that are <b>process-oriented</b> and <b>activity-driven</b>
i) Active role of learners in the learning process ii) More teacher-learner interactions iii) Engaging learners in alternative activities iv) Learners respecting and appreciating each other's contributions	i) Ideas originating from the learners ii) Learners involved in intense discussions that questioned the conventional ways of doing things iii) Learners exploring alternatives ways of solving problems and questioning teacher methods iv) Learners' appreciating each other's contributions towards understanding of scientific concepts	Reflecting on the <b>goals and purposes</b> of science teaching and learning as that of making learners understand and apply knowledge and skills in their lives

## RESEARCH FINDINGS

The purpose of the study was to explore how the teaching and learning context influences Grade 9 NS teachers' pedagogical orientations at three township schools in South Africa. In analysing data from both interviews and lesson observations, teachers showed how they designed thought-provoking teaching and learning activities and discussions that promoted critical thinking. Teachers employed teaching approaches and strategies that valued learners' ideas and stimulated them to question conventional ways of doing things, thereby exploring alternative ways of solving problems. Analysis of the data revealed that learners' socio-cultural practices, experiences and beliefs influenced teachers' pedagogical orientations in two important ways. Firstly, teachers' orientations to science teaching became more process-driven and activity-driven, which in turn influenced what specific content they chose to teach, and determined the approaches they used in science instruction. Secondly, teachers' views about the goals and purposes of science teaching changed from simply covering the curriculum requirements and preparing learners for examinations to that of building learner confidence, developing learner appreciation for the usefulness of science in their lives, gaining understanding and motivating learners to continue studying science.

**Theme 1:** *Integration of learners' socio-cultural practices, experiences and beliefs influenced the teachers' views about the goals and purposes of science teaching, from that of content coverage when preparing learners for examinations to that of making science more relevant and applicable to the learners' lives beyond the science classroom.*



The three science teachers, Tembi, Thobile and Nyiko acknowledged the importance of considering learners' poor socio-economic background when designing their teaching so that every learner in the class would be considered. As such, they selected and used examples familiar to learners, and also made efforts to consider and understand the learners' feelings and situations where possible. The teachers therefore set realistic submission deadlines of learner projects and work done at home, particularly knowing that learners came from informal settlements where there was neither electricity nor internet facilities. Because teachers allowed learners to bring in and articulate their various experiences, teachers were cautious not to side-line or marginalise input from some of the learners. They structured their lesson content, activities and examples that took note of, and also addressed, learners' everyday experiences related to the scientific concepts taught. The focus of the teachers' practices changed from simply teaching curriculum science concepts as outlined, to that of facilitating learner understanding, building learner confidence, developing learner appreciation for the usefulness of science in their lives, and motivating learners to continue studying science. The following sections show how teachers achieved this.

### **Use of Socio-economic Disadvantage as a Resource in Teaching Forms and Sources of Energy**

Teachers strongly acknowledged the importance of being knowledgeable about their learners' living conditions and challenges. They were positive that the various experiences learners go through at home provide rich resources when teaching certain topics such as energy. In a pre-lesson interview, teachers were asked about the role of knowledge of learners' socio-economic background in their teaching and gave the following responses:

Tembi: Because some learners have coal stoves, fires and paraffin at home and others come from informal settlement [name supplied] and have solar panels installed for them, this becomes so easy when we talk about renewable and non-renewable sources.

Thobile: We talk about sources of heat where some learners mention heaters to warm themselves in winter and the other group mentions '*mbaula*' [coal heater], cookers for cooking and coal stoves for the same function.

Both teachers indicated that their learners understand well when teaching concepts using such familiar examples. Tembi indicated that her teaching also becomes much easier when she employs resources and examples familiar to the learners. She mentioned that the teaching of the concept of renewable energy with the use of resources familiar to learners was far easier and more palatable to learners than handling the topic on nuclear energy, which is difficult for the learners to conceptualise, since it is unfamiliar. The teacher elaborated that no matter how many examples or cases she used to make learners understand the idea of nuclear energy, the learners always showed lack of understanding as they would regurgitate information from their notes word-for-word when answering examination questions. This was contrary to how the learners answered questions on renewable energy when sources were familiar to them.

The above discussion shows that it is important to note that familiarity with learners' background made it easier for the teachers to relate to learners' experiences during the teaching and learning process. The teachers did not view learners' poor backgrounds as barriers to the teaching and learning of science. Instead, they embraced them and used them as platforms to make learners understand sources of energy.

### **Use of Analogies to Teach Blood Circulatory System to Learners who Believed in Blood as a Sacred Substance**

In an effort to make science concepts more understandable to their learners, the teachers used different analogies and approaches to teach the blood circulatory system. For instance, Nyiko asked learners about their socio-cultural practices or beliefs that are associated with blood and its movement in the body. Many learners pointed out that they had witnessed the slaughtering of animals such as goats for rituals and the blood used to cleanse any evil spirits in the home and family. Nyiko questioned how blood can perform such a function. One learner said: 'Sir, blood is stored in the heart and the heart is full of love.' Other learners laughed but some believed him and added that smearing blood around the home is like spreading love which repels evil. It shows how learners try to explain their cultural practices using common sense. This was complicated by a learner who pointed out that a '*sangoma*', meaning a traditional healer, once smeared blood on his older family members in order to scare witches away and others said that it was meant to give them strength. These learners viewed blood as a sacred substance, due to their socio-cultural practices and beliefs.

Nyiko asked those learners how blood can transport oxygen which is required by all body tissues if it is stored in the heart in response to one of the learners' responses above. Such learner 'conceptions' only surfaced because

the teacher allowed them to share what they knew before exploring the concept. In reaching out to learners, Nyiko drew on learners' everyday experience when he used an analogy to explain the movement of oxygenated and deoxygenated blood in the human blood. Analogies help learners relate the scientific concepts learnt to familiar and relevant experiences and knowledge. This is what the teacher said:

Nyiko: You see we have roads, streets and paths where we walk and drive our cars, the same applies in the circulatory system, the veins and arteries are the roads and streets. We have roads where cars move in one direction and the others move in another direction. The same applies to deoxygenated and oxygenated blood which moves in different blood vessels.

These were some of the learners' remarks: 'Ooh, that's it' 'Yes, that makes it clear'. Nyiko jokingly said: 'Though blood is such a magical substance as indicated by some of your experiences, it is still a medium of transport in our bodies.' It shows that certain concepts are abstract for learners to conceptualise, so using examples familiar to them enhances learner understanding. Analogies could also dispel some of the socio-cultural beliefs learners hold which can impede the acquisition of proper scientific concepts. The analogy used drew on an experience that most learners are familiar with, the roads and stream of vehicles travelling on the same road in different directions and carrying different people and goods. However, it should be noted that this analogy helps learners when the sole purpose is to demonstrate the element of direction of flow of blood, and the need for blood vessels. It also demonstrates that as blood circulates it carries different components much like cars, buses and even motorcycles moving along the same highway. However, learners may end up thinking that oxygenated and deoxygenated blood carries the same substances since roads generally have similar vehicles. Learners may also think that blood movement stops at certain points in the vessels as cars do at robots. In addition, nothing is said about the need for a pumping mechanism that makes the movement continuous and in this case, the place of the heart in the circulation system.

In order to make sure that the learners correctly connect the circulatory system to the system of vehicles on the road, Nyiko asked learners to identify features in the road system that correspond with those in the circulatory system. The learners shared information in pairs. One pair asked: 'Sir what do drivers in the cars represent?' Nyiko involved one learner who answered: 'It is the heart.' This meant that there were many hearts in the human body, a misconception which some learners would carry away unless addressed. Failure by teachers to appropriately lead learners to map features of an analog with features of a target (concepts) could result in learners misunderstanding the concept being taught. Through discussions, the teacher and the learners later agreed that the driver in each vehicle is like the force in each blood vessel which causes movement of the vehicle and goods, in the same way that there is force that propels blood throughout the blood vessels. It was important for the teacher to explain to the learners that an analogy helps to understand some aspects of the concept but not all.

**Theme 2:** *Integration of learners' socio-cultural practices, experiences and beliefs influenced teachers' orientations to science teaching in that their teaching became more process- and activity-driven.*

Because teachers were knowledgeable about learners' socio-cultural practices, experiences and beliefs, they made efforts where possible to harmonise the conflict between learners' worldviews and science. The teachers' focus was on facilitating learner understanding of concepts. They designed their teaching in such a way that learners were involved in process- and activity-oriented learning. It was commendable to observe how each individual teacher formulated completely different activities and engaging learners in experiences different from those used during professional development or adapting familiar ones to suit their classroom contexts. In fact, incorporating learners' socio-cultural practices and beliefs made teachers modify their teaching strategies, explore different ways of explaining concepts, design experiments and improvise in order to enhance learners' understanding. Science teaching was contextualised and done specifically for a particular group of learners. When asked about how they would use the knowledge brought in by the learners, the three teachers pointed out that: firstly, they would explore learners' experiences before dismissing them; and, thereafter, they would adjust their instructional approaches to the benefit of the learners. It means therefore that these teachers would always be willing to adopt suitable strategies and prepare activities which engage learners fully in the learning process. They used scientific explanations that relate to learners' worldviews, thereby harmonising the conflict between learners' belief systems and science knowledge where possible. One of the teachers, Tembi, pointed out that her teaching of scientific concepts helps learners understand and makes them dismiss or make sense of their previously held ideas. It should be noted that the teachers acknowledged the role of professional development in equipping them with knowledge and skills of making concepts more comprehensible to their learners. Teachers also expressed their uneasiness in discussing scientific concepts and learners' opinions that conflict with their own beliefs and practices. An example is of Tembi (a staunch Jehovah's Witness), who felt that she was compromising her religious beliefs particularly when teaching about abortion and contraceptives under the topic reproduction, which learners showed much interest in.



## Involvement of Community Members in the Teaching and Learning of Fertility in Women and Different Forms of Contraception

It was quite notable that Indigenous Knowledge Systems (IKS) were often brought into the science classrooms which compelled the teachers to explore different ways of presenting science concepts. Learners' indigenous knowledge on causes of infertility and traditional methods of contraceptives encouraged teachers to create partnerships with community members and facilities, such as clinics and resources that provided learners with access to knowledge and experiences that extend and complement learning experiences in a science classroom. In this regard, the teachers acknowledged the community role in building up scientific knowledge. The teachers pointed out that they always encourage learners to discuss the science concepts they learn at school with their parents and other adult community members at home. The teachers ascertained learners' pre-instructional knowledge arising from their socio-cultural practices, experience and beliefs as the basis for teaching new content. Ascertaining learners' pre-instructional knowledge prevented distortion of new concepts in cases where prior knowledge from their socio-cultural practices, experiences and beliefs conflicted with new content (Mansour, 2010), as learners tend to transform meaning based on previous knowledge (Upadhyay, 2005).

### Allowing Learners to Share Everyday Experiences during the Teaching and Learning Process

Sometimes teachers did not probe for any beliefs or experiences learners had regarding the topic being taught; instead learners would ask questions to ascertain some of the anomalies they experience in their communities. For example, in a lesson on reproduction in humans, a learner from Tembi's class inquired, 'what is the length of pregnancy in humans?' which some of the learners thought was obvious. The learner pursued her issue when she queried whether it does not depend on the individual since her cousin was pregnant for a year. Another learner concurred as she pointed out that her neighbour always has pregnancies whose period stretched way beyond nine months. One learner shouted, '*Bamuthakathile!*' meaning they bewitched her. The teacher allowed learners to discuss it among themselves, which gave the teacher time to recollect and identify the most plausible explanation to give to the learners. At the end, the learners were asked to identify the gestation periods of different animals. In those discussions the learners realised that the information on the gestation periods of other animals was a result of observations and experiments in the same way the gestation period of humans was determined. When asked in the post-lesson interview about the witchcraft issue mentioned in the lesson, the teacher hoped the activity and discussion about explaining the anomaly could have dispelled such beliefs. She was not, however, certain about that. On that note, one of the teachers honestly explained.

Nyiko: To be honest with you when it comes to things involving witchcraft, I cannot help the learners much because I also don't understand whether it really happens or not.'

### Use of Argumentation in Harmonising the Two Knowledge Domains, Learners' Worldviews and Science Knowledge

In a lesson that followed after exploring the causes of infertility, Thobile asked learners to discuss the following: In some countries some women are paid to donate eggs that scientists can use in their studies; is it a good thing? One boy said, '*amaeggs azopela*', meaning eggs will be depleted. The teacher responded by asking, 'How many eggs can a 30-year-old woman produce every month for 10 years?' This was meant to show learners that quantity was not an issue here. Some learners argued from an African traditional perspective when they said, 'Such women will fail to reproduce again'. The teacher inquired how that is possible. One learner retorted, 'The ancestors will be angry, they are the ones who give you all the blessings'. The teacher's question, 'How can scientists research on reproductive diseases if there are no egg donors?' triggered class discussions to support critical thinking. Another learner said, 'Those women who donate eggs should not be paid at all since they are helping out'. In addition, some learners started discussing the different reproductive diseases in their families and communities and how scientific knowledge has helped in curbing such conditions. This kind of teaching made learners aware of the need to gather enough information that they can use to make well-grounded decisions, which is an aspect of teaching critical and analytical skills. The teacher's provision of an authentic problem stimulated learners to be actively engaged in the learning process and challenged them intellectually. They realised that sometimes they cannot follow their socio-cultural beliefs and practices without assessing the pros and cons as they realised that their current ideas cannot solve the problem at hand (Goodrum, Hackling, & Rennie, 2002).

As a result, argumentation facilitated the active participation of learners, with the teachers even acknowledging in the post-lesson interviews how their classroom discourse had changed ever since they started incorporating context in their teaching. In addition, this encouraged learner knowledge construction in that each time one learner introduced their ideas, the others would use that information to improve their own line of argument which meant

that, in the end, the desired concepts would be grasped. Throughout the process, the teachers were inculcating the tenets of the nature of science in their teaching, such as the tentative nature of scientific knowledge and its subjectivity, as different learners' views were considered based on the merit of their evidence or reasoning.

### **Classifying and Performing Food Tests using Traditional Food Items from Different Ethnic Groups**

In a lesson on nutrition, Thobile tasked learners to identify one family member or neighbour and identify what they ate and the quantities they required. Thobile tasked learners to analyse the diet in terms of whether it was healthy or not. In particular, learners needed to identify the socio-cultural practices, experiences and beliefs of the person, as people from different cultures or ethnic groups have their specific food preferences. They were also tasked to compare the diet with that of the learner from the suburbs (more socio-economically advantaged community). The learners would then determine the missing food types or remove the unwanted ones in order to make it a healthy diet. Such an activity helped to conscientise learners of the importance of healthy diets and that the palatability of food does not necessarily transform into required nutrients. The teacher explained in a post-lesson interview that his learners tend to bring in the salted and sweet food items to school, which are unhealthy.

In a related lesson, Nyiko also assigned learners a project on classifying their own traditional food into the different main classes as outlined in the curriculum. **Table 4** shows some of the types of diet that the class compiled together after presenting their different traditional food items in class.

The table shows that different ethnic groups have different traditional diets which can be classified into different food groups. The teacher helped learners to apply the knowledge they had learnt about healthy diet to classify their own traditional food.

In a practical activity, Thembi involved learners in carrying out food tests using some of the traditional food brought by learners. In this practical activity learners were excited as they were sceptical about some of the traditional food brought by others. In this way the learners realised that even traditional food has nutrients which are important for the body. Thembi indicated in a post-lesson interview that the activity helped learners appreciate their own culture and those of others and dispelled the inferiority complexes normally displayed in classes due to different ethnic origins and different socio-economic backgrounds. These findings are an indication of the need for teachers to acknowledge and incorporate diverse learners' socio-cultural backgrounds as most learners would feel a sense of belonging to a community of science learning. Importantly, it helps the teacher to embrace every learner so that no learner would feel marginalised or left out. In showing the importance of such a harmony, Aikenhead and Jegede (1999) maintained that learners' success in science is dependent on how learners perceive cultural differences between their lived experiences and those in the science classroom. Teachers should therefore carefully assist learners to connect what they experience at home with the new content learnt in the science classroom (Aikenhead & Jegede, 1999).

In spite of the teachers' practices, they expressed reservations about integrating social context into their teaching of every topic. In addition to always making efforts to understand the interaction between IKS and Western science and at the same time their ability to manage such classroom discourses, teachers expressed concerns that intense discussions in class consumed too much time to allow coverage of content within the stipulated time frame. These results are corroborated by the findings from Mensah's (2011) study where the teachers acknowledged the challenges of incorporating their learners' socio-cultural practices, experiences and beliefs in order to connect science to real life. However, Thembi, the youngest and least experienced teacher was more adventurous and took an initiative to engage learners in discussions of issues that are normally shied away from, and this improved learner participation and their eagerness to learn more.

## **DISCUSSION AND IMPLICATIONS**

Teachers' knowledge about the teaching and learning context influenced their orientations to science teaching in that their teaching became more process- and activity-driven. Science teachers' orientations to science teaching have been found to be a critical component within the PCK of science teachers. The research findings show that context influenced teachers to reframe the instruction of NS as a social process of knowledge construction rather than as a body of factual information provision. As a result, the teachers repositioned their role as that of facilitator of learning and not as source of knowledge (Meyer & Crawford, 2011). Only two of the orientations by Magnusson et al. (1999) were identified and the other seven - academic rigour, didactic, conceptual-change, discovery, project-based science, open inquiry and guided inquiry - were not. This could be because of the nature of the concepts taught or the limited number of lessons observed. In some cases there were elements of inquiry but were not really explored much in the lessons presented to warranty reporting.

Teachers made efforts to provide opportunities for learners to discover information on their own through exploring, hands-on activities and enactment of learnt science concepts. These process-oriented lesson presentations specifically related to learners' prior knowledge, helped learners to change their conceptions (Abrams & Hogg, 1998). This agrees with the social constructivist notion that science teachers' attention should be on the process of science rather than just the content (Leach & Scott, 2008). As Basili and Sanford (1991) contended, if learners understand the process of science, they are better equipped to acquire knowledge on their own. The results of the study showed that engaging learners during the teaching and learning process helped teachers to ascertain learners' difficulties which forced them to design appropriate instruction. Such tailor-made instruction was found to improve learner performance in other studies (Savinainen & Scott, 2002), as learners would engage more with the material to be learnt.

The research findings provide insights and implications to both in-service and pre-service teacher development programmes. Teacher educators should create a context where prospective teachers are engaged, challenged and stimulated to reflect upon their personal conceptions and ideas (Thomas & Pedersen, 2003). Notably, these beliefs influence the teachers' acquisition of new knowledge, its interpretation and organisation (Mansour, 2010). It therefore justifies teacher educators' role in designing their curricula with a focus on helping teachers to modify their pedagogical orientations that suit the kind of teaching and learning environment in which they are likely to work.

In particular, teacher educators should teach with a focus on exploring the different contexts that their pre-service teachers would work in after qualification. As such, these pre-service teachers would be engaged in a process of repositioning their pedagogical orientations throughout their teacher professional development. In this way, the teachers' orientations to science teaching would be challenged and reconstructed throughout their studies. A point to note is that teacher beliefs/ orientations to science teaching have been found to be tacit, enduring and changing them is thought to be a long-term sustained change in practice (Abell, 2007; Richardson, 1996). In addition, prospective teachers' beliefs were found to act as filters in preventing them from considering unfamiliar and discrepant ideas (Kellner, Gullberg, Attorps, Thor n, & T rneberg, 2011; Thomas & Pedersen, 2003), hence the need to explore them during teacher professional development. Overall, this would have a positive influence on the development of other teacher knowledge domains (subject matter knowledge, pedagogical knowledge and PCK) (Magnusson et al., 1999).

Teachers' knowledge of the teaching context influences teachers to employ pedagogical approaches which Bennett, Hogarth, and Lubben (2003) described as context-based, applications-led, or as approaches that promote links between science-technology and society (STS). This calls for in-service teacher professional-development programmes to consider exploring orientations of practising science teachers in different teaching contexts with the hope of assisting teachers redefine their beliefs about the goals and purposes of science teaching. This is particularly pertinent in South Africa, where educational reform envisions schooling in which all learners, irrespective of their background, have the opportunity to succeed (Frempong, Reddy, & Kanjee, 2011).

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# Design Principles for Lesson Study Practice: A Case Study for Developing and Refining Local Theory

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Received 31 January 2018 • Revised 8 May 2018 • Accepted 9 May 2018

## ABSTRACT

The practice of Lesson study in the field of mathematics education is often restricted due to the assumptions of education theory and its impact on the teaching and learning practice. The paper discusses possible constructs and design principles that arise from such preconceptions of Lesson study. By incorporating these principles into the facilitation of Lesson study, a stronger community of practice can be established. As part of an undergraduate mathematics education methodology course's content, two volunteer groups of students specialising in Grades 4 to 7 mathematics participated in the design and study of a research lesson. The aim was to determine how these students depict Lesson study in theory and practice through a-priori design principles, and how these principles led to the identifying of constructs that produced new principles that can inform the development of a (new) Local theory. The results indicate that the design principles produced constructs of metacognitive skills, metacognitive language and metacognitive networking that can be theorised. Recommendations follow on how Lesson study practice can be theorised about and facilitated through these design principles.

**Keywords:** mathematics education, lesson study, design-based research, design principles, metacognition

## INTRODUCTION, BACKGROUND AND ORIENTATION

Lesson study is a form of professional development established first in Japan and can be used to develop a community of practice. Prospective teachers need to be prepared to, at least, manage the pedagogical challenges of their future classrooms and, as such, Lesson study is identified as one of the mechanisms that can assist in preparing students for the mathematics education profession (Cajkler, Wood, Norton, & Pedder, 2013). Lesson study practice, therefore, offers teachers an opportunity to plan together and observe each other's lessons and then reflect on them to refine the lesson plan where needed. Lesson study is also underpinned by design principles that should be infused within its practice, including the setting of long-term goals, collegial planning of lessons, and the development of teaching and learning resources. The principles for the design of these experiences are prescriptive and provide guidelines for facilitating teaching and learning experiences in a particular context and educational milieu. The lessons offer both teachers and educationists an opportunity to reflect on and theorise about the conceptual change that may take place during the design, implementation and refinement of the lesson.

The discourse of reflective practice is embedded in a range of education programmes including undergraduate teacher education. Graham and Phelps (2003) have demonstrated the need for new programme development; especially in mathematics education such development requires the output of teachers who are able to learn to teach mathematics as specialists of both *mathematics in practice*, and of *mathematics' teaching and learning theory*. As guidelines for this professional development, some recommendations from past research exist. A report by Woodrux, Cox, Tosa, and Farrell (2013), for instance, suggests that teachers, programme administrators, policy makers and educational researchers should embed and promote reflective practice in the professional development of teachers. By implication, such reflection would kindle *metacognitive skills* and so teachers should become metacognitively aware of the skills they possess to think about teaching and learning mathematics. In addition, a

#### Contribution of this paper to the literature

- The contribution of this paper to the literature lies in the attempt to offer Local theory with constructs otherwise unknown in metacognition research.
- The paper offers constructs that can produce new principles to inform the development of a (new) Local theory.
- The findings identify these constructs as metacognitive skills, metacognitive language and metacognitive networks.

case study by Chval, Pinnow, and Thomas (2015) reported that teachers need to learn how to focus on *language* while teaching mathematics. Recent work by Wilkerson (2017) and Baber (2017) also encourages the idea of expanding the *network* of mathematical capital through *service-learning*, whereby preservice teachers become involved in community projects where they can serve the teaching practice and learn from the experience. To acquaint teachers with the necessary professional-development skills, Mevarech and Kramarski (2014) concluded that the important role metacognition plays in such undergraduate programmes should be anticipated. The assumption is then that *metacognition* promotes learning, and that learning in a professional community enhances metacognition (Mevarech & Kramarski, 2014), thereby making such learning a valuable asset in the conduct of Lesson study.

### Background and Context of the Study

Place value is a topic prescribed as part of the course work of the fourth-year BEd module. It builds on one of the topics in their previous year's subject methodology course; namely, common errors and misconceptions with regard to place value. There is a scarcity of literature on the conceptual and theoretical considerations for developing theory, and facilitating Lesson study through such theory, especially in the context of mathematics education. Jagals and Van der Walt (2016) explained that theory development plays a crucial role in the understanding and development of new pedagogy; thus to develop educational theory, design principles are needed to inform the development of a theory-based learning context. The primary research question that this study then sought to answer is: *What design principles emerge from Lesson study's practice, and how do these principles inform Local theory?* The research reported here is founded predominantly on the preconceptions and underpinning epistemologies of Lesson study's theory and practice. Through design-based research and a qualitative approach, the partaking students' (undergraduate preservice teachers of mathematics education in Grades 4 to 7) involvement in Lesson study was interpreted by means of the design principles that emerged from their Lesson study practice.

### Four Stages of Lesson Study Practice within the Course

Students who enrolled for this module received a detailed assignment schedule relating to the content of Lesson study and metacognition. Four Lesson study stages and a combination of Lesson study principles were aided in the development of Local education theory. The following four stages of Lesson study practice were implemented:

*Stage 1 – Investigation:* Students had to study literature on Lesson study and metacognition in mathematics education; they studied the South African mathematics curriculum on the topic of place value from Grade 1 to Grade 9; they chose Grade 4, 5, 6 or 7 to do a research lesson; they studied the context of a rural township school and they set both short-term and long-term goals. A lesson plan then had to be developed and presented through a series of design sessions. This was done locally, and the data obtained was used to improve instruction within these lesson plans. Once the lesson plan is presented, its effectiveness may be weak; it was expected that there is at least precision in the written and oral presentation of the lesson and that clear coherent arguments will reflect the style, sophistication and appropriateness of the presented lesson.

*Stage 2 – Planning:* The lesson plan may depend on local materials and resources and this might transform over time. During this stage it was expected that there is a clear understanding of the local needs in terms of resources and the necessary knowledge and skills to develop and design (new) resources. Students had to collaboratively plan a lesson with appropriate activities to engage students in a series of lesson design sessions (mimicking the lesson study stages). These activities had to be relevant to students' context; they presented aspects of their planned lesson weekly to the whole group of final-year students to get peer and lecturer feedback.

*Stage 3 – Research lesson:* The lesson plan caters for continuous local adaptations, including innovative design changes and changes in theory. Because of its flexibility, the lesson plan is expected to undergo improvement. It was expected that the presented lesson contributes to the needs and the level of conceptualising the mathematical texts and materials. The research lesson: one of the lesson study group members presented the lesson while the rest of the group observed the lesson. The changes (or innovations) made to the lesson plan may be adapted. For example: if prior knowledge is assessed in the beginning of the lesson and it is clear that the route of the planned



lesson cannot be followed, possible structures should be in place to accommodate anticipated processes as early as possible. Both basic and deep levels of reflection occur at this stage as the needs, resources and classroom experiences are aligned with personal beliefs, values and expectations.

*Stage 4 – Reflection:* The knowledge that is produced from the locally presented lesson embodies an understanding of the knowledge and skills needed locally. Students reflected on the lesson and refined the lesson plan. Observations from the classroom experiences can be reflected upon to accommodate change in needs and instructional approach in order to improve the teaching and learning experiences. It was expected that the local adaptations, improvements and diverse understandings of the product (or outcomes) of the lesson can be used to warrant its effectiveness locally. Reflections on the meaningfulness of the presented lesson are measured against a specific prescribed set of criteria or outcomes.

Based on these four lesson study stages, the following a-priori principles were considered important for the design of the courses' learning experiences. In Stage 1 long-term goals are considered for learning and development where existing curricula and policies are studied. In Stage 2 students should plan to conduct a research lesson and to collect data through reflection and observation. The data were then presented and discussed in terms of their implications. In Stage 3 the learning resources, teacher resources and teacher knowledge are strengthened to improve the effectiveness of the lesson through refinement and reflection. In Stage 4 the lesson plan reveals and promotes students' thinking whereas the resources support learning collegially. Motivation, improvement, collaboration and a sense of accountability is valued and is associated with knowledge of the subject, didactics and goals.

## CONCEPTUAL-THEORETICAL FRAMEWORK

Mathematics education theory can be understood as the field in which mathematics and education theories are infused. The aim is to understand and improve the teaching and learning of mathematics in context-sensitive ways (Sriraman & English, 2010). Lingard (2015) stressed the importance of developing mathematics education theories that filter the purposes, nature, and intent of theory to model and define relationships between the teaching, learning and doing of mathematics. In addition, it is the researchers' philosophical stance, or contextualised worldview, that contributes to the design of Local theory (Cobb, Jackson, Smith, Sorum, & Henrick, 2013). When the focus is not to instruct students about the theory of Lesson study, but rather to explain the nature of the relationship between the constructs that emerge from its practice, then Local theory can be developed and refined.

### Metacognitive Skills

Metacognition is commonly defined as "thinking about thinking" (Flavell, 1979, p. 908). Studies by Mavarech and Kramarski (2014) revealed that teachers, and mathematics teachers in particular, seldom effectively actuate their thinking processes. They show an inability (or unawareness) to plan, monitor and evaluate their own and their students' comprehension successfully. Teachers who do show initiative in applying their metacognitive skills show this usually during lesson planning as they outline the activities that will follow, and during lessons they are likely to adapt their instruction as needed. However, a consequence of a lack of the expression of one's thinking can hinder the students' exposure to metacognitive-oriented teachers who model the act of assessing one's thinking and understanding and follow-up with an opportunity for their students to implement metacognitive skills themselves.

When examining and investigating metacognitive skills, a vital undertaking is being mindful of students' expertise in monitoring, thinking about and managing their own particular intellectual procedures of learning (Schoenfeld, 2016). Metacognition follows up on the perceptions and manages the ideas based on reflection. Metacognition can, in this manner, be seen as a person's own support of information and administration of one's reasoning. Metacognitive skills therefore allude to comprehension and controlling information (Schraw & Moshman, 1995). However, a particular kind of language and networking is needed in Lesson study as Jagals and Van der Walt (2016) showed in the case of narrative focus-group interviews. Reference is therefore made, in this regard, to language and networking in a more transformative and metacognitive fashion, a refined way in which the Lesson study participant becomes aware of their language of thinking and expressing of their thoughts, and the networks (interpersonal, social and socially regulated) that they exhibit when doing so. These kinds of expressions are referred to as metacognitive language and metacognitive networks.

### Metacognitive Language

A language is needed to express ideas. Farrell (2015) claimed that the absence of understanding one's thinking is the result of no language of thinking being involved, and so no communication about the ideas in one's mind can exist between the metacognitive knowledge and regulatory domains. Such a language of the mind can be expressed

through the term *metacognitive language*, and represents the particular language used when reflecting on experiences or experiences of thinking. Ducasse, Denker, and Lienhard (2009) proposed the notion of exhibiting your reflections, for example, expressing your thinking verbally (spoken language) or non-verbally (through art, mystic and gestures). Such a language has different functions in mathematics education; Nachlieli and Tabach (2012) demonstrated three types of discourses in mathematics education, discussed next.

*Ideational and mathematical language* refers to the ideas that emerge as students discuss mathematical concepts and the use of appropriate strategies. This often involves algebraic symbols or expressions, graphs or tables in real-world problems. This language builds on ideas (as in constructivism) and is observed to have a gradual increase in the level of difficulty as more complex mathematical ideas emerge from discussions. This serves as an imperative description of mathematical ideas. *Interpersonal and social language* refers to informal and formal use of words, indicating ownership or sharing of ideas. These ideas can refer to various scenarios where the individual asks for assistance, explains their own thinking or translates or rephrases an idea for someone else. *Textual and pedagogical language* includes the terms or words used which relate to one another. For instance, a teacher can acknowledge a learner's choice of use of visual or symbolic representations. The pedagogical aspect implies forged linguistics between the tasks and strategies that refer directly to education as a task of teaching and learning. Textual and pedagogical language serve as functions of discourse in mathematics education (Nachlieli & Tabach, 2012). For a deeper elaboration on these discourses the reader can refer to Jagals (2015).

It appears that metacognitive language is closely coupled with a networking nature (considering the social attributes linked to it). In doing so, the expression of one's thinking through a metacognitive language hints of the hidden role of the networks that emerge through this language.

### Metacognitive Networking

Theories of networking usually include the characteristics that arise from thinking. A network as a set of actors (or capacities such as skills and thoughts) that are linked due to a type of relationship that exists between them (i.e. cognitive, social and affective relationships). The actors could exist as nodes joined through links. In terms of metacognition, network aspects can be informative about the nature of teaching and learning when individuals collaborate during a group task (such as Lesson study). Examples of such a meta-language include: *I think ... I know ... I feel ...* The particular roles that individuals portray in these networks of thinking, knowing and feeling, as well as the thinking and reflecting processes, can be portrayed as metacognitive networks, as Jagals and van der Walt (2016) showed in their analysis of metacognitive networks. Pasquali, Timmermans, and Cleeremans (2010) conveyed this thinking about networks in terms of networks' metacognitive nature as such networks can help answer the question: *What is the cognitive nature of the relationship of this thinking?* Such networks imply that individuals in a group setting take on certain roles (in terms of social network analysis, e.g. a coordinator, a socially weak member, a gate keeper). They can also portray specific individual metacognitive networks that are interpersonal in nature, such as reflecting on one's own thinking (see Jagals, 2015, p. 165-169 for detailed portrayals of these networks), and networks that represent socially shared metacognition, as in the case of theory of mind (Papaleontiou-Louca, 2008). There are three types of metacognitive networks that exhibit the levels of the locale of metacognition. These include networks on a social level as a social network, networks on an interpersonal level and networks on a socially shared level. The *social network* portrays the different social roles and the dynamics between participants in this network. The *interpersonal metacognitive* networks reflect the unique metacognitive characteristics that all members of the social network hold (e.g. being a compulsive planner, a mediator of knowledge within the group). The *socially shared metacognitive network* shows how ideas are collaborated and shared, how one individual plans for and with another. This third metacognitive network type represents the metacognition shared by two people involved in the same activity.

### Underlying Assumptions of Lesson Study

Craddock, O'Halloran, McPherson, Hean, and Hammich (2013) proposed that teachers' professional development and the reinforcement of teaching and learning practice strengthens the value of theory by highlighting its implications in educational practice. While education theory influences teaching practice, it also reveals knowledge about teaching and learning experiences, and puts forward alternative practices and ideas that result from these experiences (Bernath & Vidal, 2007). This pragmatic view on the development of effective teaching and learning experiences relates to the Japanese model of adapted Lesson study. To apply, understand and explain constructs as components of the knowledge that emerge from and result in theory, Bernath and Vidal (2007) argued that such theories shift from traditional educational pedagogy towards practically relevant educational theory. Lesson study can then be facilitated by aligning its principles in practice and revisiting them with theory. Nickerson and Whitacre (2010) claimed that the knowledge and skills of conducting Lesson study include planning, analysing, testing out, reflecting on and refinement of lessons.

In doing so, the value of Lesson study in mathematics education seems indispensable. In support of this, Cobb et al. (2013) suggested that pedagogies should be re-examined to bring theory and practice together, and to develop and refine theory. Furthermore, to conduct Lesson study requires deep reflection as a metacognitive skill when planning, monitoring and evaluating the effectiveness of the lesson. Flavell (1979) defined this reflection as metacognitive skill (also see Frith, 2012). Likewise, individuals can find it challenging to express their thinking about these metacognitive skills if they have to explain their reasoning to other members of the Lesson study group. During such collaboration on the design and refinement of lessons, group members (usually between five and eight) plan together, observe and reflect on each other's inputs and learn to work collegially in a network. Theory development to facilitate Lesson study therefore includes these skills to hypothesise about the route to follow and what learning trajectory to plan for. Stemming from these two assumptions, design principles can be developed to facilitate Lesson study in undergraduate teacher-preparation programmes.

### Concepts Underpinning Lesson Study

Lesson study originated in Japan as an inquiry model for developing professionalism of teachers. Referring to the adapted Japanese Lesson study model implies that in other contexts, such as a South African mathematics education course, the Lesson study model can be adapted to suit the particular needs of the setting or milieu (or content) in which the Lesson study practice takes place. Participants involved in the Lesson study process typically exhibit collaborative, planned, reflective and observational qualities during the stages of Lesson study. These qualities also underlie the particular constructs identified in the introduction of this paper, including: metacognitive skills (Flavell, 1979); language (Chval et al., 2015); and networking (Baber, 2017; Wilkerson, 2017).

### THE RELATIONSHIP BETWEEN DESIGN PRINCIPLES AND LOCAL THEORY

The unique makeup of the metacognitive nature of skills, language and networks has allowed theory to evolve in complexity. The theory of metacognitive locale by Jagals (2015) is but one example where Local theory was developed based on the metacognitive characteristics of language and networks that emerge during a series of Lesson study stages. The relationship between a particular kind of language and a particular kind of network produces a kind of reflective experience, and this informs the principles needed to design Lesson study practice. These design principles on which the Lesson study stages are based exist a-priori in the literature. These principles include the setting of long-term goals, studying existing curricula and policies, reflecting on existing data and observations, discussing implications, strengthening resources, scrutinising the role of the lesson plan in terms of developing students' thinking, and including motivation as a valuable sense of accountability. Therefore, Local theory does not appear to exist alone; instead, the principles underpinning Lesson study's practice support and explain the instructional activities as well as outline the implications of the activities in practice. The connection, then, between the design principles and the Local theory is a complex one, discussed next.

When Lesson study stages are followed, hypothetical constructs can emerge which act as archetypes of the design principles on which these stages are based. For example, Jagals and Van der Walt (2016) showed that constructs of metacognitive networks emerged during a series of lesson-design stages whereby preservice teachers were involved in conducting Lesson study. These principles do not appear to be consecutive; in other words, they do not seem to emerge as a consequence of another principle, or emerge in any particular order. Examples of such constructs can include (but are not limited to) metacognitive skills, metacognitive language and metacognitive networks, as identified for the purpose of this paper. Throughout Lesson study's stages, the sessions during which lessons are planned together can serve as design sessions. It is therefore possible that a lesson study stage can consist of a number of design sessions. The design principles on which this practice is based can serve as guidelines and structures, sometimes predetermined, or as part of a conjectured process. This series of stages and sessions with the incorporated design principles can assist in facilitating Lesson study meaningfully, and this can inform the development and refinement of theory. This is done on four conditions.

First, the theory that needs to be developed requires deep reflection on the constructs that emerge from Lesson study's practice as they support and explain the design principles that can be used to test and refine the theory (Cobb et al., 2013). Second, by implementing the design principles, new knowledge can emerge that supports the impact of the principles on how the constructs are interpreted. This can result in a localised or contextualised explanation of the design principles' structure and function in Lesson study. Third, a meta-theory can act as a standard theory to refine the design principles and inform the development of Local theory. The meta-theory mainly focuses on the effect(s) of the teaching practice and does not only explain the relationship between the constructs that emerge but also support the purpose of both guidelines produced and the Local theory. Lastly, the constructs that emerge from implementing the design principles can be predetermined, making them purposively conveyed in the design of the Local theory. This predetermined, hypothetical conjecture can be implemented by following the theory's guidelines.

Local theory, therefore, predicts and explains the nature of the constructs which do not necessarily have to form part of the steps or guidelines of design principles. Rather, Local theory regards the constructs as the result or output of the design principles. Similarly, Cobb et al. (2013) and Gravemeijer (2004) have reported on the input and output variables in the development of design principles as part of Local theory's development. These design principles can then be reflected upon and refined to provide more informed or alternative principles. The design principles can then inform the facilitation of Lesson study. To do so, two options are available. The first option suggests that the design principles obtained a-priori from literature inform the facilitation of the Lesson study stages as indicated by Larsen and Lockwood (2013). The second option indicates that the Local theory can also inform the design principles as is the case with a study done by Nickerson and Whitacre (2010). Within a larger project, this can be done with a design-based research identity (such as the case with Jagals, 2015). The Lesson study stages therefore indicate continuous design sessions (or even micro stages) that produce recurring or comparable results (in the form of design principles and/or constructs) and enable the teacher as a researcher to formulate, test and refine the conjectured design principles. The teacher can therefore act as a researcher-facilitator who makes use of Lesson study as a teaching experiment. Cobb et al. (2013) and Gravemeijer (2004) explained that the role of the teaching experiment is to test and improve the design principles. The design of these teaching experiments forms the basis of a planned Lesson study stages (Bustang, Zulkardi, Darmawijoyo, Dolk, & van Eerde, 2013) that could inform the way in which Lesson study is facilitated in the classroom as part of a mathematics education course's content. The following methodology was thus employed.

## METHODOLOGY

In order to identify and develop the design principles to facilitate Lesson study, a design-based research methodology was applied with a qualitative approach. The aim was to interpretively explore the constructs that emerge from implementing Lesson study's stages and to derive design principles from these constructs to inform the development and refinement of a Local theory. Based on the conceptual-theoretical framework of this study, it is believed that these principles can inform the development of Local theory through an understanding of nature of the relationship between them.

### Population and Sampling

The study began by inviting two volunteer groups (Group A and Group B) of fourth-year mathematics education students enrolled for a course on the methodology of Grades 4 to 7 mathematics. As part of their coursework, students had to plan and design a mathematics lesson on the topic of Place value (with an emphasis on didactics) and present it to a Grade 6 class at a nearby primary school in a township area as part of Lesson study's stages. The participants represented both male and female students from various ethnic backgrounds and their home language is Afrikaans, English and/or Setswana. They have also observed, planned and presented mathematics lessons in similar schools during the work-integrated learning opportunities the urban campus offered through its Bachelor of Education (BEd) programme. In Group A there were six students represented by one male and five females while in Group B there were five students represented by one male and four females. The participants were encouraged to think aloud and share ideas during design sessions across the four Lesson study stages, similar to a focus-group context.

### Data Collection

The aim of the design sessions was to create an opportunity for participants to engage in the Lesson study stages. Data include transcriptions of video recordings of all the design-group sessions. A framework to outline the design sessions was borrowed from the work of Cobb et al. (2013) and include four design-based research stages, mimicking the Lesson study stages: 1) investigate problems and set goals; 2) plan the lesson and resources; 3) research the lesson's effectiveness; and 4) reflect and refine the lesson. Lesson study was facilitated at the university where participants were enrolled and, on completion of the first draft of the research lesson, a volunteer from each group was asked to video-record and present the lesson while other members of the group observe and reflect in order to generate notes and recommendations for refinement. This also added validity and trustworthiness to the data as it resembles multiple perspectives on the same phenomenon.

### Data Analysis

The sessions' transcriptions were analysed through conversation analysis to describe, summarise and explain the constructs, to identify and refine the design principles, and to inform the development of Local theory. To do so, the verbatim-transcribed recordings were analysed and coded using the *codes-to-theory model* for qualitative

**Table 1.** Application of the codes-to-theory model

Code	Category	Sub-category	Description of the sub-category to inform the design principles
MCS	Metacognitive skills	Planning	Setting goals, selecting appropriate strategies, predicting the outcome of an event, organising strategies
		Monitoring	Recalling and reflecting to judge consciously the ideas, actions and contributions of oneself and others
		Evaluation	Appraisal of the efforts, processes and products of the planned experiences and the revision of goals
MCL	Metacognitive language	Ideational and mathematical	Ideas emerge as students discuss mathematical concepts and the use of appropriate strategies, awareness of the strategies and gradual increase in the level of difficulty
		Interpersonal and social	Informal and formal use of words, the sharing of ideas, reference to scenarios, translating or explaining for oneself and/or others
		Textual and pedagogical	The use of terms or words in relation to one another, forged linguistic ties between tasks and strategies; new information creates opportunities for chance in the description and understanding
MCN	Metacognitive network	Social network	A social network based on the dynamics and interaction of members of the group (they act as a liaison, a bridge or gatekeeper, an investigator)
		Interpersonal metacognitive networks	These networks reveal what metacognitive skills (e.g. planning, monitoring or evaluating) members exhibit individually
		Socially shared metacognitive network	These networks reveal what metacognitive skills (e.g. planning, monitoring or evaluating) members exhibit during their interaction in group discussion of the Lesson study stages

enquiry by Saldana (2015). The process involved coding the transcriptions, categorising them and aligning them with the constructs of metacognitive skills, metacognitive language and metacognitive networking as [Table 1](#).

It is important to note that, for development of the Local theory, the three emerging constructs inform, through their sub-categories, the design principles that need to be considered in the facilitation of Lesson study. Examples of statements for each category and sub-category are offered in [Table 2](#) in the results section of this paper.

## TRUSTWORTHINESS AND VALIDITY

Through inter-coder reliability (with a reliability coefficient of 0.9) we refer to the extent to which the same codes were assigned to transcribed text by different coders. The authors collaborated on the consistency of the codes and the ideas that were coded to ensure that the findings presented reflect this consistency. Also, the guidelines by Elliott, Fischer, and Rennie (1999) were followed, including: participant checking and comparing the results with the conceptual-theoretical framework of the study. Furthermore, there was a thick description of the empirical investigation and findings, employing within-method triangulation where transcriptions of the design sessions, field notes and observations served as different methods within the same methodological approach (Curtin & Fossey, 2007).

## RESULTS AND FINDINGS

The Lesson stages allowed us to explore the constructs that emerged as a result of the a-priori design principles. The constructs were identified as: metacognitive skills, metacognitive language and metacognitive networks. Underpinning these constructs are students' expectations, understandings of one another, available time and working together in determining their success in Lesson study. These constructs, therefore, inform the way in which students became aware of the role that the constructs play across the stages of Lesson study, and in so doing, informed the design principles that need to be taken into consideration when facilitating Lesson study in the future.

In each of the themes that follow, a summary of the actual pattern of codes that the data revealed is depicted to provide a profile of the themes. Each profile contains the frequency (Hz) of responses for the particular sub-categories that emerged. Note that the frequencies serve as indicators of the quotes from transcriptions that represent the sub-category completely. It is possible that more responses could have been counted as they could imply or hint upon a sub-category, yet these were believed to have been too implicit for identifying design principles.

[Table 2](#) provides a summary of the profiles for each sub-category and theme with examples across the four Lesson study stages.

**Table 2.** Summary of the profiles of the themes and sub-categories with examples

Theme	Sub-category	Stage 1 (Investigation)	Hz*	Stage 2 (Planning)	Hz	Stage 3 (Research lesson)	Hz	Stage 4 (Reflection)	Hz
Metacognitive skills	Planning	<i>I think we must first start with the outcomes because the outcome is going to be our basic guideline [Student 1]</i>	7	<i>write what we are going to do in the introduction, what we are going to teach and learn and what we are going to do at the end and the activities also [Student 2]</i>	8	<i>The school environment was a lot better than I thought [Student 9]</i>	3	<i>We had too many activities [Student 2]</i>	4
	Monitoring	<i>I think not at all, since what we learn here and what they are doing there is entirely different [Student 1]</i>	8	<i>I agree, but we shouldn't focus too much on making it interesting, we should stick with the columns [Student 2]</i>	5	<i>They were pretty good. You could see in their faces that they understand [Student 9]</i>	4	<i>... we said that there was a problem, that not all kids can read English [Student 2]</i>	8
	Evaluation	<i>Even if they don't get around to it, they can still tell the teacher ... and she can still use the idea. It's a good idea [Student 3]</i>	6	<i>I don't think this is part of their prior knowledge, but I like the idea, I think it is going to work [Student 5]</i>	2	<i>We also say the big block and the small blocks...but then volume comes in again [Student 4]</i>	5	<i>I think our lesson worked. I think it worked very well [Student 2]</i>	6
Metacognitive language	Ideational and mathematical	<i>I was thinking: I can make a place value chart [Student 6] Lets see what the CAPS document says [Student 7]</i>	7	<i>Can we not ask them like a question to make them think about place values? [Student 2]</i>	5	<i>Let's see, what is the difference between this block and this smaller block? [Student 6]</i>	6	<i>They got a worksheet with base ten blocks but they didn't know what base 10 blocks are or how to use it to represent place values [Student 5]</i>	3
	Interpersonal and social	<i>From now on we will be straight forward with each other [Student 3]</i>	3	<i>We said that we will test their prior knowledge, but how are we going to test their prior knowledge? [Student 2]</i>	4	<i>We can be assistants. The assistant goes and help to quickly see of the kids understand. Then we can discuss it. [Student 2]</i>	5	<i>I think it went well. The time was limited and we could see the kids picked up on that [Student 10]</i>	4
	Textual and pedagogical	<i>If we have to plan a lesson, we would know how to carry on because we know exactly what to do [Student 4]</i>	10	<i>We have to look at what level they are on [Student 5]</i>	2	<i>If you write it like this: four times ten plus eight times one, it's correct [Student 4]</i>	8	<i>We were unsure what to do, but saw what we did worked [Student 6]</i>	4
Metacognitive networking	Interpersonal	<i>I compiled a lesson plan template and I completed my own form [Student 1]</i>	11	<i>I think we must start with the outcome, because the outcome will be our guide [Student 1]</i>	4	<i>I will outline the words here, if someone wants to add anything, they can [Student 11]</i>	5	<i>I really struggled ... [Student 10]</i>	8
	Social	<i>So, we have decided in the first lesson we are not going to talk about fractions [Student 10]</i>	15	<i>What are we going to do in the introduction? What will they learn? What activities can we use? [Student 2]</i>	7	<i>We can move away from what they understand to what they can apply [Student 5]</i>	5	<i>There are many ideas which we can do better [Student 8]</i>	7
	Socially shared	<i>Do you get what I am saying? [Student 3] Did you understand what I mean? [Student 6]</i>	6	<i>We have to take everybody's ideas into consideration [Student 8]</i>	5	<i>We realised what we did not know [Student 4] We had a lot of ideas and could not easily reach consensus. There were always problems with the ideas we had. But then we worked on that [Student 8]</i>	6	<i>As a group we have come together and did research about a specific subject, to expand our knowledge so that we can develop an effective lesson [Student 10]</i>	5

\* This column represents the number of times the sub-category was located within the data per Lesson study stage and serves as the frequency of the coded data.



## METACOGNITIVE SKILLS AS A DESIGN PRINCIPLE

For the theme *metacognitive skills*, participants from both groups showed growth in their depictions of Lesson study and its value for practice as they learned to think about their thinking and to manage their ideas, a metacognitive conduct. At first, they were unaware of knowing how to plan and set realistic goals for Lesson study. They had diverse ideas that were “scattered” as they were unsure about what activities to include in their lesson and how to choose which ideas are more suitable.

The profiles of the data summarised in **Table 2** suggest that participants who plan, monitor and evaluate their contributions to the design sessions do so mainly by monitoring and evaluating the other member’s ideas. In particular, it seems that those who contributed to the least overall with the skill of *planning* exhibited more monitoring and evaluating skills. In stage 2, it seemed that participants did not know what to focus on, when to focus on the content and when to focus on the methodology of the lesson. Reflecting on how they felt/ what they experienced when they had initially engaged with Lesson study team members, there was a sense of uncertainty, particularly during Stage 2:

*I would say that we were not sure what to expect ... We have to start all over ... We felt that our ideas were not important as some ideas will work and others' not ... Now we are much more confident ...*

In terms of the skill of *monitoring* (reflecting on what had happened during their lesson presentation), they related the theory of Lesson study with its practice and communicating about it, as is evident from Stage 3:

*There are many ideas which we can do better ... it was very insightful ... we looked at how the learners did the work ... they all seem to understand the work, but they made the same small errors ... If we had to do it again, we will be better prepared ...*

The skill of *evaluating* was predominantly applied when participants reflected on the design of the lesson and on its presentation, thus reflecting on the teaching and learning experience. They evaluated the intelligence of the learners whom they taught: *They were very smart*, as well as the overall impact of the lesson: *Yes, I think our lesson worked. I think it worked very well.*

During the second and third stage, they divided the work amongst themselves and arranged additional sessions. They worked together, collaborated and made decisions about their ideas, specifying what to include and exclude in the lesson.

## METACOGNITIVE LANGUAGE AS A DESIGN PRINCIPLE

Across all stages, not being able to express their reasoning clearly, and lacking the vocabulary of their thinking about their thinking, participants explained that, even though they worked together, they often became frustrated when their ideas are not understood or recognised.

It seems as if the *interpersonal and social language* was the least exhibited when *ideational and mathematical language* was used to express ideas. It implies that participants’ mathematics vocabulary did not feature when they discussed the lesson plan, teaching activities or other pedagogical related matters of the lesson (Stage 1). Those who did use *ideational and mathematical language* expressed less concern about the text of the lesson plan and used less *pedagogical language* (Stage 2) related to teaching strategies and activities. It seemed overall that participants had difficulty with externalising their ideas as was evident from their discussion in Stage 3:

*We talk past each other and do not understand what the other one means. ... we do not understand what each other means. I don't know what they don't know and what someone else is thinking about my idea ... we had too many good activities and we do not know how to say that we do not want to use this or that idea ...*

Participants also seem to have grown their awareness of language as was reflected on in Stage 4:

*We now know each other and we can say this or that won't work. At first, we were afraid of what someone else might say ... we didn't want to demotivate anyone ... and felt that we need some way of saying what we think ...*

In order to get focus, participants discussed what their lesson outcomes should be; this presented a problem, not only for interpreting the curriculum documents, but also to put clearly down in words on the lesson plan what they expect from their learners at the end the lesson:

*We have outcomes, we want them to be able to identify and apply ... The outcomes must be smart. It must be specific, measurable, attainable, relevant and traceable ... so we have to look at it again ...*

## METACOGNITIVE NETWORKS AS A DESIGN PRINCIPLE

The nature of networking between group members also developed along with their metacognitive skills and language. In stage 3, participants decided to work with each other's ideas, and not necessarily to come up with new ones all the time. In stage 3, participants had realised what their strengths and weaknesses were, and the nature of their metacognitive networking is likely to be the key to overcome the barriers participants had during Lesson study.

*We are all here, we know what to do. We have to take everyone's ideas into consideration ... (Stage 2)*

Discussions seemed to have flowed in a rather linear manner. First participants discussed and shared ideas in a rather *socially* open way:

*We started with an idea and talked about it and made a combination of all the ideas. (Stage 3)*

Then they reflected on these inputs on an *interpersonal level*:

*It helped to understand the concept better ... Lesson study is difficult if one student feels separated from another ... (Stage 3)*

They finally *socially shared* and regulated each other's ideas and their preconceptions of Lesson study:

*When we get together we can say, this stuff works great and then we take other ideas and we build on that. (Stage 3)*

Overall, the results indicate that participants communicated their ideas about teaching (e.g. teaching strategies and resources) more easily than their ideas about mathematics. It seemed that the role of a social responsive community of practice has led to the development of a mid-way in stage 3, through which they became more focused, more relaxed with their ideas and more open to new judgements and new ideas.

In this sense, metacognitive skills, metacognitive language and metacognitive networking appear to form a conceptual framework of students' depictions of Lesson study. When aligned against the design principles, the constructs offer a view on some preconceptions on Lesson study to refine the design principles and to inform the development of Local theory. The discussion that follows illustrates this in two parts. First, the emerging results are discussed in terms of the constructs metacognitive skills, metacognitive language and metacognitive networks as themes in which the design principles are attributed. Second, the implications of the design principles on Local theory development are discussed to show how these principles inform Local theory.

## DISCUSSION

To facilitate Lesson study, design principles were developed and tested out (see [Table 1](#)) in the form of four Lesson study stages. From these design principles, three constructs emerged from students' depictions of Lesson study, namely metacognitive skills, metacognitive language and metacognitive networking. By aligning the constructs with the design principles and following three preconceptions of Lesson study were derived to refine the design principles and inform Local theory. Students' depictions suggest that it is possible that the design principles of Lesson study can foster metacognitive skills, promote awareness of students' metacognitive language to collaborate and create opportunities for metacognitive networking. The following preconceptions outline this discussion.

## EMERGING CONSTRUCTS AS DEPICTIONS OF DESIGN PRINCIPLES

First, to develop design principles of Lesson study, the assumptions that underpin Lesson study must be considered. Clarity was needed as to what outcomes of Lesson study will be assessed and/or anticipated in a final-year mathematics education methodology module. It is possible that similar studies can produce different constructs, depending on the local issues of the theory. In this case, we proposed that facilitators of Lesson study must first consider what underpinning knowledge, skills and values they want their students or colleagues to demonstrate and this must be in line with the design principles of Lesson study. Furthermore, the use of a task, such as lesson planning, and the opportunity to carry out this task in a series of manageable sessions, made it possible to observe for emerging constructs.

Since metacognitive skills are an important aspect of Lesson study, it could be expected that students will plan, monitor and evaluate their lessons. In the stages below, examples are provided of some of the implications that the emerged constructs have in terms of the design principles for Lesson study practice.

Metacognitive skills appeared to be the product of social interaction. Iiskala, Vole, Lehtinen, and Vauras (2015) introduced the concept of socially shared metacognitive regulation through a social network analysis approach. This explains why students who participate in group discussions in Lesson study's design stages monitored and evaluate other's ideas and became metacognitively aware of the required language and networking qualities they exhibited and experienced. When reflecting on the research lessons, they judged whether the contributed knowledge was part of their planning and pedagogical content knowledge.

The results show that students also planned their time for additional sessions, discussed whether the outcomes are clear enough and reflected on their own experiences. When aligned with the design principles, the construct of metacognitive language did not fit with the overall framework, suggesting that communication ought to be promoted in the facilitation session. This will likely infuse a stronger sense of being in the groups.

Since participants felt cautious about their contribution to the group, another conceptual point to consider is finding ways to develop participation. This relates closely to the networking construct that, in a way, depends on the metacognitive skills and metacognitive language as also can be shared, observed and developed over time (Cajkler et al., 2013). In addition, a stronger capacity to express one's thoughts, to reason and to redefine meaning in the design sessions, was needed and can undermine participation. However, being immersed in a group long enough can imprint a sense of group culture where the group members develop a deeper understanding of their own, and others' contributions.

## ALIGNING THE CONSTRUCTS WITH DESIGN PRINCIPLES ACROSS LESSON STUDY STAGES

When aligned with **Table 1**, the constructs serve a dual purpose. They indicate possible outputs of the theory and, serve as an input of the theory. At this point, overlaps between the constructs can unfold suggesting that, for example, metacognitive skills can be communicated about, associating it with language. Also, an expression of one's thinking can impact on the nature of others' understanding (Frith, 2012) and is associated with networking. The results point out that the preconceptions are epistemological in nature as they align with the design principles on which Lesson study was based. Participants recalled not only what they think worked in Lesson study, but also what they think could have been planned and implemented differently. The theory is then connected via a meta-theory that underpins the relationships between the constructs. As such, a Local theory can be developed about the constructs that emerged from the design principles. This Local theory can then serve as a meta-theory of the preconceptions on Lesson study.

The findings in this study indicate, that a Local theory can be developed to explain the constructs that emerge from design principles. The constructs then play a key role in the nature of the design principles and their presence suggests that the design principles and Local theory are interrelated. Also, it seems possible that a Local theory can be developed to explore, test and refine the role existing constructs play in design principles. Liden (2011) suggested that the theory–practice relationship must be revisited in empirical research since the interpretation of the findings depends on theory and implicates theory. Several aspects of design principles and Local theory require further investigation. These aspects include: understanding the nature of the relationship between metacognitive skills, language and networking. The design principles produced an understanding of the constructs and preconceptions of Lesson study which include metacognitive skills, language and networking. Because of its output, it is suggested that facilitators who wish to promote these skills in their classroom can consider meaningful activities that include collaborative and problem-based learning as teaching approaches.

## THE VALUE OF DESIGN PRINCIPLES AND LOCAL THEORY IN THE FACILITATION OF LESSON STUDY

The purpose of design principles is to serve as instructional guidelines that address the issues emerging from practice. In contrast, the purpose of a Local theory is to explain and understand the nature of these design principles and their association to the constructs in a particular local setting. According to Craddock et al. (2013), this reinforces professional development and suggests a relationship between Lesson study's theory and practice. As an argument to include both design principles and Local theory in the facilitation of Lesson study, Bernath and Vidal (2007) suggested that improving educational quality takes place when researcher (e.g. facilitators and teachers concerned with theory and practice) bring forward new ideas and strategies to progress not only the teaching experience at the present but also to predict the quality of the learning experiences in the future. To accomplish this in the current study, the local route of Lesson study with its hypothesised learning trajectory is

aligned against the design of design principles. The design principles' theoretical structure contextualises the teaching and learning environment and describes, interprets, explains and justifies the observations and reflections of the constructs that emerge when applying the design principles. The design principles then transform the practical issues (such as: What skills are necessary? How can these skills best be communicated? How are these skills connected?) into research problems that can be studied in terms of mini-pedagogical experiences or research lessons (Cobb et al., 2013). Then the design principles do not only provide guidelines for the educational experience, but also play a role in the rationale of the theoretical constructs that emerge from the Lesson study stages which, in turn, inform the Local theory, or way of teaching. When Lesson study is done, new ideas regarding best practices and effective teaching can develop through observations of, and reflections on the teaching and learning experience. The experiences can then be researched to determine how the emerging the underlying constructs of Lesson study informs design principles and Local theory. To do so, the constructs have to be explored, examined and understood as parameters or archetypes of the design principles and their relationship has to be explained through the Local theory, this will inform the development and refinement of Local theory.

It is then worth noting that the design principles have transformative potential for the teaching and learning field and, through Lesson study practice, this can lead to new ideas or theory. This impacts on the curriculum transformation processes, curriculum design and the inclusion of metacognition as a valuable component in Lesson study practice. This, however, remains in theory and need to be tested out in a variety of fields with the assistance of Lesson study's stages. Only then can the theory be revised, refined and adapted to suit the teaching and learning needs of the teacher, based on their particular Lesson study setup.

## CONCLUSION AND FUTURE DIRECTIONS

When facilitating Lesson study, constructs can emerge that can inform design principles to improve practice and this can be used to inform the development and refinement of theory. The preconceptions outlined above explain that Lesson study can be facilitated with the underpinning assumptions of metacognitive skills, metacognitive language and metacognitive networking. As these constructs emerge from students' depictions of Lesson study, they can align with the design principles identified in **Table 1** to refine the principles for future lessons. In doing so, these design principles can be employed to inform future Lesson study experiences and can therefore enhance Lesson study practice and theory. In conclusion, students who work collaboratively in Lesson study can preconceive the Lesson study theory from practice and, in the process, reflect on their own depictions of Lesson study with the emerging preconceptions built into the design principles. In the development of design principles and Local theory the constructs that underpin Lesson study, inform the development and refinement of theory by scrutinising the preconceptions that the theory holds to refine the theory accordingly.

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# Modelling Course-Design Characteristics, Self-Regulated Learning and the Mediating Effect of Knowledge-Sharing Behavior as Drivers of Individual Innovative Behavior

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Received 9 February 2018 • Revised 28 May 2018 • Accepted 8 June 2018

## ABSTRACT

Literature identifies factors promoting Individual Innovative Behaviour (IIB) among employees. The effects of Knowledge-Sharing Behaviour (KSB), Self-Regulated Learning (SRL) and Course-Design Characteristics (CDC) to facilitate developing IIB among undergraduate technology university students is not well understood. The research question and objectives aim to address this literature gap by examining how SRL and CDC act as antecedents of IIB, via the action of knowledge-sharing behaviour. The research employed a quantitative cross-sectional survey. The subjects were 268 students enrolled in technology programmes, from seven Kenyan public universities. Data collection was with the aid of a questionnaire. A 2,000-bootstrap sample generated tested standardised total, direct and indirect effects. Findings are summated in a KSB-IIB structural equation model, with the results largely supporting all hypotheses. Results reveal that CDC and SRL act as significant drivers of KSB and IIB among undergraduate technology students. Recommendations enable academic university education managers to leverage attributes of IIB antecedents.

**Keywords:** course-design characteristics, individual innovative behaviour, knowledge-sharing behaviour, self-regulated learning

## INTRODUCTION

This study was inspired by the paucity of multi-disciplinary studies that simultaneously investigate the antecedents of Individual Innovative Behaviour (IIB), and the possible mediating role of Knowledge-Sharing Behaviour (KSB), in the context of undergraduate technology students. Many existing studies, which correlate KSB with IIB, have focused on organisations and employees, and not students in a university setting (Afsar, 2016; Seo, Kim, Chang, & Kim, 2016), making this an area where there are still questions to be explored. Additional information regarding the study reported on in this paper can be obtained from Ngugi and Goosen (2017).

## THEORETICAL AND CONCEPTUAL FRAMEWORKS

This section presents the key theoretical underpinnings that support and inform the study, with a view to providing justification for the seven study hypotheses. The section attempts to explore the sub-components of the selected individual and contextual factors of Course-Design Characteristics (CDC) and Self-Regulated Learning (SRL). Further, the dependent endogenous variable of IIB is discussed, and how it is influenced by CDC, SRL and KSB. The theoretical and conceptual frameworks, which guide the study, are thus presented.

### Course-Design Characteristics (CDC)

Individual innovative behaviour has also been correlated with job design (Battistelli, Montani, & Odoardi, 2013), as well as course design (Tabata & Johnsrud, 2008).

### Contribution of this paper to the literature

- This study contributes by validating the CDC construct as significant antecedent driver of IIB, investigating relationships surrounding CDC.
- The study bridges the knowledge gap on research modelling the mediating influence of KSB on IIB, with CDC and SRL as possible antecedents of knowledge-sharing behaviour in the university education setting, and context of undergraduate technology students.
- This study contributes to KSB and IIB literature by examining the mediating mechanisms through which CDC and SRL influence IIB. This study generated empirical evidence that bands CDC and SRL at contextual and individual levels, and how these drivers impact technology students' KSB and IIB.

The Job Characteristics Model (JCM) represented one attempt at unravelling the concept of job design. The JCM has historical roots in the work of Hackman and Oldham (1980), whose model hinged on the idea that the task or job itself is pivotal to employee motivation, presented five intrinsic components or factors for any given job or task. These five components described the extent of task identity, job feedback, autonomy, task variety and task significance. The JCM outlined the interrelationship between the five job characteristics, the associated psychological states, and the resultant personal outcomes. Overall, the outcomes indicated a higher level of motivation, satisfaction, and effectiveness. Hence, the five job characteristics may exert a significant influence on the effectiveness and satisfaction of IT lecturers and employers, as well as the quality of higher education institution graduates.

More recently, Oldham and Fried (2016, p. 25) conducted an extensive review of job design research and theory and found a link between “motivational characteristics of employees’ jobs and their creativity”. Other researchers, who have linked job design and creativity, include Coelho and Augusto (2010), Raja and Johns (2010), and Zhang and Bartol (2010). Specifically, Dwivedula, Bredillet, and Müller (2017, p. 609) compiled a comprehensive review of literature, grounded in a job design perspective. In their theoretical lenses review, they conceptualized work motivation in temporary organizations, in the context of leadership, innovation and entrepreneurship as driving forces of the global economy, by utilizing the job design perspective. The review identified “various facets of job design that constitute motivating nature of work”.

Morgeson and Humphrey (2006) sought to address related issues, by developing the Work Design Questionnaire (WDQ), which was an adaptation of the framework by Morgeson and Campion (2003). The questionnaire shifted the focus from job to work design and developed three major categories of work characteristics, namely motivational, social, and contextual. For the purpose of the present study, only the motivational work characteristics were considered, as in the view of the researcher, they had attributes that could be linked to the contextual factors in IT education. Morgeson and Humphrey (2006) dichotomized motivational work characteristics into task and knowledge characteristics.

This study expands the work of Morgeson and Humphrey (2006), by focusing on two motivational constructs of their work design questionnaire, to develop a new construct, termed course-design characteristics. CDC, in the context of the study, refer to students’ perceptions of the range of knowledge and task requirements in a technology course. The idea to develop this new construct was informed by a suggestion by the conceptualized students study by Cotton, Dollard and de Jonge (2002), with the university as a form of a job. Consequently, an examination of students’ work context may provide an answer and linkage to the development of innovative tendencies among undergraduate technology students.

### *Task characteristics*

*Task identity*, according to Morgeson and Humphrey (2006, p. 1323), is defined as “the degree to which a job involves a whole piece of work, the results of which can be easily identified”. Similarly, task identity is defined by Burke (1990, p. 23) as “the degree to which the job requires the completion of a ‘whole’ and identifiable piece of work, doing the job from the beginning to the end with a visible outcome”.

*Autonomy*. The task characteristic of autonomy has received great attention in literature on motivational work design (Barrick, Mount, & Li, 2013; Battistelli, et al., 2013; Langfred & Rockmann, 2016; Parker & Zhang, 2016; Parker, Van den Broeck, & Holman, 2017). Hackman and Oldham (1980, p. 79) defined autonomy “as the degree to which the task provides substantial freedom, independence, and discretion in scheduling the work and in determining the procedures to be used in carrying it out”. Similarly, autonomy, according to Karasek (1998, p. 291), refers to the extent of a worker’s potential control over her/his tasks and her/his “conduct during the working day”.

*Task Variety* is defined by Morgeson and Humphrey (2006, p. 1323) as referring to “the degree to which a job requires employees to perform a wide range of tasks”. A similar definition of task variety by Burke (1990, p. 21) is

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“the degree to which a job requires a variety of different activities in carrying out the work, which involves the use of a number of different skills and talents of the employee”. Evidence from research suggested that task variety enhances learning (Narayanan, Balasubramanian, & Swaminathan, 2009).

### Self-Regulated Learning (SRL)

According to Fink (2007), learners tend to be inspired and get involved fully when academic programs are well designed. The differences between learners and lecturers in their views of course design have hindered the realization of the expected returns of the education system, as the graduates may not be well prepared for the complex, competitive and changing world. Martín, Potočnik, and Fras (2017) posited that today’s undergraduates will be tomorrow’s employees. Evidently, this preparation of tomorrow’s employees transcends the core preparation at higher education institutions, through rigid courses and fixed examination systems. It calls for a preparation of the cognitive framework of undergraduate learners, in terms of positive psychology, to instill traits such as self-regulated learning (Pintrich, 2000). Such traits have been found to be durable enough to influence long-term behaviour and performance. Thus, self-regulated learning provides a lens for viewing individual-level determinants of learner innovativeness.

According to Boekaerts, Pintrich and Zeidner (2000, p. 751), self-regulation “involves cognitive, affective, motivational and behavioural components that provide the individual with the capacity to adjust his or her actions and goals to achieve desired results in light of changing environmental conditions”. While Forgas, Baumeister and Tice (2009), in their introductory review on the psychology of self-regulation, also referred to cognitive, affective and motivational processes, Schraw, Crippen, and Hartley (2006) modelled self-regulation in science education and partitioned it into three components, namely cognition, metacognition, and motivation.

Zimmerman, Boekaerts, Pintrich, and Zeidner (2000, p. 14) defined self-regulated learning “as self-generated thoughts, feelings, and actions that are planned and cyclically adapted to the attainment of personal goals”. Further, Effeney, Carroll and Bahr (2013, p. 58) viewed self-regulated learners as having the capacity to “actively set goals, decide on appropriate strategies, plan their time, organize and prioritize materials and information, shift approaches flexibly, monitor their learning by seeking feedback on their performance and make appropriate adjustments for future learning activities”. Some recent studies specifically promote the uptake of SRL in various contexts at the university level of education. Seraphin, Philippoff, Kaupp, and Vallin (2012) found evidence that metacognitive reflection is a significant driver of change in the scientific thought patterns of students, resulting in better critical-thinking and scientific skills.

According to Zimmerman and Schunk (2012), there is vast literature on self-regulated learning at various levels of the education system. Barak (2010, p. 381) investigated the field of technology education and proposed a compensative model for SRL comprising of cognitive, metacognitive, and motivational domains. The findings provided evidence that SRL “is highly correlated with an individual’s motivation to handle challenging assignments and with his or her internal satisfaction from being engaged in a task that contributes more to creativity than to receiving external rewards”.

Specifically, in a distance education context, Rockinson-Szapkiw, Wendt, and Lunde (2013) looked at the influence of electronic versus print textbook formats on higher education institution learners’ self-regulated learning strategies, motivation, and text anxiety.

In the context of educational technology and society, Liu and Chi (2012) investigated learner affective performance in web-based learning, by using entrepreneurship as a metaphor. In an adjacent context, the PhD thesis of O’Shea (2011) looked at integrating cognitive, motivational, and emotional self-regulation in early-stage entrepreneurs.

Zheng, Skelton, Shih, Leggette, and Pei (2009) found an imperative need for engineering faculty to adapt new instructional strategies that can help engineering learners to effectively regulate their learning motivation, strategies, and efforts, particularly in the early stages of learning. Their findings proposed a new instructional strategy and its implementation plan for a freshmen entry-level course, which included direct instruction to learners as stand-alone learning contents, and immersion instruction, which merged instruction as salient cues and scaffolded it into the Problem/Project-Based Learning (PBL) process through a co-curricular design project. In that study, the course project required learners to identify a problem and provide innovative technological solutions that could impact and improve learners’ studies and lives around campus. This is indeed the future of how IT courses ought to be taught.

### **Measures of self-regulated learning**

One of the most widely used measures of SRL is the Motivated Strategies for Learning Questionnaire (MSLQ), reported on by Pintrich, Smith, Garcia, and McKeachie (1991). This scale has nine learning strategies that contribute to self-regulation among learners, namely:

- 1) Rehearsal,
- 2) Elaboration,
- 3) Organization,
- 4) Critical thinking,
- 5) Metacognitive SRL,
- 6) Time and study environment,
- 7) Effort regulation,
- 8) Peer learning, and
- 9) Help seeking (Pintrich et al., 1991, p. v).

The definitions of the nine sub-constructs by Pintrich et al. (1991) were retained to convey the original meaning. For the purpose of this study, the first five constructs were used to represent the individual context of SRL. The researcher deemed the construct of time and study environment to be more of a contextual antecedent of the study, and thus not apt for use as an individual factor.

### **Knowledge-Sharing Behaviour (KSB)**

Defining KSB, according to Yi (2009, p. 68) and Ryu, Ho, and Han (2003), refers to a set of individual behaviours involving sharing and/or disseminating one's acquired "work-related knowledge and expertise with other members within" the organisation.

Literature, such as Bartol and Srivastava (2002, p. 65), suggests that KSB has four major components by which individuals share their knowledge within an organisation, which include, firstly, the

*contribution of knowledge to organizational databases; second sharing knowledge in formal interactions within or across teams or work units; third, sharing knowledge in informal interactions among individuals; and fourth sharing knowledge within communities of practice, which are voluntary forums of employees around a topic.*

In the present study, an attempt was made to adapt the four components of the KSB scale by Yi (2009), or as assessed by the scale identified by Ramayah, Yeap, and Ignatius (2014), both of which contained Communities of Practice (CoP), as well as Written Contributions (WC), Organisational Communications (OC) and Personal Interactions (PI).

Camelo-Ordaz, García-Cruz, Sousa-Ginel, and Valle-Cabrera (2011) explored how affective commitment mediated the relationship between human resource management and the two independent variables of knowledge-sharing behaviour and individual innovative behaviour.

According to Lu, Leung, and Koch (2006), knowledge-sharing behaviour is time consuming and is often viewed as loss of power. It also involves trust and this human factor demands considerable expense of time, resources, and energy, as learners balance the motivation to help each other learn and share their hard-earned knowledge. This may lead to KSB being a possible mediating variable in the relationship between the individual and contextual antecedents of individual innovative behaviour.

### **Individual Innovative Behaviour (IIB)**

According to Messmann and Mulder (2011), the challenge of providing solutions to emerging problems and challenges require students to develop innovative tendencies. This has, however, not been the case, as many countries in Africa have failed to attain the critical threshold of producing knowledge workers, who can trigger the process of innovation, and hence leverage technological innovations to provide solutions for societal challenges (World Bank, 2011). This makes the need for the stimulation of innovation in Africa, as a factor for societal development, even more explicit. All is not lost for Africa, however, as it is beginning to command the attention of business executives, as well as scholars, as a viable investment destination. In South Africa, Shuttleworth is credited for developing the Ubuntu operating system, which has found wide application (Hill, Helmke, & Burger, 2009). The telecommunications industry in Africa has clearly leapfrogged the Western world in the field of mobile technologies (Nyaundi, 2011).

The study employed the four components of individual innovative behaviour detailed by de Jong and den Hartog (2010, p. 24), i.e. “opportunity exploration, idea generation, idea championing and idea implementation”. Seminal work by Scott and Bruce (1994), on the determinants of IIB, found empirical evidence that problem-solving style, leadership and work climate have a significant influence on IIB.

### **Aim, Research Questions and Hypotheses**

The aim of this study was to develop and test a structural model, which hypothesizes that CDC and SRL are positively related to KSB among technology students. In turn, CDC, SRL and KSB are positively related to students’ IIB, with KSB acting as a mediator variable.

To achieve the study purpose, the primary research question was: What is the influence of CDC and SRL on the IIB of undergraduate technology students in Kenya, and how does KSB mediate the relationship between these individual and contextual antecedents of IIB?

Based on the main research question, the study sought to answer seven secondary research questions, which are stated as follows, using full terminology:

- 1) What are the psychometric properties of the proposed course-design characteristics, self-regulated learning, knowledge-sharing behaviour and individual innovative behaviour scales in the context of university education, and are these valid and reliable measures?
- 2) What is the relationship between course-design characteristics and the endogenous variable of individual innovative behaviour?
- 3) What is the relationship between self-regulated learning and the endogenous variable of individual innovative behaviour?
- 4) What is the relationship between knowledge-sharing behaviour and the endogenous variable of individual innovative behaviour?
- 5) What is the relationship between course-design characteristics and students’ knowledge-sharing behaviour?
- 6) What is the relationship between self-regulated learning and knowledge-sharing behaviour?
- 7) How does knowledge-sharing behaviour mediate the relationship between course-design characteristics and SRL and the endogenous variable of individual innovative behaviour?

Based on the literature review, the study sought to simultaneously test seven hypotheses associated with the research questions, which are:

- Hypothesis 1) Course-design characteristics are positively related to technology students’ individual innovative behaviour.
- Hypothesis 2) Self-regulated learning is positively related to technology students’ individual innovative behaviour.
- Hypothesis 3) Knowledge-sharing behaviour is positively related to technology students’ individual innovative behaviour.
- Hypothesis 4) Course-design characteristics are positively related to technology students’ knowledge-sharing behaviour.
- Hypothesis 5) Self-regulated learning is positively related to technology students’ knowledge-sharing behaviour.
- Hypothesis 6) Knowledge-sharing behaviour mediates the relationship between the interaction of individual innovative behaviour and course-design characteristics among technology students.
- Hypothesis 7) Knowledge-sharing behaviour mediates the relationship between the interaction of individual innovative behaviour and self-regulated learning among technology students.

Based on an extensive literature search (see e.g. Choi, Kim, Ullah, & Kang, 2016; French, McCarthy, Baraitser, Wellings, Bailey, & Free, 2016; Laycock, Bailie, Matthews, & Bailie, 2016), it became evident that this study was necessary, because of the paucity of studies on the mediating role of KSB in linking the individual and contextual antecedents of IIB. This paucity is especially in the context of university students in Africa, and specifically a developing country like Kenya (Afsar, 2016; Seo, et al., 2016). Consequently, the study offers theoretical and practical applications, by providing a multi-disciplinary lens, to explore the individual and organisational antecedents of IIB and the possible mediating role of KSB in that relationship.

Specifically, this study could contribute theoretically by seeking to validate the CDC construct as a significant antecedent and driver of IIB, by investigating relationships surrounding CDC. Further, the study seeks to bridge the knowledge gap on research that models the mediating influence of KSB on IIB, with CDC and SRL as possible

antecedents of knowledge-sharing behaviour in the setting of university education, in the context of undergraduate technology students.

## RESEARCH METHODOLOGY

The research setting was undergraduate technology classes from public chartered universities in Kenya. The students selected were undertaking technology programmes. The participants were either in their third or fourth years of study, and had participated in project work as prescribed in their study programmes. The study was conducted in various counties of Kenya, with a rider that universities included be publicly chartered.

### Research Design

In a cross-sectional study, a quantitative, non-experimental research design was chosen to explore the relationships between the constructs, as such a design is suitable for data obtained in a relatively short period of time (Creswell, 2013). The research method chosen was a correlation survey of an explanatory nature, as this method can produce a quantitative description of various aspects of the population under study (Fowler, 2002). A survey was considered most appropriate to measure the perceptions and attitudes of technology students, as it embraces the positivist framework and the related quantitative methods (Creswell, 2013). Further, survey research elicits “standardized information in order to define or describe variables or to study relationships between variables” (Malhotra & Grover, 1998, p. 409).

### Data-Collection Instruments

The measurement of the latent exogenous and endogenous variables made use of a set of quantitative self-report measures. This entailed the use of Likert scales, in conjunction with other demographic measures. The CDC scale was composed of 20 items, which measured knowledge characteristics, and 24 items that gauged task characteristics. The measurement of SRL was with the aid of a revised version of the 31 items from the Motivated Strategies for Learning Questionnaire (MSLQ). The measure of KSB involved a variation of the scale from Yi (2009). Finally, the measure of IIB was based on the scale by De Jong and Den Hartog (2010), which had 11 items, which measured the four sub-constructs of opportunity exploration, idea generation, championing, and implementation. The actual wording used, however, was changed, where necessary, to fit the context of undergraduate technology students – see [Table 1](#).

**Table 1.** Scales, subscales and examples of items used in data-collection instruments

Scale	Subscale	Number of items	Example of item
Course-Design Characteristics	Knowledge Characteristics	20	The project work requires a depth of knowledge and expertise.
	Task Characteristics	24	The project work involves performing a variety of IT tasks.
Self-Regulated Learning	Rehearsal	4	I make lists of important items for this course and memorize the lists.
	Elaboration	6	When I study for this class, I pull together information from different sources, such as lectures, readings, and discussions.
	Organisation	4	When I study the readings for this course, I outline the material to help me organize my thoughts.
	Critical Thinking	5	Whenever I read or hear an assertion or conclusion in this class, I think about possible alternatives.
	Metacognitive Self-Regulation	12	If I get confused taking notes in class, I make sure I sort it out afterwards.
Knowledge-Sharing Behaviour		20	I frequently share ideas and thoughts on specific topics through email communication.
Individual Innovative Behaviour		11	I look for opportunities to improve an existing process, technology, product, or service.

### *Self-regulated learning scale*

Pintrich and De Groot (1990) developed the original MSLQ, which had two (motivation and learning strategies) broad subscales. Usually, the motivation subscale is shown as having three subcomponents, namely value, expectancy and affective. Kahraman (2011, p. 73), however, is of the opinion that under the original motivation



scale, there were six subcomponents, namely “intrinsic goal orientation, extrinsic goal orientation, task value, control of learning beliefs, self-efficacy for learning and performance and test anxiety”.

### ***Measurement of course design characteristics***

The construct of course design characteristics was inspired by literature drawn from the field of human resource management. Other work included Pukienė and Škudienė (2016) looking at the role of human resource management and affective commitment in Innovative Work Behaviour (IWB). The CDC was an adaptation of the work design questionnaire, formulated by Hackman and Oldham (1980) and later improved by Morgeson and Humphrey (2006). The WDQ scale has been used extensively in literature, and consists of four subscales, namely task and knowledge characteristics, as well as aspects relating to social and work contexts.

### **Population, Sampling, and Sample Technique**

The context as already described, of technology students, was employed in delineating the sample population of students. The study was conducted in the Kenyan university education sector, with a focus on public universities, which offer applicable technology courses. As of September 2015, Kenya had 33 public universities and 37 private universities. Out of the public universities, seven universities (21%) were selected at random as the target population, based on logistical and time considerations. Therefore, a representative selection of these universities was made, using stratified random sampling techniques.

Within these, the target populations were three clusters of Bachelor courses, which were classified as falling under the field of computing by the International Standard Classification of Education (ISCED). A ‘technology’ student was thus defined as qualifying for inclusion in the sample if (s)he was:

- a) enrolled for a Bachelor of Science (BSc) in Computer Studies or BSc in Information Technology or Bachelor of Business (Information Technology);
- b) enrolled in the third or fourth year of study; and
- c) had recently undertaken project work as part of the programme requirement.

The generalizability of the study relied on the representativeness of the respondents. Fifty students were selected from each public university, using simple random sampling, to yield a sample of 350 undergraduate technology students. A response rate of 81% (n=284) was achieved. Sixteen responses were discarded, as they contained missing data; hence, 268 students satisfied the minimum criteria for inclusion and were retained for further use.

The survey was conducted over the period 2014-2015, in order to cater for different university’s academic calendars - some of the universities involved used a trimester system, while others used a semester system. The questionnaire was estimated to take approximately 35 minutes to complete.

The researcher requested lecturers in the programmes involved to assist in the process of administering the questionnaires to an agreed sample of participants.

### **Validity and Reliability**

The estimation of the internal consistency reliability in terms of composite or construct reliability was based on the computation of coefficient alpha (Cronbach, 1951) using the critical value of 0.7 (Hair, Anderson, Babin & Black, 1998). The results suggest that the scales had suitable reliability, as they were all above this critical value of 0.7 – see **Table 2**. Further, each of the composite scales had at least three items, which were adequate to realize content adequacy. To ensure construct validity, the measurement items were sourced and adapted from previous validated multi-disciplinary measures with proven and acceptable reliability, as recommended by Boudreau, Gefen, and Straub (2001). Confirming construct validity involved an exploration of the convergent validity and discriminant validity, as during the pilot study, the nomological and face validity were already examined. Content validity was achieved by using measures available from literature, which had acceptable psychometric properties (Hair et al., 2010). The results of the study indicated that there was evidence of convergent validity, since all the average variance extracted values were above 0.5 (Hair et al., 2010), as well as above the correlation coefficients for the other variables, thus providing support for discriminant validity.

**Table 2.** Reliability coefficient of scales and subscales

Scale	Cronbach's Alpha	Number of Items
Self-Regulated Learning	0.945	31
Knowledge Characteristics	0.720	13
Task Characteristics	0.777	17
Knowledge-Sharing Behaviour	0.884	16
Individual Innovative Behaviour	0.789	11
<b>Total number of items</b>		<b>88</b>

### Data Analysis

Following Gaskin (2016), data analysis started with the preliminary stages of data entry, exploration, and screening by examination of the “outliers, independence of errors, absence of multicollinearity, normality, linearity, and homoscedasticity of residuals”, as recommended by Su, Cuskelly, Gilmore, and Sullivan (2017, p. 1178). Besides the exploration of missing values, outlier patterns were examined by following the three steps suggested by Field (2005).

The next step was an exploratory factor analysis, through an examination of the appropriateness of data, communalities, dimensionality, and factor structure to obtain an orderly simplification. Following this, Confirmatory Factor Analysis (CFA) techniques were used to assess the model fit, validity and reliability, common method bias, invariance and second-order factors. The existence of common method bias was tested using Harman’s single-factor test in the Statistical Package for Social Sciences (SPSS) and the common latent factor method in the Analysis of Moment Structures (AMOS) (Byrne, 2016; Fuller, Simmering, Atinc, Atinc, & Babin, 2016). This data analysis made use of SPSS version 18. SPSS was also used to generate descriptive and inferential statistics.

Other data-analysis techniques used included computation of correlation, multiple linear regression, and Structural Equation Modelling (SEM). For the statistical treatment of data, the study utilized the two-stage model-building procedure (Schumacker & Lomax, 2010) that required developing a measurement model and later a structural model. AMOS 18 software was employed to conduct the SEM analysis, generating data for hypothesis testing. This study innovates by applying the advanced analytical techniques of SEM, which is well-suited to analyse correlations between the hypothesized constructs. Using SEM analysis, the computation of the direct, indirect, and total effects involved an examination of the effect of the exogenous variable on the endogenous variable to compute the direct effect, as well as an examination of the indirect effect of the exogenous variables of CDC and SRL, through the mediating variable of KSB. Finally, the sum of the direct and indirect effects provided a measure of the total effect (Schreiber, Nora, Stage, Barlow & King, 2006) – see **Table 3**.

**Table 3.** Standardized total, direct and indirect effects and corresponding standardized two-tailed significance bias corrected confidence intervals after bootstrapping

		Course-Design Characteristics	Self-Regulated Learning	Knowledge- Sharing Behaviour
Knowledge-Sharing Behaviour	Total Effects	0.531**	0.316**	
	Direct Effects	0.664**	0.435**	
	Indirect Effects	0.000	0.000	
Individual Innovative Behaviour	Total Effects	0.552**	0.261**	0.872**
	Direct Effects	-2.04	-0.035	0.846**
	Indirect Effects	0.439**	0.261**	0.000

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

Following the suggestion of Shrout and Bolger (2002), mediation analysis employed bootstrapping techniques, using 2,000 bootstrap samples, to generate the bootstrapped *ab* term, as well as the corresponding *p*-values. The bootstrapping method has been applied by multiple authors to test mediation in the field of KSB (Liou, Chih, Yuan & Lin, 2016) and IIB (Du, Liu, Straub, & Knight, 2017). Cheung, Gong, Wang, Zhou, and Shi (2016) applied bootstrapping in studies involving both KSB and IIB.

Because of the sample size involved, the bootstrapping method proved to be a suitable analytic strategy for testing hypotheses 6 and 7, on the direct and indirect effects. This study employed the parametric bootstrap method, which involves measurement of the parameter estimates between the independent variables (CDC and SRL) and the mediator variable (KSB), in addition to the relationship between the mediator variable and the dependent variable of IIB. The generated parameter estimates were later used to create a sampling distribution of the indirect effect (Lee, Lei, & Brody, 2015; Tofighi & MacKinnon, 2016).

Criteria for identification of ideal fit indices provided by Marsh, Balla, and McDonald (1988, p. 8) included “accurately and consistently reflect differences in” goodness-of-fit “for competing models of the same data”. The model fit indices available for use in SEM could be grouped into four types, as indicated in **Table 4**.

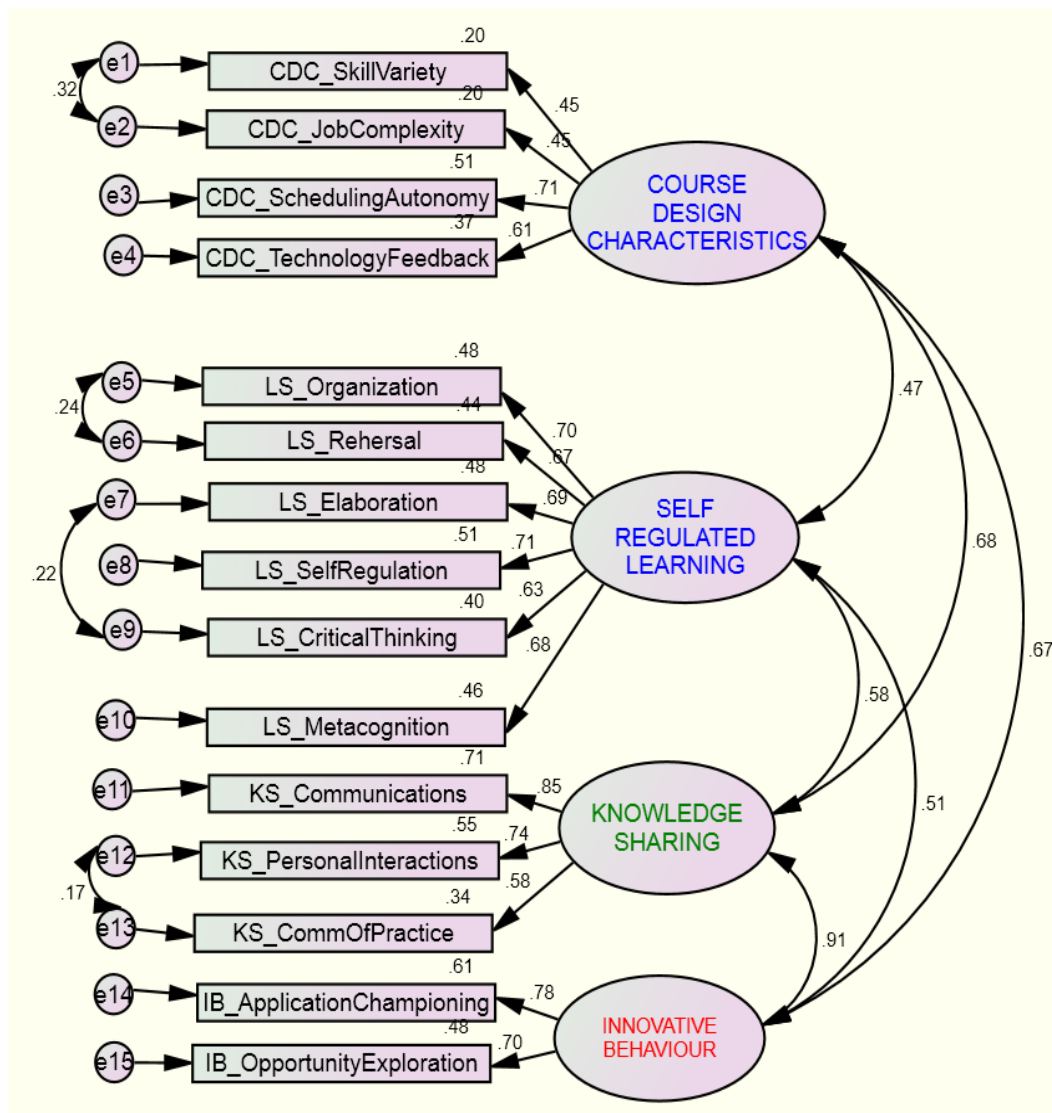
**Table 4.** Grouping of model fit indices based on Newsom (2012)

Absolute Fit Indices	Relative Fit Indices	Parsimonious Fit Index	Non-Centrality-Based Indices
Normed Chi-Square ( $\chi^2$ )			Comparative Fit Index (CFI)
Adjusted Goodness-of-Fit Index (AGFI)	Non-Normed Fit Index (NNFI)	Parsimony Goodness-of-Fit Index	Centrality Index
	Tucker-Lewis Index (TLI)		Root Mean Square Error of Approximation (RMSEA)
Goodness-of-Fit Index (GFI)			

The results suggested a good model fit ( $\chi^2= 92.84$ ,  $p< 0.001$ ,  $GFI=0.94$ ,  $AGFI=0.91$ ,  $CFI=0.95$ ,  $NNFI=0.90$ ,  $TLI=0.93$ , and  $RMSEA=0.061$ ). The path coefficients results provided ample evidence to suggest that CDC and SRL had significant direct effects on IIB. Hence, there was support for hypotheses 2 and 4.

### DISCUSSION OF RESULTS

The examination of the reliability and validity of the measures utilized CFA. The resulting measurement model is presented in **Figure 1**.



**Figure 1.** Measurement model used for discriminant and convergent validity analysis

These results suggest that most of the factor loadings were above 0.7, except for two variables from self-regulated learning and course design characteristics. Further factor analysis extracted four factors, which explain 82.3% of the total variance. In addition, twelve out of the nineteen variables had standardized regression weights just below 0.7. The weights of the items, however, were above 0.6 for seventeen of the items, and the related t-values were significant.

The main finding of the present study was that knowledge-sharing behaviour partially mediated the effect of course-design characteristics on individual innovative behaviour, and fully mediated the effect of self-regulated learning on individual innovative behaviour. Further, KSB had a significant direct effect on IIB. Hence, the study reveals that both CDC and SRL have significant positive indirect effects on individual innovative behaviour. The study thus contributes to KSB and IIB literature by examining the mediating mechanisms through which both CDC and SRL ultimately influence IIB. The present study generated empirical evidence that bands CDC and SRL at the contextual and individual level respectively, and how these two drivers impact technology students' KSB and IIB.

Figure 2 shows the final model of the mediating effect of KSB on IIB, with the four oblong shapes representing each of the four main variables in this study, including CDC and SRL. The rectangular shapes represent the elements contributing to each of these four variables.

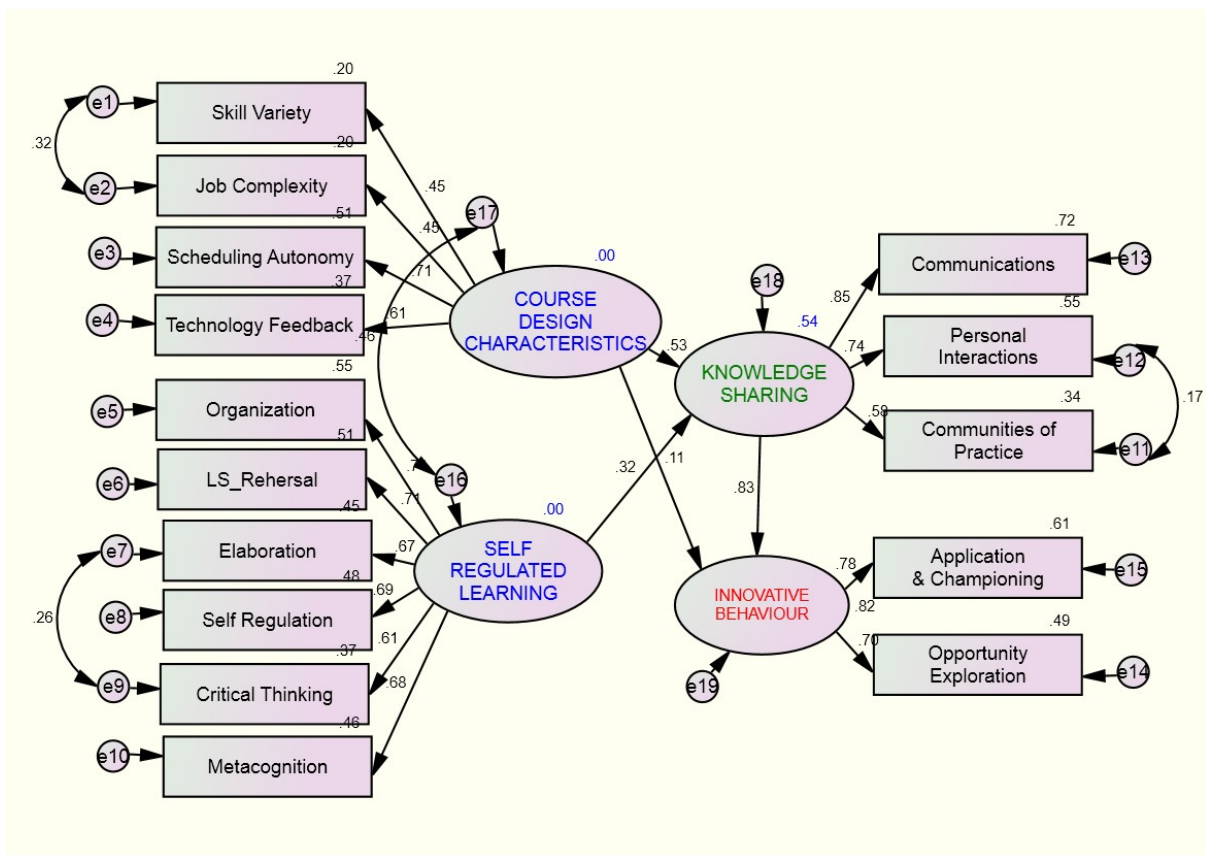


Figure 2. Final model of the mediating effect of KSB on IIB

### Course-Design Characteristics as Contextual Antecedent

The study presents CDC as a contextual antecedent of both KSB and IIB. The construct of CDC explores the contextual-level factors that act as barriers or enablers in the context of university education, for promoting innovative competencies in undergraduate technology students. This has the implication that it matters how courses are designed, as this ultimately influences the individual innovative behaviour of university students. The need, therefore, is for university management to involve those responsible for programme evaluation, so as to ensure that contextual factors are embedded in the design of courses. This may translate to developing policies and guidelines that inform the process of programme design.

In addition, the task and knowledge design components in the process of course design demand the development of an innovative ecosystem. In the domain of entrepreneurship and innovation, such an innovative

ecosystem comprises “academic coursework, access to mentors, the organization of business plan competitions, (and) student clubs with networking events” (Heukamp, 2015, p. 214).

### Self-Regulated Learning

Past studies (see e.g. Holman, Totterdell, Axtell, Stride, Port, Svensson & Zibarras, 2012) suggested that SRL has a significant positive effect on the innovative work behaviour of employees. The results of this study complement these works by demonstrating that, at the individual level, SRL is a significant antecedent of IIB. This has the implication that SRL promotes IIB, which may facilitate better foundations for students’ innovation, not only in university education, but also in the world of work.

Courses that speak to and inform the IT learner are more likely to stimulate innovative tendencies than courses that have limited IT feedback. This finding is well corroborated by the available literature (Battistelli, et al., 2013; De Spiegelaere, Van Gyes, De Witte, Niesen, & Van Hootehem, 2014; Hofmans, Gelens, & Theuns, 2014).

Similarly, the path linking SRL and KSB, though significant ( $\beta=.287$ ,  $p<.01$ ), was not very strong, in comparison to the path linking CDC and KSB.

### Knowledge-Sharing Behaviour as Mediator

The present study confirms the findings of Radaelli, Lettieri, Mura, and Spiller (2014), who posited that idea promotion is enabled by knowledge-sharing behaviour. While the sharing of best practices in the research by the latter authors promoted idea generation among healthcare professionals in hospice and palliative care organisation, this has now also been confirmed in the context of technology students in higher education. Further, Seo et al. (2016) found a significant effect for employees’ knowledge-sharing behaviour on individual innovative behaviour for a sample of 188 personal trainers from 11 fitness clubs. More closely related to the present context of university education, the present study affirms the findings of Martín, et al. (2015), who explored the determinants of students’ innovation in university education, utilizing a sample of 78 students.

## CONCLUSION

The findings were summated in a knowledge-sharing–innovative-behaviour SEM, with the results largely supporting all hypotheses. The findings lend support to the positive effect of course-design characteristics in fostering technology students’ individual innovative behaviour. The indirect relationship between course-design characteristics and individual innovative behaviour was significant and partially mediated by knowledge-sharing behaviour. The results of the research suggest a significant indirect relationship between self-regulated learning and individual innovative behaviour, which is fully mediated by knowledge-sharing behaviour. The results also reveal that both course-design characteristics and self-regulated learning act as significant drivers of knowledge-sharing behaviour and individual innovative behaviour among undergraduate technology students.

### Theoretical Implications

- 1) **Drivers of knowledge-sharing behaviour:** The study findings contribute significantly to our understanding of the roles of the three significant drivers of IIB among technology students, through a focus on SRL, CDC and KSB. While Martín et al. (2015) examined the role of knowledge sharing on IWB among students, their study did not include the variables of the present study of SRL and course design characteristics, the latter having further enriched the theoretical underpinnings.
- 2) **Self-regulated learning predicting individual innovative behaviour:** By establishing a positive direct link between SRL and IIB, this conclusion extends the findings of Martín et al. (2015) for technology students, who engage in SRL as an explicit part of good study practices.
- 3) **Course-design characteristics predicting individual innovative behaviour:** This study amplified the critical role played by decision-making, methods, and scheduling autonomy, technology feedback, task identity, task variety, task significance (Morgeson & Humphrey, 2006) in the context of technology education. The study lays a foundation for theoretical sense by elucidating the salient features of the course-design characteristics–knowledge-sharing relationship, in predicting the behavioural outcome of individual innovative behaviour. This finding agrees with literature that suggests that knowledge-sharing behaviour mediates individual innovative behaviour among employees (Chiu, Wang, Shih & Fan, 2011; Ramayah et al., 2014; Titi Amayah, 2013).
- 4) **The mediating role of knowledge-sharing behaviour:** The results suggest that knowledge-sharing behaviour positively mediates the relationship between CDC, SRL and the exogenous variable of IIB. Hence, the study contributes to literature on both SRL and IIB, by introducing knowledge-sharing behaviour as the

situational variable that interacts with both CDC and SRL to influence IIB. Prior studies have only provided evidence that knowledge-sharing behaviour has a significant effect on IIB, and that individual and contextual factors can enhance the level of IIB among employees (Afsar, 2016; Camelo-Ordaz et al., 2011; Choi et al., 2016; Seo et al., 2016).

### Practical Implications

- 1) **University management:** The results of this study generate a significant lesson for managers involved in the university sector, on how to leverage the attributes of SRL and CDC at individual and contextual level, to trigger IIB: it is important for university management to understand what fosters individual innovative behaviour among students.
- 2) **Implications for curriculum experts:** Since task and knowledge characteristics have the potential to enhance both knowledge-sharing behaviour and individual innovative behaviour, the review of university curricula should progress beyond the minimum requirements placed by a specific the university education regulator. With this background, curriculum planners and reviewers should consider carefully how the university designs specific task and knowledge characteristics.
- 3) **Implications for faculty:** With regard to the development of faculty to facilitate an innovative climate, the demand by technology students is for frequent communication on developments in their field. Hence, lecturers should communicate regularly with students about the latest developments in their field of study, expectations from industry, and values of the university in spurring innovation.
- 4) **Other drivers of knowledge-sharing behaviour at individual and contextual level:** The SEM model generated explains only 46.5 % of the variance in the individual innovative behaviour of technology students. Hence, future research should explore alternative and additional factors that act as antecedents of KSB.

### Limitations

The study that this article reports on does not claim perfection, as it has a few potential limitations that require more attention in future research. Firstly, the results were collected using self-reporting measures, which has the potential limitation of introducing common method variance. To overcome this challenge, the research design incorporated use of reverse coded items to reduce this possibility. McGrath, Mitchell, Kim, and Hough (2010) posit that respondents may respond to question items moderately or provide neutral answers leading to common method bias. To control for common method bias, Harman's one-factor test was applied as suggested by Podsakoff and Organ (1986). Common method bias was not a problem in the present study. To avoid a situation where common method bias is problematic, however, future research should collect data from multiple sources such as observer ratings and other methods devoid of self-reporting (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003).

The second limitation is aligned to methodological issues regarding the instruments used. The construct of course design characteristics was an attempt by the researcher to develop a construct for use in a university setting. The construct of CDC represents the contextual determinants of individual innovative behaviour. Being a new scale, it requires to be validated as a comprehensive measure for assessing course design, before full scale application to the university sector. This requires an investigation of the psychometric properties of the new scale using a different sample.

Thirdly, the generalizability of the findings may also pose some limitation. This study utilized a sample of technology students undertaking a computer related undergraduate programme in public universities. As suggested by MacCallum and Austin (2000, p. 211), the results and "conclusions may be limited to the particular sample, variables, and time frame". There is a possibility that the outcome may not generalize well in the context of private universities, that may have unique characteristics and organizational culture that are distinctively different from public universities.

It is therefore desirable if the model provided is tested in a different context of students to explain the individual and contextual antecedents of individual innovative behaviour. In addition, the findings may not generalize well to students in other academic programmes. Since the data was collected from students undertaking computer related programmes under the general domain of technology education, the implications of the findings to other technology subjects, such as Engineering or other university level programmes such as Arts and Humanities should be interpreted with caution.

Fourthly, the cross-sectional design is plagued by inherent weaknesses. Possibly a longitudinal study to investigate the development of individual innovative behaviour for a cohort group over the duration of their undergraduate programme may present different results. The results of such a four year longitudinal study continuing for the duration of the undergraduate programme should provide empirical evidence of changes in



both knowledge-sharing behaviour and individual innovative behaviour. Consequently, university education providers and policy makers can take appropriate actions to make the university education more responsive to developing individual innovative behaviour in university students.

A fifth limitation may relate to the narrow range of individual and contextual exogenous variable identified by the researcher. As explained by the quantitative results, there could be other factors that are significant antecedents of knowledge-sharing behaviour and individual innovative behaviour other than CDC and SRL included in the study. Elaborating on the other antecedents, refining the definition of each construct, and operationalizing each construct into additional measurement items would help overcome the limitation. Due to concerns on response rate and user fatigue, the present study could not include more variables, on consideration of questionnaire length and respondents fatigue.

## Recommendations

The authors recommend that especially with regard to future research, the following avenues be explored:

- 1) **Additional individual and contextual factors to explain students' knowledge-sharing behaviour and individual innovative behaviour:** The present study proposes only a subset of the many possible individual and contextual factors that act as antecedents of both knowledge-sharing behaviour and individual innovative behaviour. Hence, other important antecedents could have been left out of the present study. Future research should take a more extensive approach to cover variables, other than CDC and SRL. One possible extension would be to explore additional theories that provide significant individual and contextual factors. One possible field is to use alternative theories, such as creativity theory, that explores the "production of novel and useful ideas or solutions concerning products, services, processes, and procedures" (Rego, Sousa, Marques, & e Cunha, 2012, p. 429).
- 2) **Influence of learning strategies on knowledge-sharing behaviour and individual innovative behaviour:** Another possible extension of the model might involve exploring the effect of each of the individual factors of the SRL scale. Hence, future studies could explore the effects of rehearsal, self-regulation, metacognition, elaboration and critical thinking on knowledge-sharing behaviour and the endogenous variable of individual innovative behaviour.
- 3) **Influence of task and knowledge characteristics on individual innovative behaviour:** The study investigated the effect of CDC on both KSB and individual innovative behaviour. The CDC scale is a composite scale of two main sub-factors: task and knowledge characteristics. It would be interesting to investigate the effect of each of the two subscales of task and knowledge characteristics, in order to explore how they influence individual innovative behaviour. This could involve an exploration of how the existing and new academic programmes can be redesigned to accommodate an increase in both task and knowledge demands.
- 4) **Additional research in other programme areas and universities:** The scope of this study was a sample of students undertaking undergraduate technology courses. Hence, future research could involve other programme areas, to establish the generalisability of the findings to other disciplines. In addition, the sample was from public universities in Kenya. It would be noteworthy to replicate the study among private universities and perform a test of significant differences in the variable of the study in the two independent samples. Such a study will help to establish an all-encompassing view of the antecedents of innovation in universities in Kenya.
- 5) **Different methodologies of data collection:** The current study used survey methodology, which has some limitations. As technology students work on projects under supervision by faculty, future research using different observation methods may provide empirical data and overcome the problem of self-reporting of individual innovative behaviour among students.
- 6) **Model replication:** Future studies should aim at model replication to establish if the results can be replicated using different student samples from other disciplines. Kline (2005, p. 65) observed that it is "critical to eventually replicate a SEM if it is ever to represent anything beyond a mere statistical exercise". Consequently, so as to ensure that the present model is not just another statistical endeavour, future studies should replicate the model and proceed to explore other drivers of both knowledge-sharing behaviour and individual innovative behaviour. This should help to establish meaningfulness and provide generalisability of findings.
- 7) **Further research with the course-design characteristics questionnaire:** The CDC scale has been proposed by the researcher and has therefore not been validated in the context of students in university education. Consequently, additional research is required to establish the psychometric properties of the scale CDC, as well as its multi-dimensionality and factor structure. Hence, more research with a specific focus on populations and other types of universities is recommended.

- 8) **Role of autonomy in individual innovative behaviour:** The study finding that Scheduling Autonomy accounted for fourteen percent of the variance in individual innovative behaviour makes it a significant factor in the design of undergraduate courses. The autonomy is with respect to the extent to which the design of the curriculum allows students increasing options and independence to schedule their work during the semester, make relevant and weighty decisions regarding the programme, as well as have the liberty to choose the task methods required. This scenario poses a real dilemma for university regulators and curriculum designers, as it raises the question of whether to provide for more scheduling autonomy in course design, or remain rigid in course design, as per the existing design, policies, rules, regulations, and standards that inform the sector. This then provides a new avenue for further research on the operationalization of autonomy in the context of programme design and delivery of instruction to students.
- 9) **Role of organisation in individual innovative behaviour:** The study provided empirical evidence that organisation as a learning strategy explains 14% of the variance in individual innovative behaviour. This finding should inspire future research to conceptualise and explore the role of organisation in developing individual innovative behaviour among undergraduate technology students. For instance, could it be that students with more organisational skills tend to innovate more? Future conceptual models investigating the individual level antecedents could explore the mechanics through which organisation influences individual innovative behaviour and, in the process, make the results more intelligible. This represents contributing something new and original towards scholarly debates in the field, by filling a major gap in knowledge identified in the literature.

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# Dissimilarities in Attitudes between Students in Service and Mainstream Courses towards Statistics: An Analysis Conducted in a Developing Country

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Received 24 January 2018 • Revised 25 April 2018 • Accepted 1 May 2018

## ABSTRACT

In this study, we firstly investigate the attitudinal differences towards statistics between students (from a developing country) in service module and mainstream courses; and, secondly, differences in their attitudes over time, at the beginning and at the end of these courses. Knowledge regarding descriptive and inferential statistics are required for students at tertiary level in many disciplines, and the literature confirms (especially in developing countries) the under-preparedness (at all year levels), inadequate performance and low motivation of students in such courses. An international acknowledged instrument (SATS-36) revealed students' (from different faculties) initial attitudes towards statistics on six components (affect, cognitive competence, value, difficulty, interest and effort) and statistical significant differences between pre- and post-test data. The main implication from these findings are that students (in all faculties) tend to decrease in attitudinal scores over time, and educators can take awareness of this when designing pedagogy in statistics modules.

**Keywords:** attitudes towards statistics and gender, learning statistics, student attitudes in mainstream statistic courses, student attitudes in service module statistic courses, teaching statistics

## CONTEXT AND PURPOSE

Over the last two decades statistics education emerged worldwide as a discipline in its own right (Garfield & Ben-Zvi, 2007; Jose, 2017), although it is closely connected to mathematics education. Garfield and Ben-Zvi (2007) reviewed multiple studies (conducted by researchers globally over a variety of disciplines including students at all levels) focusing on the teaching and learning of statistics and probability. Through their investigation, they identified difficulties students have in learning statistics and suggested educators should revisit traditional teaching methods. Recently, Jose (2017) argued that researchers altogether should investigate different pathways (such as writing literature reports, conferences and workshops participation) to acquire innovative knowledge about methodology and statistics. Within the South African education system, the topics statistics and probability are initially introduced to students as a component of the mathematics school curriculum (CAPS) (Department of Basic Education, 2011). Furthermore, fundamental and progressive statistical knowledge that requires competencies such as representing data, calculating probability, the notion of distribution, variability, sampling and statistical inference, is required in a variety of courses over many faculties (science, engineering, business, humanities, education and others) at tertiary level. The students enrolled for these courses do not necessarily have a strong mathematical background. The unsatisfactory performance of students (particularly in developing countries) in mathematics at school is well documented and confirmed by international tests of educational achievement, such as TIMSS (Trends in International Mathematics and Science Study) (Juan & Visser, 2017; Spaull, 2013), and similar trends are experienced at tertiary level (Rylands & Coady, 2009). Juan and Visser (2017) collected data from almost twelve thousand Grade 9 South African students from different socio-economic environments and confirmed the influence of socio-economic factors on science achievement. Rylands and Coady (2009)

### Contribution of this paper to the literature

- Statistics students in service modules revealed lower attitudinal scores towards statistics than students in mainstream courses. However, all students decreased in attitudinal scores over time.
- Statistics students in different faculties should ideally be engaged in a well-planned set of activities, focusing on their particular professional development, aimed at strengthening their competencies and gradually improving their attitudes towards the subject.
- Some teaching and learning practices were identified from this investigation, which can be used by statistics educators from different disciplines to enhance statistical reasoning, thinking and literacy in students.

highlighted the importance of students' (from an Australian public university) strong mathematical secondary school background on their performance in science subjects at first-year tertiary level. Furthermore, research findings (Yousef, 2017) from data collected at a non-Western (Arabic) setting from 750 undergraduate business students, confirmed a selection of aspects play a role in students' understanding of quantitative course material, apart from their mathematical knowledge. Some of these aspects are the teaching style of the lecturer in relation to how the lecturer speaks, the pace and structure of presenting the content, the communication between lecturer and student, language of instruction, and the availability of course content via an electronic learning environment.

In addition, positive attitudes of students towards statistics could influence students' enrolment, achievement and motivation towards quantitative courses (Coetzee & van der Merwe, 2010). Research results from Coetzee and van der Merwe (2010, p. 1), conducted in South Africa, revealed "the degree to which students perceived themselves to be competent in mathematics was related to the degree to which they felt confident in their own ability to master statistics". We were of the opinion that students from different faculties view and experience the learning of statistics courses (mainstream courses versus service module courses) differently; findings from Sulieman (2015), comparing 440 undergraduate students' (from the American University of Sharjah in the UAE) attitudinal differences across different majors, strengthened this opinion.

A mainstream statistics course is catering for students who major in statistics or in mathematical sciences, while a service module statistics course is catering for students whose majors falls outside the natural sciences, such as commerce, health sciences or engineering. Mainstream courses usually have a stronger theoretical base than service courses, although both focus on contextual applications and interpretations. Related to this study, both courses are offered by experienced lecturers, in statistical and pedagogical knowledge, and both courses consist of a similar layout (with a rather strong focus on assessment).

In this study, we explored the attitudes of students at a public university in South Africa, in the Faculty of Science (students enrolled for statistics as a mainstream course), the Faculty of Management and the Faculty of Engineering (students enrolled for statistics as a service module course). We expect students in mainstream statistics modules to have a more positive outlook towards statistics than students enrolled for service reasons.

The *purpose* of the study is to explore the initial attitudinal differences of students between mainstream and service course and to track these over time (from the beginning to the end of a course). The two *research questions* this inquiry attempts to answer are as follow:

- What are the initial differences between the attitudes of students in service and mainstream courses toward statistics?
- Are there changes in the attitudinal scores of statistics students (between mainstream and service courses) from the beginning (labelled as the pre-test) to the end of the particular module (labelled as the post-test)?

This inquiry can broaden our knowledge about how students in developing countries across disciplines experience statistics courses. It strives to identify some teaching and learning practices which can be used by statistics educators from different disciplines to enhance statistical reasoning, thinking and literacy in students and to improve their disposition towards the subject.

## LITERATURE PERSPECTIVES

### Underlying Theoretical Framework

We grounded our view on learning statistics so that students develop a conceptual understanding of the content, on the "Statistical Reasoning, Thinking, and Literacy" framework from Garfield and Ben-Zvi (2007, p. 380). According to this framework, there are clear distinctions between statistical literacy, reasoning and thinking. Although all three components are interconnected, and a type of hierarchy does exist, statistical literacy forms the foundation for reasoning and thinking. Garfield and Ben-Zvi (2007, pp. 380–381) explained *Statistical Literacy* (which is often the expected outcome of introductory courses in statistics) as an "understanding and using the basic

language and tools of statistics: knowing what basic statistical terms mean, understanding the use of simple statistical symbols, and recognising and being able to interpret different representations of data”, whereas *Statistical Reasoning* is “the way people reason with statistical ideas and make sense of statistical information”, and *Statistical Thinking* “involves a higher order of thinking than statistical reasoning ... the way professional statisticians think”. We are of the opinion all three components are important for students to develop a proficiency in statistics.

Garfield and Ben-Zvi (2007), supported by other literature sources (Bakker & Gravemeijer, 2004; Chick & Watson, 2002; Garfield & Chance, 2000; Pfannkuch, 2005) in the field of statistics education and based on original work (proposed 10 principles) from Garfield (1995), introduced a list of eight principles about how students learn statistics. These research-based principles (Garfield & Ben-Zvi, 2007, pp. 387–389), which provide insight to educators, are: (1) “students learn by constructing knowledge” (they enter the learning environment with prior knowledge and tend to accept new ideas only if their previous ideas do not work); (2) “students learn by active involvement in learning activities” (they tend to learn cooperatively when solving problems); (3) “students learn to do well only what they practice doing” (they tend to learn more efficiently when they experience applying new ideas); (4) “difficulty students have in understanding basic concepts of probability and statistics” can easily be underestimated, as well as an overestimation of; (5) “how well students understand basic concepts”; (6) “learning is enhanced by having students become aware of and confront their errors in reasoning” (they are often slow to change misconceptions); (7) “technological tools should be used to help students visualize and explore data, not just to follow algorithms to pre-determined ends” (these tools provide students opportunities to explore); and (8) “students learn better if they receive consistent and helpful feedback on their performance” (they require time to reflect on the feedback, make changes and attempt problems again).

Although these principles emerged from studies conducted globally, we are of the opinion these eight principles are applicable for the teaching and learning of statistics in a South African context. Related to this inquiry, the instruction of both mainstream and service courses is informed by strong educational research following the before-mentioned notion from Jose (2017), but also considering the above-mentioned principles from Garfield and Ben-Zvi (2007). It almost seems as if the course instructors are still searching for the best scenario to intertwine theory and practice for both mainstream and service courses.

### Literature Perspective on Attitudes

An overview of the literature suggests a relation between learning statistics and a positive attitude towards the discipline. Coetzee and van der Merwe (2010) confirmed this and explained attitudes towards statistics as a multidimensional concept, focusing first on an affective domain such as emotions and motivation, second on a cognitive domain such as beliefs and knowledge about the discipline, and third on a behavioural domain with regards to tendencies in studying the content. We considered the theory on learning statistics and fostering a confident attitude towards statistics as equally important components.

## RESEARCH DESIGN

### Research Paradigm

This inquiry relates to an attempt to measure the attitudes of students’ in mainstream and service courses towards statistics, conducted from a post-positivist worldview (Creswell, 2013). The term *post-positivism* refers to a thinking that does not focus on the reductionist views of positivism but, rather, implies an evidence-based, quantitative approach to research. From this viewpoint, we reflect a need to examine reasons that affect results. Such developed knowledge is based on measures, completed by participants, and reflect a real-world reality. Phillips and Burbules (2000) discussed some fundamental assumptions related to this paradigm. Two of these assumptions, relevant for this study are, firstly, the collection of data on an instrument to shape knowledge and, secondly, the attempt to explain a situation by studying the relationship between variables.

### Research Instrument

Multiple surveys, measuring students’ attitudes towards statistics, exists in the literature (see e.g. Nolan, Beran, & Hecker, 2012). From these, a large interest in monitoring and assessing students’ attitudes in statistics modules has developed, mostly with the aim to predict and improve performance. In this study, we selected an internationally acknowledged instrument, Survey of Attitude toward Statistics (SATS-36), based on two reasons. Firstly, it has been used both locally, (Coetzee & van der Merwe, 2010) and internationally (Mills, 2004; Schau, Stevens, Dauphinee, & Del Vecchio, 1995; Vanhoof, Kuppens, Sotos, Verschaffel, & Onghena, 2011); and, secondly, the instrument comprises of a pre-test and a post-test. Schau et al. (1995) originally introduced SATS-28, consisting of 28 questions separated among four factors: *affect* (describing students’ feelings concerning statistics); *cognitive*

**Table 1.** Descriptive statistics of the pre-test participants

Item	Category	Freq.	%
Gender	Female	236	39.3
	Male	364	60.7
If the choice had been yours, how likely is it that you would have chosen to take statistics?	Not at all likely	155	25.8
	Somewhat likely	260	43.3
	Very likely	178	29.7
Home Language	Afrikaans	18	3.0
	English	115	19.2
	Indigenous South African or African language	442	73.7
	Other (Chinese, French, etc.)	24	4.1

**Table 2.** Descriptive statistics of the post-test participants

Item	Category	Freq.	%
Gender	Female	182	50.3
	Male	180	49.7
If the choice had been yours, how likely is it that you would have chosen to take statistics?	Not at all likely	113	31.2
	Somewhat likely	126	34.8
	Very likely	123	34.0
Home Language	Afrikaans	6	1.7
	English	99	27.3
	Indigenous South African or African language	250	69.1
	Other (Chinese, French, etc.)	7	1.9

*competence* (relating students' attitudes about their intellectual knowledge and skills when applied to statistics); *value* (unfolding students' attitudes about the usefulness, relevance, and worth of statistics in personal and professional life); and *difficulty* (telling students' state of mind about the difficulty of statistics as a subject). Later, Schau (2003) extended the original form to a 36-item version (SATS-36) including two additional factors: *interest* (describing students' level of individual interest in statistics); and *effort* (clarifying the amount of work the student expends to learn statistics). The responses for the SATS-36 survey were measured on a seven-point Likert scale (1 = strongly disagree, 4 = neither disagree nor agree, 7 = strongly agree), where higher scores correspond to a more positive attitude and lower scores to a more negative attitude. Together with the SATS-36 questionnaire, we included a few additional items to explore participants' biographical data and former mathematics achievement in Grade 12.

## Participants

### *Pre-test sample*

Six hundred undergraduate statistics students, studying on a full-time basis at the University of Johannesburg (UJ), took part in the pre-test investigation. A convenient sampling method was utilised and participants completed the survey online via the UJ student portal during the first term of the academic year in 2017. The participants consisted of 130 first-year students from the Faculty of Science (39 female, 91 male, N = 169); 196 third-year students from the Faculty of Engineering (42 female, 154 male, N = 267); and 274 first-year students from the Faculty of Management (155 female, 119 male, N = 483). **Table 1** displays descriptive statistics of the pre-test sample.

### *Post-test sample*

The participants (362) in the post-test, sampled similar to the pre-test, were all full-time UJ students. The collection of data (comparable with the pre-test) was during the last term of the 2017 academic year. These participants consisted of 80 first-year students from the Faculty of Science (26 female, 54 male, N = 132) and 282 first-year students from the Faculty of Management (156 female, 126 male, N = 400). **Table 2** shows descriptive statistics for the post-test sample. From **Table 1** (pre-test statistics), approximately 26% of participants were not at all likely to choose statistics to be part of their degree if the choice had been theirs and only 19% of participants indicated English (the medium of instruction at UJ) as their home language. From **Table 2** (post-test statistics), even more participants (31%) indicated they were not likely to choose the subject by choice and 27% confirmed English as their home language.

We viewed both aspects, the eagerness of choosing statistics as a subject and home language versus language of instruction, as relevant for this study and, in general, to inform statistics pedagogy.

**Table 3.** Example item per factor in SATS-36

Factor	Example Items
Affect (6 items)	1. I will like statistics
Cognitive Competence (6 items)	31. I can learn statistics
Value (9 items)	10. Statistical skills will make me more employable
Difficulty (7 items)	34.* Statistics is highly technical
Interest (4 items)	20. I am interested in using statistics
Effort (4 items)	2. I plan to/did work hard in my statistics course

\*negatively worded items are reverse coded to assure that high scores represent a positive attitude (i.e., 1 becomes 7, 2 becomes 6.)

**Table 4.** Cronbach alpha levels per factor

Factor	Faculty	Cronbach alpha	
		Pre	Post
Affect	Science	0.8	0.9
	Management	0.8	0.9
Cognitive Competence	Science	0.6	0.7
	Management	0.8	0.8
Value	Science	0.7	0.8
	Management	0.8	0.9
Difficulty	Science	0.5	0.5
	Management	0.6	0.5
Interest	Science	0.8	0.8
	Management	0.9	0.9
Effort	Science	0.8	0.8
	Management	0.7	0.7

### Ethical Measures, Validity and Reliability

Regarding *ethical measures*, on both data-collection occasions, participants were informed about the purpose of the inquiry; they intentionally participated, and their confidentiality and anonymity were ensured. The *validity* of SATS-36 has been studied in literature reports, locally and internationally (Coetzee & van der Merwe, 2010; Nolan et al., 2012; Vanhoof et al., 2011).

The instrument was confirmed to be a valid measure of students' attitude towards statistics as it covers the particular domain. However, much debate has taken place on whether six or four factors should be included in the measure. Reasons were raised to maintain the six-factor model, such as its validation in several studies and allowing researchers to compare recent findings with former studies. Furthermore, Vanhoof et al. (2011) thoroughly investigated the structure of the SATS-36 survey, by confirmatory factor analysis - they confirmed that the six-factor model outperformed the four-factor model in their investigation. **Table 3** displays an example item per factor.

**Table 4** displays the Cronbach alpha levels per factor to confirm internal consistency. All factors (affect, cognitive competence, value, difficulty, interest and effort) showed acceptable levels consistent with former studies (Coetzee & van der Merwe, 2010; Nolan et al., 2012). Moreover, the difficulty factor showed a low (although acceptable) level of internal consistency (Cronbach alpha = 0.5 to 0.6). Vanhoof et al. (2011) pointed out that this could largely be due to two of the items (item 22 and item 36) in the difficulty factor, which asks about most people's attitudes regarding the difficulty of statistics, rather than the students' own attitude. Furthermore, Vanhoof et al. (2011) suggested that removing the two items from the analysis could increase the level of internal consistency. However, we decided to maintain the two items in the analysis so that it is more comparable with other studies.

### DATA ANALYSIS AND FINDINGS

The purpose of the study is to explore the initial attitudinal differences of students between mainstream and service course and to track these from the beginning to the end of a course. Data were obtained from students enrolled in the Faculties of Management, Engineering and Science and analysed by the Statistical Package of the Social Sciences (SPSS version 24). From **Figure 1** (displaying pre-test data), attitudes in terms of *affect*, *cognitive competence*, *value*, *effort* and *interest* can be seen as more positive in nature, whereas *difficulty* seems to be more neutral. Surprisingly, the *effort* factor falls near the top of the seven-point Likert scale - which is unlikely to become more positive in post-test results. Van Appel and Durandt (2017) compared these pre-test attitudinal scores. They found significant differences in attitudes towards statistics and between genders. Four factors (affect, difficulty, interest and effort) contributed towards the attitudinal differences between courses and three factors (affect,

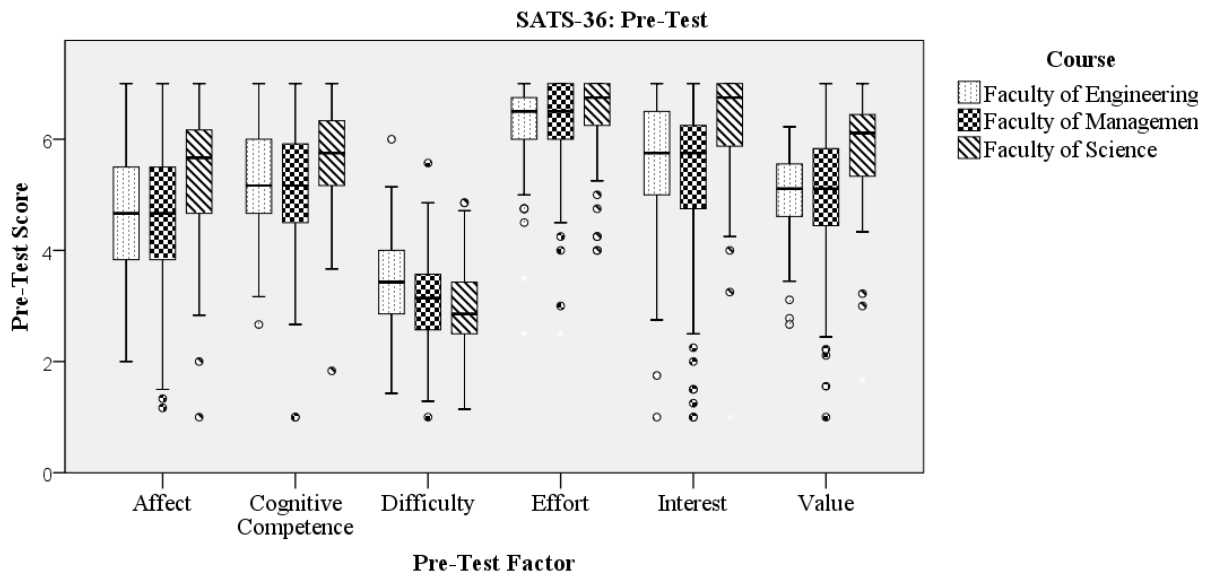


Figure 1. Boxplots illustrating pre-test attitudinal scores

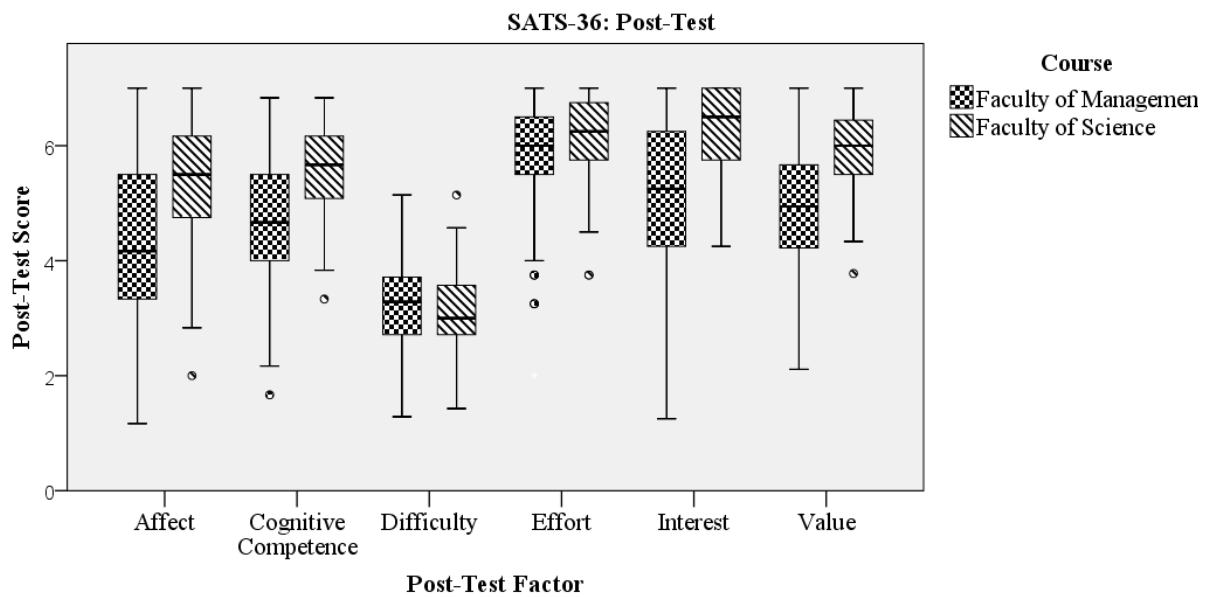


Figure 2. Boxplots illustrating post-test attitudinal scores

difficulty and effort) contributed towards attitudinal differences in gender. More specifically, they established that students in service courses enjoyed statistics less than students in the mainstream courses, they experienced the subject as more difficult, had lower interest in learning the content, and needed to put in more effort to learn statistics. Similarly, female students enjoyed statistics less, found the subject more difficult, and needed to put in more effort to learn statistics than their male counterparts did.

In Figure 2 (displaying post-test data), all factors are shown more positive in nature, except for the *difficulty* factor (similar to pre-test data).

To investigate the attitudinal difference towards statistics between the service and mainstream modules for the post-test data (the width of the gap between service and mainstream modules), we carried out multiple two-sample independent Mann-Whitney U tests. This is a non-parametric hypothesis test used to determine significant differences in a scale or ordinal variable. Table 5 displays the Mann-Whitney U test results.



**Table 5.** Differences in attitudes (pre-test versus post-test)

Factor	Test Variables	Mean Rank	Mann-Whitney U	p-value (2-tailed)
<b>Mainstream vs service module</b>				
Affect	Faculty of Science	243.55	6316	0
	Faculty of Management	163.9		
Cognitive Competence	Faculty of Science	246.63	6070	0
	Faculty of Management	163.02		
Value	Faculty of Science	266.29	4497	0
	Faculty of Management	157.45		
Difficulty	Faculty of Science	169.07	10285	0.228
	Faculty of Management	185.03		
Interest	Faculty of Science	258.85	5092	0
	Faculty of Management	159.56		
Effort	Faculty of Science	204.47	9442.5	0.025
	Faculty of Management	174.98		
<b>Gender</b>				
Affect	Female	165.03	13383	0.003
	Male	198.15		
Cognitive Competence	Female	171.22	14509	0.060
	Male	191.89		
Value	Female	174.48	15102	0.199
	Male	188.6		
Difficulty	Female	179.51	16017	0.715
	Male	183.52		
Interest	Female	169.15	14133	0.024
	Male	193.98		
Effort	Female	192.48	14381	0.043
	Male	170.39		

Firstly, the findings indicated that five factors (affect, cognitive competence, value, interest and effort) showed significant differences ( $p$ -value  $< 0.05$ ) in attitudes towards statistics between mainstream and service modules in the post-test. More specifically, we found that students' attitudes in mainstream statistics modules were significantly higher in *affect*, *cognitive competence*, *value*, *interest* and *effort*, compared with students in service modules. This shows that there was no visible improvement in closing the attitudinal gap between mainstream and service modules in statistics, over the period in this study. Secondly, we found significant differences in *affect*, *interest* and *effort* between genders. When compared to the pre-test results (reported in Van Appel & Durandt, 2017) we realised that female students did not find statistics more difficult anymore, but showed less interest in the course. However, a thorough investigation into this will be left for further research.

To investigate, within each faculty, the difference in participants' attitudinal scores towards statistics between the pre-test and post-test, our sample consisted only of participants that answered both these surveys - 161 students from the Faculty of Management and 54 students from the Faculty of Science. **Figure 3** displays participants' responses on one of the added questions (apart from SATS-36, view the discussion on 'research instrument'), 'If the choice had been yours, how likely is it that you would have chosen to take statistics'.

Somewhat disturbing, after two semesters of statistics, there was no visual increase in the likelihood of students in the Faculty of Management (service module) choosing the subject by choice. Keeping in mind the requirement for statistical competence in many professions, statistic educators could reflect on these results when considering methods of instruction.

**Table 6** displays descriptive statistics regarding participants' attitudes towards statistics for both the pre-test and post-test. The mean, median and modal scores (out of 7) for each factor indicated a more positive attitude towards statistics. *Difficulty* seemed to be the most negative prevailing attitude, with a modal score of 3 for students in the Faculty of Science and 3.1 for students in the Faculty of Management. To comprehend the development of participants' attitude towards statistics, we compared the initial attitude (pre-test) with the ending attitude (post-test).

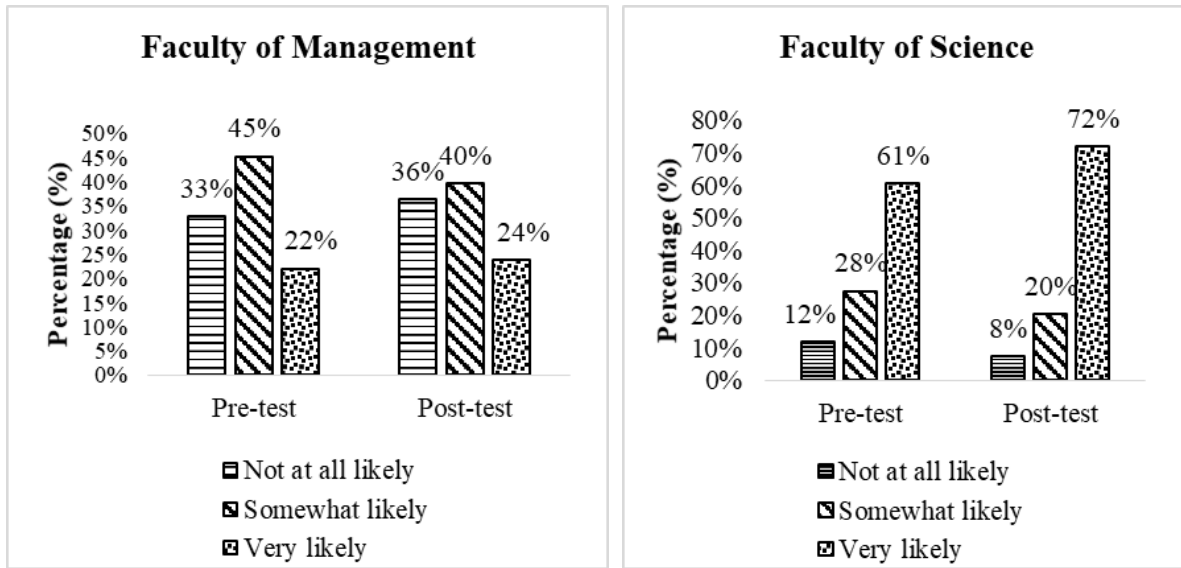


Figure 3. Findings displaying participants' likelihood to choose statistics as a subject

Table 6. Descriptive statistics for pre-test and post-test data

Factor	Faculty	Mean		Median		Mode		Std. Dev.	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
Affect	Science	5.5	5.3	5.6	5.5	6.5	5.8	1.1	1.2
	Management	4.7	4.5	4.7	4.5	4.0	4.7	1.1	1.3
Cognitive Competence	Science	5.8	5.5	5.8	5.6	5.7	5.8	0.7	0.8
	Management	5.2	4.8	5.2	4.8	5.2	4.0	0.9	1.0
Value	Science	5.9	6.0	6.1	6.1	6.1	6.7	0.7	0.7
	Management	5.0	4.9	5.0	5.0	5.6	5.7	1.0	1.0
Difficulty	Science	3.0	3.0	2.9	3.0	3.1	2.7	0.7	0.6
	Management	3.1	3.2	3.1	3.3	3.0	3.9	0.7	0.7
Interest	Science	6.3	6.3	6.8	6.5	7.0	7.0	0.8	0.8
	Management	5.4	5.1	5.5	5.3	6.0	6.5	1.3	1.4
Effort	Science	6.7	6.2	6.8	6.3	7.0	6.3	0.4	0.8
	Management	6.4	6.0	6.8	6.3	7.0	6.5	0.6	0.8

A multiple paired two-sample Wilcoxon Signed Rank tests (displayed in Table 7 and Table 8) were applicable. The Wilcoxon signed-rank test is a non-parametric statistical hypothesis test to compare two related samples. In Table 7, significant differences ( $p$ -value  $< 0.05$ ) were found between the pre-test and post-test scores in the Faculty of Management with regarding to the factors *affect*, *cognitive competence*, *interest* and *effort*, at a 95% confidence level. More specifically, the ranks indicated all six factors have significantly decreased in attitude in the post-test. Similarly, we found statistically significant differences ( $p$ -value  $< 0.05$ ) between the post-test and the pre-test scores in the Faculty of Science for *cognitive competence* and *effort*, at a 95% confidence level. The ranks, displayed in Table 8, indicated these two factors have significantly decreased in attitude in the post-test. For both faculties there has been a decrease in *cognitive competence* and *effort* in the post-test, which indicated participants' attitudes about their intellectual knowledge and skills when applied to statistics decreased. From the findings, we could conclude participants' confidence in their skills and ability to learn statistics has decreased significantly. Furthermore, participants indicated that they spent less time learning statistics, shown by the significant decrease in post-test *effort*. Students in the Faculty of Management showed a significant lower *affect* and *interest*, indicating they enjoyed statistics less and found fewer interests in the subject.

**Table 7.** Wilcoxon Signed Ranks – Faculty of Management

Factor	Ranks	N	Mean Rank	Sum of Ranks	Z	p-value (2-tailed)
Affect	Negative	86 <sup>a</sup>	80.85	6953	-2.76	0.006
	Positive	62 <sup>b</sup>	65.69	4073		
	Ties	13 <sup>c</sup>				
Cognitive Competence	Negative	97 <sup>a</sup>	83.13	8063.5	-4.328	0
	Positive	54 <sup>b</sup>	63.19	3412.5		
	Ties	10 <sup>c</sup>				
Value	Negative	86 <sup>a</sup>	77.56	6670.5	-1.734	0.083
	Positive	65 <sup>b</sup>	73.93	4805.5		
	Ties	10 <sup>c</sup>				
Difficulty	Negative	67 <sup>a</sup>	70.28	4708.5	-0.887	0.375
	Positive	76 <sup>b</sup>	73.52	5587.5		
	Ties	18 <sup>c</sup>				
Interest	Negative	92 <sup>a</sup>	74.27	6833	-3.773	0
	Positive	49 <sup>b</sup>	64.86	3178		
	Ties	20 <sup>c</sup>				
Effort	Negative	106 <sup>a</sup>	74.74	7922.5	-6.473	0
	Positive	33 <sup>b</sup>	54.77	1807.5		
	Ties	22 <sup>c</sup>				

a. Post\_Factor < Pre\_Factor; b. Post\_Factor > Pre\_Factor; c. Post\_Factor = Pre\_Factor

**Table 8.** Wilcoxon Signed Ranks – Faculty of Science

Factor	Ranks	N	Mean Rank	Sum of Ranks	Z	p-value (2-tailed)
Affect	Negative	28 <sup>a</sup>	24.23	678.5	-1.215	0.225
	Positive	19 <sup>b</sup>	23.66	449.5		
	Ties	7 <sup>c</sup>				
Cognitive Competence	Negative	31 <sup>a</sup>	26.68	827	-2.458	0.014
	Positive	17 <sup>b</sup>	20.53	349		
	Ties	6 <sup>c</sup>				
Value	Negative	18 <sup>a</sup>	23.14	416.5	-1.143	0.253
	Positive	27 <sup>b</sup>	22.91	618.5		
	Ties	9 <sup>c</sup>				
Difficulty	Negative	24 <sup>a</sup>	25.73	617.5	-0.05	0.96
	Positive	25 <sup>b</sup>	24.3	607.5		
	Ties	5 <sup>c</sup>				
Interest	Negative	15 <sup>a</sup>	17.37	260.5	-0.248	0.804
	Positive	16 <sup>b</sup>	14.72	235.5		
	Ties	23 <sup>c</sup>				
Effort	Negative	37 <sup>a</sup>	21.51	796	-4.338	0
	Positive	5 <sup>b</sup>	21.4	107		
	Ties	12 <sup>c</sup>				

a. Post\_Factor < Pre\_Factor; b. Post\_Factor > Pre\_Factor; c. Post\_Factor = Pre\_Factor

## CONCLUSION

The professional development of students at tertiary level over a variety of disciplines requires statistical competencies. Statistics students (more so in developing countries) generally display lower attitudinal scores towards the subject, lack fundamental mathematical knowledge and perform unsatisfactorily in statistics courses (Coetzee & van der Merwe, 2010; Juan & Visser, 2017; Rylands & Coady, 2009; Spaul, 2013; Van Appel & Durandt, 2017). Students learn statistics through active involvement and participation in the learning activities and by fostering, a more positive disposition towards the subject and former studies almost pleaded for innovative teaching and learning strategies (Garfield & Ben-Zvi, 2007; Jose, 2017).

In this study, we compared the attitudes of students towards statistics in the Faculty of Science (students enrolling for statistics as a mainstream course) with the attitudes of students in the Faculties of Management and Engineering (students enrolling for statistics as a service module course). We attempted to answer the two *research questions*:

- What are the initial differences between the attitudes of students in service and mainstream courses toward statistics?
- Are their changes in the attitudinal scores of statistics students (between mainstream and service courses) from the beginning (labelled as the pre-test) to the end of the particular module (labelled as the post-test)?

Aligned with the theoretical framework on “Statistical Reasoning, Thinking, and Literacy” from Garfield and Ben-Zvi (2007, p. 380) and the strong relation between learning statistics and fostering a positive attitude toward the discipline, the researchers conducted this investigation. Quantitative data were collected on two occasions via the valid and reliable SATS-36 instrument. Findings revealed significant differences in attitudes of students between service and mainstream courses towards statistics and between genders. Likewise, significant differences in attitudes were detected between the pre-test and post-test scores. The finding revealed, on average, students’ attitudes towards statistics did not change over two semesters or become more negative over time. These findings compare with other studies (for example, Schau, 2003; Sizemore & Lewandowski, 2009).

Although this South African study accentuates that statistics students in service modules reveal lower attitudinal scores towards statistics than students in mainstream courses, all students find the subject rather difficult and they are less likely to choose statistics by choice. It is therefore crucial for statistics educators to consider the teaching and learning practices per discipline, but also across different disciplines. Furthermore, educators should investigate a broad spectrum of interventions to scaffold course content to address the *difficulty* factor in statistics courses. Keeping students involved and motivated throughout a statistics course places another responsibility on the educator and requires a certain amount of innovation. Ideally, statistics students in different faculties should be engaged in a well-planned set of activities, focusing on their particular professional development, aimed at strengthening their competencies and gradually improving their attitudes towards the subject. This is left for further investigation.

## ACKNOWLEDGEMENTS

We gratefully acknowledge the valuable contribution of Carmel McNaught in the preparation of this paper and Candace Schau for granting consent for SATS-36 in 2017.

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## Students' Achievement in Basic Electronics: Effects of Scaffolding and Collaborative Instructional Approaches

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Received 24 January 2018 • Revised 7 March 2018 • Accepted 1 May 2018

### ABSTRACT

This study determined effects of scaffolding and collaborative instructional approaches on students' achievement in Basic Electronics. A quasi-experimental research design was adopted for the study. The performance of 105 Senior Secondary two (SS 2) students in Basic Electronics was obtained after being taught with scaffolding and collaborative instructional approaches using the Basic Electronics Cognitive Achievement Test (BECAT). Data collected were analyzed using mean and ANCOVA. Results revealed that a collaborative instructional approach is more effective in improving student achievement in Basic Electronics than a scaffolding instructional approach. Also, gender had no significant influence on students' achievement in Basic Electronics when taught using scaffolding and collaborative instructional approaches. It was concluded that the collaborative instructional approach is a viable teaching method for improving students' achievement in Basic Electronics. It was recommended that teachers adopt the collaborative instructional approach for teaching Basic Electronics.

**Keywords:** basic electronics, scaffolding instructional approach, collaborative instructional approach, cognitive achievement, gender

### INTRODUCTION

Basic Electronics is one of the vocational courses offered at the upper level of the Nigerian secondary school system. It is a branch of science and technology which deals with the study of the flow and control of electrons in electrical circuits and their behaviour and effects in vacuums, gases, and semiconductors. The objectives of the curriculum are to: (i) support understanding of the basic electronic components in addition to circuits; (ii) lay a good foundation for communication and control systems; (iii) provide a foundation for creativity and technological development in electronics; and (iv) stimulate, develop and enhance entrepreneurial skills in electronics (Nigerian Educational Research and Development Council (NERDC, 2007). In order for these objectives to be realized, teachers of electronics, apart from being versed in the subject matter, needs to be skilled in the selection of appropriate instructional methodologies, as well as effectively put them to use in the classroom. This will greatly determine their instructional success, which is measured by the academic achievements of the students they teach (Ofojebe, 2010).

Essentially, the Nigerian post-primary school is structured into two systems namely; secondary schools and technical colleges. For a student to be admitted into any of the two, s/he must have completed the six years of the primary school as well as the first three years of secondary education (Federal Republic of Nigeria, FRN, 2013). This is why there are two main curricula for secondary education in Nigeria: the conventional secondary school curriculum developed and controlled by the Nigerian Educational Research and Development Council (NERDC), and the technical college curriculum, developed and controlled by the National Board for Technical Education (NBTE). However, there are schools in Nigeria that operate the two curricula. Such schools are science and technical colleges, and they exist in almost every state of the Federal Republic of Nigeria, and are owned by either

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#### Contribution of this paper to the literature

- Scaffolding and collaborative instructional approaches are effective for improving students' cognitive achievement.
- Male students performed better in the Basic Electronics cognitive achievement test than female students.
- The collaborative instructional approach significantly improved student achievement in Basic Electronics over the scaffolding instructional approach.
- There was no significant effect of gender on students' cognitive achievement in Basic Electronics.
- The treatments given to the students did not influence the mean score of one gender over the other in the Basic Electronics Cognitive Achievement Test.

government or private entities. Such schools that operate the two curricula are of particular interest to this study. Literature from examination bodies in Nigeria (National Examinations Council, NECO, 2013) show that the academic achievement of the students in science and technical schools is a source of concern.

In recent times, there have been reports that the academic achievement of students has been below expectation (Animasahun, 2014). According to Ogundola, Abiodun, and Jonathan (2010) this failure to meet expected standards is attributable to the continuous use of unsuitable instructional methodologies (mostly a traditional didactic instructional approach) by teachers. Teachers of courses like Basic Electronics are therefore faced with the challenge of presenting relevant classroom activities that can facilitate conceptual change, allow understanding, and recognize individual differences amongst students. Constructivist-based instructional approaches have these qualities.

The goal of instruction is to make the learner see the world through her/his own eyes, and not through the eyes of anyone else, much less the teacher's. Ertmer and Newby (2013) submitted that, in order to help learners see things based on their own conceptualization, a more learner-centred strategy needs to be adopted. This is the central focus of the constructivist theory of learning. In the constructivist theory of learning, students are assisted to develop and construct their own understanding of the material based upon their own knowledge, beliefs and experiences, in concert with new knowledge presented in the classroom. The theory is a branch of cognitivism since both of them conceive learning as a mental activity. But the constructivist theory of learning differentiates itself from traditional cognitive theories in a number of ways. For instance; most cognitive psychologists think of the mind as a reference tool to the real world; constructivists believe that the mind filters input from the world to produce its own unique reality (Ertmer & Newby, 2013). This suggests that learners do not transfer knowledge from the real world into their memories but, rather, build personal interpretations of the world based on their experiences and interactions. This makes their interpretation of knowledge open to constant modification. Hence, within the contexts in which knowledge is relevant, new meaning surfaces. Basically, to constructivists, both the learner and environmental factors are crucial, because the interaction between the two creates knowledge. Every action is viewed as an interpretation of the current situation based on an entire history of *previous* interactions (Husa & Ron, 2010). Thus, in constructivism, it is impossible to isolate units of information or divide up knowledge domains according to a hierarchical analysis of relationships.

The development of present-day constructivist theory is considered to originate in the work of two early twentieth-century contemporary epistemological theorists, Jean Piaget in 1976 and Lev Vygotsky in 1986, whose cognitive theories of learning were developed as reactions to *behaviorism* which was the dominant science at the time (Cholewinski, 2009; Wyer Jr., 2014). Behaviourist theory is based upon an objectivist epistemology (Harasim, 2017). Piaget's research focused on the cognitive nature of constructivist learning, and Vygotsky's on its social nature. According to Elander and Cronje (2016), most of the modern teaching and learning techniques we have today are offshoots of objectivism or constructivism. To Cholewinski (2009), this 'revolution' saw constructivism develop as a powerful challenge to behaviourist instructional design and began a paradigm shift in educational design and practices away from 'traditional' methods, which are based upon behaviorist principles, toward those based upon 'constructivist' theories of learning. Constructivist theory of learning first started to receive prominent attention in Japan when educational institutions began to strive toward more constructivist-based instruction in the late 1990s (Cholewinsky, 2009). However, based on available literature, the first time it was used in Nigeria was by Afolabi and Akinbobola in 2009. Afolabi and Akinbobola examined a constructivist problem-based learning technique and the academic achievement of physics students with low ability levels in a Nigerian secondary school (Afolabi & Akinbobola, 2009). Their findings led to them to recommend the teaching strategy for use in Nigerian classrooms.

The constructivist theory of learning was preferred in this study because it specifies instructional methods that assist learners to actively explore complex topics/ environments. In Basic Electronics, students can be assisted into thinking as an expert user of that domain might think. This is in tandem with McNaught (2014) who noted that "having to cope with an uncertain future calls for a variety of intellectual, interpersonal and personal capabilities".

Some of these capabilities are critical thinking, creative thinking, self-managed learning, adaptability, problem solving, communication skills, interpersonal skills and groupwork, and computer literacy. McNaught further remarked that “‘directed instruction’ may be useful in many specific situations but our ultimate goals in education are ‘constructivist’”. Since, knowledge is not abstract but is linked to the context under study and to the experiences that the participants bring to the context. Essentially, learners are supported to construct their own understandings and then to validate, through social negotiation, these new perspectives. The constructivist theory of learning underpins a number of important approaches, these include: situated learning, concept mapping, collaborative instructional approach, anchored instruction, problem-based learning, cognitive apprenticeship, discovery learning, and scaffolding (Cholewinski, 2009; Jackson, 2006; Jia, 2010; Lai-chong & Ka-ming, 1996; Rowe, 2006; Wu, Hwang, Su, & Huang, 2012). This study focused on scaffolding and the collaborative instructional approach.

Scaffolding refer to the process by which a teacher, an instructor or a more knowledgeable peer assists a learner, altering the learning task so the learner can solve problems or accomplish tasks that would ordinarily be impossible for him and to learn from the experience (Reiser, 2004). While McNamara and Brown (2008) defined the collaborative instructional approach as a successful teaching strategy in which small teams, each with students of different levels of ability, use a variety of learning activities to improve their understanding of a subject. If the potentials of scaffolding and collaborative instructional approach are fully utilized, the academic achievement of student of subjects like Basic Electronics could improve.

In line with Bloom’s taxonomy of educational objectives and from past question papers of the examination bodies testing students at the secondary level in Nigeria, the type of testing employed for a subject like Basic Electronics, measures both cognitive and psychomotor achievements. However, this study focused only on cognitive achievement. Cognitive achievement reveals how well the educational objectives in the cognitive domain have been realized by a student. It is measured using cognitive achievement tests. When designing achievement tests, whether it is product or process assessment, care should be taken so that there is no gender bias.

Gender refers to state of being male or female. For a long time, gender was listed by researchers as one of the factors that influenced the academic achievement of the child (Abubakar & Oguguo, 2011; Gupta, Sharma, & Gupta, 2012). Some researchers believed that boys often out-perform their female counterparts in most subject areas, while some conclude the other way round (Jabor, Machtmes, Kungu, Buntat & Nordin, 2011; Maliki, Ngban & Ibu, 2009). Current trends show that the gap that once existed between genders is fast closing (Abubakar & Bada, 2012). This suggests that females are getting more exposure to educational activities.

### Statement of the Problem

Despite the huge resources expended by Nigerian stakeholders in the educational sector, mass failure in public examinations, especially in science- and technology-related areas which include Basic Electronics, is still being recorded every year (Animasahun, 2014). Recent statistics of academic achievement among students of Basic Electronics over a period of five years (2008–2012) corroborates this. During this period 2,176 candidates sat for examination in the subject in Nigeria. Out of this number, only 771 candidates scored a credit grade or higher, representing a low 35.4% success rate (NECO, 2013).

It was observed by chief examiners of Basic Electronics (NECO, 2010) that this mass failure could be attributed to teachers’ use of unsuitable instructional methodologies, especially traditional teacher-centred methods, in teaching the subject. Hence, teachers need to adopt a learner-centred instructional approach, which will emphasize contextualized and constructive processes, and equip the students with higher-order thinking skills for easy adaptability and flexibility.

Moreover, studies carried out by many researchers have indicated that constructivist approaches are very effective teaching techniques in modern-day teaching. Since constructivist-based approaches are learner-centred, they emphasize contextualized and constructive processes, and equip the students with higher-order thinking skills (Cholewinsky, 2009). Literature also reveals that scaffolding and collaborative instructional approaches are among the most popularly adopted constructivist approaches. Therefore, the problem of this study is, since constructivist-based instructional approaches are more effective than traditional approaches, but have not been used in teaching Basic Electronics, would they be effective for improving student overall achievement in Basic Electronics? Hence, the present study was designed to find out the effects of scaffolding and collaborative instructional approaches on science and technical school students’ achievement in Basic Electronics in North-Central Nigeria, with a view of finding out which of the two approaches is more effective.

The specific objectives of the study were to determine the effect of:

1. Scaffolding and collaborative instructional approaches on students’ cognitive achievement in Basic Electronics.
2. Gender on students’ cognitive achievement in Basic Electronics when taught with scaffolding and collaborative instructional approaches.

## Research Questions

The following research questions guided the study;

1. What is the effect of scaffolding and collaborative instructional approaches on students' cognitive achievement in Basic Electronics?
2. What is the effect of gender on students' cognitive achievement in Basic Electronics when taught with scaffolding and collaborative instructional approaches?

## Hypotheses

The researchers tested the null hypotheses stated below at 0.05 level of significance:

- H<sub>01</sub>:** There is no significant difference between the mean scores of students in Basic Electronics Cognitive Achievement Test when taught using scaffolding instructional approach and those taught with collaborative instructional approach.
- H<sub>02</sub>:** There is no significant difference between the mean scores of male and female students when taught with scaffolding and collaborative instructional approaches in the Basic Electronics Cognitive Achievement Test.
- H<sub>03</sub>:** There is no significant interaction effect of treatments given to students and their gender with respect to their mean scores on the Basic Electronics Cognitive Achievement Test.

## METHODOLOGY

The study adopted a quasi-experimental research design; specifically the pre-test post-test non-equivalent control-group experimental design was used. A quasi-experimental design was considered suitable because the study is an experiment where random assignment of subjects to experimental and control groups is not possible, and so intact classes were used (Nworgu, 2006). The researchers randomly assigned intact classes to treatment groups, in order not to interrupt the normal classes of the students and the school time-table.

A sample of 105 (77 males and 28 females) from four schools was drawn using a purposive sampling technique from all the 122 senior secondary school year two (SS II) students of Basic Electronics in the eight science and technical schools offering Basic Electronics in North-Central. This was because few schools offered Basic Electronics and their student population was small. Three types of instruments were used in the study. The first instrument was the lesson plans. Two (2) sets of lesson plans for teaching of the six Basic Electronics topics selected for the study were prepared by the researchers in line with both scaffolding and collaborative instructional approaches ([Appendices B and C](#)). Each set contained six lesson plans that were used to teach the students. Each contact lasted for 80 minutes (a double period). The second instrument was an 80-item test blueprint that was developed by the researchers from the lesson plans in line with the six topics that formed the content of this study. The topics were: electrical conduction properties of elements, majority and minority charge carriers, p-n junction diode, diode parameters, electrical rectification and dc power supplies (NERDC Basic Electronics curriculum (2007)). This test blueprint was used to generate 80 items (see [Table 2](#)). After a face and content validation (details below) was done on this draft Basic Electronics Cognitive Achievement Test (BECAT), it was then subjected to a pilot study at ABI Private Schools, Birnin Kebbi. The psychometric test analysis was done to determine the Difficulty Index and Discrimination Index of each item. According to Okoro (1999), "An item is good if it has Difficulty Index ranging from 20 to 80; Discrimination of 0.20 and above and its entire distractor index a negative decimal". Hence, out of the 80 items generated, a total of 55 items had appropriate difficulty and discrimination indices. From the 55 items that had good difficulty and discrimination indices, 50 items were selected and used for the final version of the BECAT. The third instrument was thus the final BECAT. BECAT has 50, four-option multiple-choice items, generated using the test blue-print drawn on six Basic Electronics topics selected. [Appendix A](#) shows a sample of the questions in the BECAT.

The three instruments – lesson plans, test blueprint and BECAT – were validated by three people with Industrial and Technology Education background. One of them was a lecturer of Electrical and Electronics Technology Education drawn from Department of Industrial Technology and Education (ITE), Federal University of Technology, Minna; the second was a teacher of Electronics, with at least five years' experience at the secondary school level in Abuja and the third was an experienced staff of the Department of Examination Development, National Examinations Council, who was a teacher of Basic Electronics before joining the council as a Basic Electronics examination officer. Since the BECAT items are multiple-choice, reliability testing of BECAT was carried out with the use of Kuder-Richardson 20 (K-R 20) and a reliability coefficient of 0.88 was obtained. Data collected were analyzed using mean and ANCOVA at 0.05 level of significance.

**Table 1.** Distribution of Schools Used for the Study According to Name of School, Group, Treatment Method and Number of Students

S/No.	Name of School	Treatment group	Treatment Method	Total No. of Students
1	Federal Science and Technical College, Otukpo	B	Scaffolding	26
2	Federal Science and Technical College, Doma	A	Collaborative	25
3	Synto Secretariat, Suleija	A	Collaborative	27
4	Federal Science and Technical College, Kuta	B	Scaffolding	27
<b>TOTAL</b>				<b>105</b>

## Experimental Procedure

The study took place during the normal school setting. The timetable of each school and lesson duration was followed without alteration. Detailed instructions with lesson plans for the six selected topics were given to the four research assistants during the one-week training that was conducted for them. The training pack included detailed lesson plans on the six Basic Electronics topics for the instructional approach to be undertaken by each research assistant; as well as the procedural steps for implementing the instructional approach on which they were trained. Treatment group A was taught using the Collaborative Instructional Approach. In this treatment group, the research assistants divided the students into group of threes and explained to each group about how they will work together, sharing ideas and solving the given problems as a team. Also, the scoring of assignments was on a group basis. The think-share-pair strategy was used. On the other hand, Treatment group B was taught using the Scaffolding Instructional Approach. In this treatment group, the research assistants simply used series of scaffolds, such as flash cards, visual (pictorial) scaffolds and question cards to facilitate the lessons. **Table 1** shows the distribution of schools used for the study according to name of school, group, treatment method and number of students.

The influences of extraneous variables were checked as follows: firstly, the influence of Hawthorne effect was addressed by using each school's regular Basic Electronics teacher. These teachers were grouped into two and trained in isolation of each other. Secondly, the influence of pre-test sensitization was addressed by retrieving all pre-test question papers and by rearranging the post-test questions in such a way that the first question in the pre-test became the last in the post-test. Thirdly, the influence of initial group differences was addressed by the use of analysis of covariance (ANCOVA) for the data analysis. Fourthly, the influence subjects' interaction was controlled by the use of intact classes for each treatment group in each school used for the research, so that subjects (students) from one treatment group do not introduce biases in the results by crossing to a treatment group they were not originally assigned to.

In the first week, BECAT was administered to both the Treatment groups A and B. This was followed by a six-week period of treatment of the two groups. Each lesson lasted for 80 minutes (a double period). At the end of the treatment period, a post-test was administered on both groups with BECAT containing the same questions, but rearranged such that the last item in the pre-test became the first item in the post-test. The scores that were obtained from both groups were compared to determine if there is any significant difference in their cognitive achievement. Therefore, the scores were collected and kept in the custody of the researchers for use in further analyses.

## Method of Data Analysis

The data collected for the study were analysed using mean statistics and analysis of covariance (ANCOVA). Mean statistics was used to answer the two research questions of the study. While the null hypotheses were tested using ANCOVA at 0.05 level of significance. ANCOVA was considered suitable because the study involved two independent variables (teaching methods and gender), a dependent variable (post-test scores) and a covariate (pre-test scores). Also, Nworgu (2006) stated that the most appropriate statistical technique for analysing data from a pre-test-post-test control-group design is ANCOVA.

**Table 2.** An 80-Item Test Blue Print for Basic Electronics Based on Six Topics

S/No TOPIC	Number of Items in Cognitive level							Total
	%	K	C	App	Anal	S	E	
1. Electrical conduction properties of elements	10	-	1	1	3	2	1	8
2. Majority and minority charge carriers	15	-	1	2	4	3	2	12
3. P-N junction diode	20	2	2	2	3	4	3	16
4. Diode parameters	15	1	1	1	3	4	2	12
5. Electrical rectification	20	1	2	3	4	3	3	16
6. DC power supplies	20	1	2	4	3	4	2	16
TOTAL	100	5	9	13	20	20	13	80

K = Knowledge, C= Comprehension, App = Application, Anal = Analysis, S = Synthesis, E= Evaluation

**Table 3.** Pre-test and Post-test Mean Scores of Treatment Groups Taught Basic Electronics with Scaffolding and Collaborative Instructional Approaches in the BECAT

Group	N	Pre-test $\bar{x}$	SD	Post-test $\bar{x}$	SD	Mean Gain $\bar{x}$
Group A (CIA)	52	11.19	2.61	35.60	1.14	24.41
Group B (SIA)	53	11.25	2.63	25.51	1.45	14.26

CIA = group with Collaborative Instructional Approach, SIA = group with Scaffolding Instructional Approach.

## RESULTS

### Research Question 1

What is the effect of scaffolding and collaborative instructional approaches on students' cognitive achievement in Basic Electronics?

**Table 3** shows that Treatment group A (group treated with the Collaborative Instructional Approach) had a pre-test mean score of 11.19 and a standard deviation (SD) of 2.61. Post-test mean score was 35.60 and a standard deviation of 1.14. These yielded a pre-test, post-test mean gain of 24.41. However, Treatment group B, (group treated with the Scaffolding Instructional Approach) had a pre-test mean score of 11.25 and a standard deviation of 2.63. In the same vein, treatment group B had a post-test mean score of 25.51 and a standard deviation of 1.45, giving a pre-test, post-test mean gain of 14.26. With these results, the students in Treatment group A performed better in the cognitive achievement test than the students in Treatment group B. Hence, collaborative instructional approach appears to be more effective than scaffolding instructional approach in Basic Electronics.

### Research Question 2

What is the effect of gender on students' cognitive achievement in Basic Electronics when taught with scaffolding and collaborative instructional approaches?

**Table 4** shows that male students taught Basic Electronics using the Scaffolding Instructional Approach had a pre-test mean score of 11.15 and a standard deviation of 2.74. The post-test mean score was 25.73 and a standard deviation of 1.40. These give a pre-test, post-test mean gain of 14.11. Similarly, their female counterparts taught using the Scaffolding Instructional Approach had a pre-test mean score of 11.62 and a standard deviation of 2.51, a post-test mean score of 24.85 and a standard deviation of 1.46, giving a pre-test, post-test mean gain of 13.23. Also, male students taught Basic Electronics using the Collaborative Instructional Approach had a pre-test mean score of 11.47 and a standard deviation of 2.71, a post-test mean score of 36.00 and a standard deviation of 1.08 giving a pre-test, post-test mean gain of 24.53. Their female counterparts taught using the Collaborative Instructional Approach, had a pre-test mean score of 10.43 and a standard deviation of 2.55 and a post-test mean score of 34.50 and a standard deviation of 1.19, giving a pre-test, post-test mean gain of 24.07. From these results, male and female students taught Basic Electronics using the Collaborative Instructional Approach had a higher mean gain than those taught using the Scaffolding Instructional Approach in the BECAT. Also, male students performed better than the females. This could perhaps indicate an effect attributable to gender on the achievement of students taught Basic Electronics.



**Table 4.** Pre-test and Post-test Mean Scores of Male and Female Students Taught Basic Electronics with Scaffolding and Collaborative Instructional Approaches in the BECAT

Gender	Scaffolding Instructional Approach					Collaborative Instructional Approach						
	N	Pre-test		Post-test		Gain	N	Pre-test		Post-test		Gain
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$
Male	40	11.15	2.74	25.73	1.40	14.11	38	11.47	2.71	36.00	1.08	24.53
Female	13	11.62	2.51	24.85	1.46	13.23	14	10.43	2.55	34.50	1.19	24.07

**Table 5.** Summary of Analysis of Covariance (ANCOVA) for Test of Significance of Three Effects: Treatment, Gender and Interaction on Students' Cognitive Achievement in Basic Electronics

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	15764.673	4	3941.168	265.228	0.000
Intercept	276.267	1	276.267	18.592	0.000
Pre-test	200.050	1	200.050	13.463	0.000
Gender	1.188	1	1.188	0.080	0.778*
Treatment	11915.704	1	11915.704	801.888	0.000*
Gender * Treatment	1.326	1	1.326	0.089	0.766
Error	1485.955	100	14.860		
Total	74324.000	105			
Corrected Total	17250.629	104			

\*Significant at sig. of F &lt; .05

## Hypotheses

- H<sub>01</sub>:** There is no significant difference between the mean scores of students in the Basic Electronics Cognitive Achievement Test when taught using scaffolding instructional approach and those taught with collaborative instructional approach.
- H<sub>02</sub>:** There is no significant difference between the mean scores of male and female students when taught with scaffolding and collaborative instructional approaches in the Basic Electronics Cognitive Achievement Test.
- H<sub>03</sub>:** There is no significant interaction effect of treatments given to students and their gender with respect to their mean scores on the Basic Electronics Cognitive Achievement Test.

The data in **Table 5** shows the F-calculated values for three effects: treatment, gender and interaction on students' cognitive achievement in Basic Electronics. The F-calculated value for treatment is 801.888 with a significance of F at 0.000 which is less than 0.05. This result shows that there is a significant difference between the mean scores of students in the Basic Electronics Cognitive Achievement Test when taught using the scaffolding instructional approach and those taught with the collaborative instructional approach. The null-hypothesis one is therefore rejected at 0.05 level of significance. The F-calculated value for gender is 0.080 with a significance of F at 0.778 which is greater than 0.05. This result shows that there is no significant difference between the mean scores of male and female students when taught with scaffolding and collaborative instructional approaches in Basic Electronics Cognitive Achievement Test. The null-hypothesis two is therefore accepted at 0.05 level of significance. Also, the interaction of treatments and gender has an F-calculated value of 0.089 with significance of F of 0.766. From this, 0.766 is obviously greater than 0.05. Hence, there is no significant effect of treatments given to students on their gender with respect to their mean scores on the Basic Electronics Cognitive Achievement Test. The null-hypothesis three is therefore accepted at 0.05 level of significance.

## Findings of the Study

The following were the findings recorded:

1. Scaffolding and collaborative instructional approaches are effective for improving students' cognitive achievement. However, the collaborative instructional approach was more effective than the scaffolding instructional approach.
2. There was an effect of gender on students' cognitive achievement in Basic Electronics.
3. There was a significant difference between the mean scores of students in Basic Electronics Cognitive Achievement Test when taught using the scaffolding instructional approach and those taught with the collaborative instructional approach, in favour of the collaborative instructional approach.

4. There was no significant effect of gender on students' cognitive achievement in Basic Electronics.
5. There was no significant interaction effect of treatments given to students and their gender with respect to their mean scores on the Basic Electronics Cognitive Achievement Test.

## DISCUSSION OF FINDINGS

The data in **Table 3** provides answer to research question one. The finding revealed that scaffolding and collaborative instructional approaches are effective for improving students' cognitive achievement. However, the collaborative instructional approach was more effective than the scaffolding instructional approach. Analysis of covariance was used to test hypothesis one (**Table 5**). This indicated that there was a significant difference between the mean scores of students in the Basic Electronics Cognitive Achievement Test when taught using the scaffolding instructional approach and those taught with the collaborative instructional approach, in favour of the collaborative instructional approach. This confirmed that the difference between the collaborative instructional approach and the scaffolding instructional approach was statistically significant.

These imply that scaffolding and collaborative instructional approaches are effective for teaching Basic Electronics. However, the collaborative instructional approach is more effective than scaffolding instructional approach. This finding is similar to that of Gokhale (1995) who found that students who participated in a collaborative instructional approach performed significantly better on a critical-thinking test than students who studied individually as in scaffolding. Similarly, Dooly (2008) discovered that, in the collaborative instructional approach, students actively exchange, debate and negotiate ideas within their groups, and this increases the students' interest in learning. Importantly, by engaging in discussion and taking responsibility for their learning, students are encouraged to become critical thinkers. By working in small groups, students tend to learn more of what is being taught and retain the information longer, and also appear more satisfied with their classes. Therefore, the difference observed between the two groups is as a result of the collaborative instructional approach being more effective in improving students' cognitive achievement in Basic Electronics than the scaffolding instructional approach.

The data in **Table 4** provides an answer to research question two. The results revealed that there was an effect of gender on students' cognitive achievement in Basic Electronics. In the same vein, analysis of covariance was used to test hypothesis three (**Table 5**) for interaction of treatments and gender revealed that there was no significant interaction effect of treatments given to students and their gender with respect to their mean scores on the Basic Electronics Cognitive Achievement Test. Also, analysis of covariance was used to test hypothesis two, (**Table 5**). With these results, there was a significant difference between the mean scores of students in Basic Electronics Cognitive Achievement Test when taught using the scaffolding instructional approach and those taught with the collaborative instructional approach, in favour of collaborative instructional approach.

These imply that both scaffolding and collaborative instructional approaches are not gender-biased in teaching of subjects like Basic Electronics. This finding is similar to findings of several other studies that have been conducted on effects of gender on achievement of male and female students in sciences and other fields. For instance, Nwagbo and Obiekwe (2010) affirmed that there was no significant difference between male and female students' achievement. This view was reiterated by Afolabi and Akinbobola (2009) who discovered that there was no significant gender difference in the performance of students taught with a problem-based learning technique in a physics achievement test. Abubakar and Bada (2012), and Ogbuanya and Owodunni (2013) also found that gender is not significant in the academic achievement between females and males. Hence, these findings confirmed that when males and females are exposed to academic activities in subjects like Basic Electronics, under the same environmental conditions, and taught by the same teacher using the same methodology, their performance level would be the same.

## CONCLUSION

The need to find the most appropriate instructional approach to assist Basic Electronics students in their academic activities, stimulate and sustain their interest is very important. This is because interest is a key ingredient for recording high achievement in any academic pursuit and especially in technology education. This study therefore ascertained the comparative effects of scaffolding and collaborative instructional approaches on secondary school students' achievement in Basic Electronics in North-Central Nigeria. The study found out that the collaborative instructional approach is more effective in improving students' cognitive achievement in Basic Electronics than the scaffolding instructional approach. Also, the study revealed that, gender had no influence on students' cognitive achievement in Basic Electronics. The study also revealed that collaborative and scaffolding instructional approaches are not gender-biased. Students recorded higher cognitive in Basic Electronics when the collaborative instructional approach was used for teaching the subject, irrespective of gender. These results therefore show that collaborative instructional approach is a workable teaching method for Basic Electronics.

The following recommendations are made:

- A collaborative instructional approach is recommended for teachers of electronics and other related trade subjects in secondary schools for use in the teaching of their subjects;
- It is recommended that the Nigerian Educational Research and Development Council (NERDC) should consider incorporating collaborative instructional approaches into the teaching of subjects like Basic Electronics when next they are reviewing the curriculum;
- Government and other stakeholders in the provision of qualitative technology education should do more in providing schools with state-of-the-art tools and equipment needed for the teaching and learning of Basic Electronics; and
- It is recommended that training and retraining workshops, seminars and conferences be organized the National Universities Commission (NUC) along with other sister agencies in collaboration with the Ministries of Education both at federal and states levels, to enlighten teachers of technology education with a view of improving their knowledge with skills on the use of collaborative instructional approaches.

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## APPENDIX A

**SAMPLE OF BASIC ELECTRONICS COGNITIVE ACHIEVEMENT TEST (BECAT)****STUDENT BIODATA**

STUDENT'S REGISTRATION NUMBER .....

NAME OF SCHOOL .....

GENDER.....[MALE/FEMALE]

1. The electronic configuration of a silicon atom is
  - A. 2, 10, 2.
  - B. 2, 8, 4.
  - C. 2, 7, 5.
  - D. 2, 4, 8.
2. Materials that only allow electricity to pass through them at an increased temperature are called
  - A. conductors.
  - B. insulators.
  - C. resistors.
  - D. semiconductors.
3. The major part of the current in an intrinsic semiconductor is due to
  - A. conduction of band electrons.
  - B. holes in the valence band.
  - C. thermally-generated electrons.
  - D. valence-band electrons.
4. Electrons experience high mobility than holes because they
  - A. are lighter.
  - B. collide less frequently.
  - C. have negative charge.
  - D. need less energy to move them.
5. Doping materials are called impurities because they
  - A. alter the crystal structures of the pure semiconductors.
  - B. change the chemical properties of semiconductors.
  - C. decrease the number of charge carriers.
  - D. make semiconductors less than 100 percent.
6. Current flow in a semiconductor depends on the principle of
  - A. all of THESE.
  - B. diffusion.
  - C. drift.
  - D. recombination.
7. The process of adding impurities to a semiconductor is known as
  - A. diffusion.
  - B. doping.
  - C. mixing.
  - D. refining.
8. What is the most widely used semiconductor material in electronics?
  - A. Antimony
  - B. Carbon.
  - C. Germanium.
  - D. Silicon.

## APPENDIX B

### SAMPLE OF SCAFFOLDING INSTRUCTIONAL APPROACH (SIA) LESSON PLAN

**SUBJECT:** *Basic Electronics*

**TOPIC:** *Electrical Conduction Properties of Elements*

**CLASS:** *SS II*

**LESSON DURATION:** *80 minutes*

**DATE:**

**OBJECTIVES:** *At the end of the lesson, the students should be able to*

1. Explain the electrical conduction properties of elements.
2. Define semiconductors, give examples and write their electronic configuration.
3. Discuss the crystal structure of semiconductors.
4. Explain the classification of semiconductors and show it diagrammatically.

**INSTRUCTIONAL MATERIALS:**

1. Semiconductor devices such as diodes, transistors, SCRs, ICs of different types.
2. Basic Electronics textbook,
3. The periodic table,
4. Chemistry textbook, and
5. Semiconductor questions card sheets.

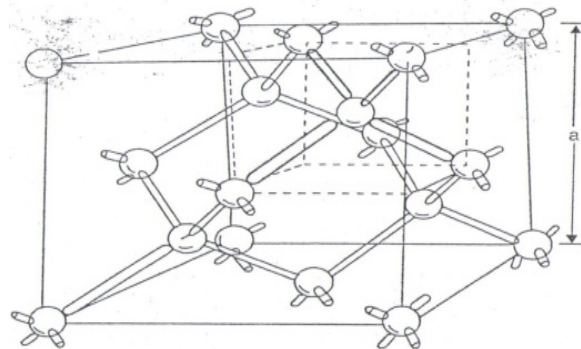


**PRELUDE:** The teacher introduces the topic by making a few comments e.g. **Semiconductors are midway between good conductors and insulators. Their uses have become indispensable in today's world.**

The teacher then asks the students to place the following materials – Basic Electronics Textbook, Periodic Table and chemistry textbook – on their table.

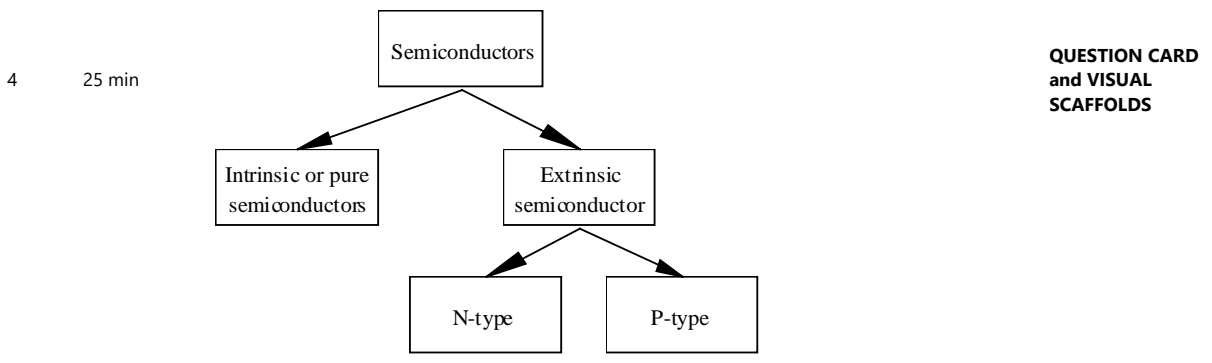
The teacher asks the students to open their textbooks to the relevant pages.

Stage	Duration	Content	Teacher's activities	Students' activities	Scaffold	SIA Strategy
1	8 min	Electrical conduction properties of elements	The teacher distributes the <b>question cards</b> on electrical conduction properties of elements	The students collect the <b>question cards</b> , search for the information in their textbooks and make a list of the properties in their notebook	Is there anything like electrical conduction properties of elements; are there any classification; how are the types defined; which one of them forms the topic being studied?	<b>QUESTION CARD</b>
2	12 min	Semiconductors, examples, their electronic configuration	The teacher passes some semiconductor devices such as diodes, transistors, SCRs, ICs of different types to the students to both see and touch	Students see and touch the semiconductor devices such as diodes, transistors, SCRs, ICs of different types. Draw and label them with their circuit symbols.	Give examples of semiconductors and show their electronic configurations	<b>VISUAL SCAFFOLDS</b>
3	15 min	The crystal structure of semiconductors	The teacher distributes the <b>question cards</b> on the crystal structure of semiconductors	The students collect the <b>question cards</b> , search for the information in their textbooks, make a note and draw crystal structure of semiconductors in their notebook	With the aid of a diagram briefly explain the crystal structure of semiconductors	<b>QUESTION CARDS</b>



**Crystal structure of semiconductors**

		The classification of semiconductors, symbols of classes of semiconductors.	The teacher distributes the <b>question cards</b> the classification of semiconductors, symbols of classes of semiconductors.	The students collect the <b>question cards</b> , search for the information in their textbooks and make a list of the classification of semiconductors in their notebook	How would you explain the classification of semiconductors and how would you show it diagrammatically?	
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**EVALUATION:** (For 15 min)

The teacher randomly call on students to answer the following questions:

1. Explain the electrical conduction properties of elements.
2. Define semiconductors, give examples and write their electronic configuration.
3. Discuss the crystal structure of semiconductors.
4. Explain the classification of semiconductors and show it diagrammatically.

**ASSIGNMENT:** The teacher instructs the students to make detailed notes on the topic, study them and prepare for a shotgun test next week.

## APPENDIX C

### SAMPLE OF COLLABORATIVE INSTRUCTIONAL APPROACH (CIA) LESSON PLANS

**SUBJECT:** *Basic Electronics*

**TOPIC:** *Electrical Conduction Properties of Elements*

**CLASS:** *SS II*

**LESSON DURATION:** *80 minutes*

**DATE:**

**OBJECTIVES:** *At the end of the lesson, the students should be able to*

1. Explain the electrical conduction properties of elements.
2. Define semiconductors, give examples and write their electronic configuration.
3. Discuss the crystal structure of semiconductors.
4. Explain the classification of semiconductors and show it diagrammatically.

**INSTRUCTIONAL MATERIALS:**

1. Semiconductor devices such as diodes, transistors, SCRs, ICs of different types.
2. Basic Electronics textbook,
3. The periodic table,
4. Chemistry textbook, and
5. Semiconductor questions card sheets.

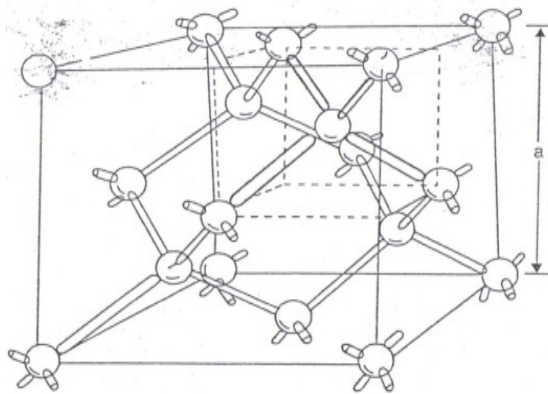
**PRELUDE:** The teacher calls out names of students to constitute their various groups comprising of three students each.

The teacher introduces the topic by making a few comments e.g. **Semiconductors are midway between good conductors and insulators. Their uses have become indispensable in today's world.**

The teacher then asks the students to place the following materials Basic Electronics Textbook, Periodic Table and chemistry textbook on their table.

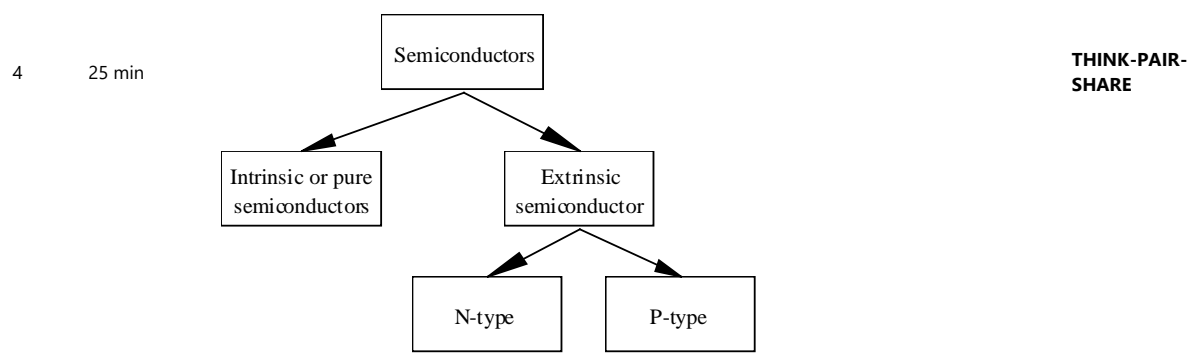
The teacher asks the students to open their textbooks to the relevant pages.

Stage	Duration	Content	Teacher's activities	Students' activities	Task	CIA Strategy
1	8 min	Electrical conduction properties of elements	The teacher distributes the <b>task cards</b> on electrical conduction properties of elements to the groups	The groups collect the <b>task cards</b> , search for the information in their textbooks and make a list of the properties in their notebook	Study about electrical conduction properties of elements, state their classification	<b>THINK-PAIR-SHARE</b>
2	12 min	Semiconductors, examples, their electronic configuration	The teacher passes some semiconductor devices such as diodes, transistors, SCRs, ICs of different types to each group for the members to both see and touch	Group members see and touch the semiconductor devices such as diodes, transistors, SCRs, ICs of different types	Give examples of semiconductors and show their electronic configurations	<b>SIMPLE JIGSAW</b>
3	15 min	The crystal structure of semiconductors	The teacher distributes the <b>task cards</b> on the crystal structure of semiconductors to the groups	The groups collect the <b>task cards</b> , search for the information in their textbooks, make a note and draw crystal structure of semiconductors in their notebook	With the aid of a diagram briefly explain the crystal structure of semiconductors	<b>SIMPLE JIGSAW</b>



**crystal structure of semiconductors**

The classification of semiconductors, symbols of classes of semiconductors	The teacher distributes the <b>task cards</b> the classification of semiconductors, symbols of classes of semiconductors to the groups	The groups collect the <b>task cards</b> , search for the information in their textbooks and make a list of the classification of semiconductors in their notebook	Explain the classification of semiconductors and draw the diagram
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**EVALUATION:** (For 13 min)

The teacher randomly calls on students from groups to answer the following questions:

1. Explain the electrical conduction properties of elements.
2. Define semiconductors, give examples and write their electronic configuration.
3. Discuss the crystal structure of semiconductors.
4. Explain the classification of semiconductors and show it diagrammatically.

**ASSIGNMENT:** The teacher will instruct the groups to make detailed notes on the topic, study them and prepare for an inter-group quiz next week.

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# Competencies in Mathematical Modelling Tasks: An Error Analysis

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Received 23 January 2018 • Revised 6 April 2018 • Accepted 1 May 2018

## ABSTRACT

This paper aimed to investigate the type of modelling task that may elicit competencies that are more aligned with demands from the biomedical technology industry. The inquiry identified strengths and weaknesses in students' modelling competencies by analysing errors in two types of modelling tasks: atomistic and holistic. By using subtasks, errors could be identified according to the Newman error categories and compared with six modelling competencies according to the framework of Blum and Leib. First-year biomedical technology students at a South African university made more errors in *interpreting, validating and presenting*, these being modelling competencies required to convert mathematical results to real-world results. The findings indicated that competencies embedded in *atomistic* tasks are more relevant to workplace demands in the local setting than those elicited in holistic modelling tasks. The implications for classroom practices are discussed.

**Keywords:** biomedical technology, mathematical modelling, error analysis, atomistic modelling, holistic modelling

## INTRODUCTION

Mathematics is embedded in everyday phenomena but often remains isolated and unconnected with the real world. Contextually rich problems offer learning opportunities that allow students to connect the world of mathematics with real life. Contexts not only suggest strategies for problem-solving but can be an avenue to develop diversified skills. Schoenfeld (2001) warned that when skills are isolated from contexts, they are destined to be without meaning and purpose. For Freudenthal (1991, p. 75), contexts are "domains of reality disclosed to the learner in order to be mathematised". Reality is entrenched in contexts that relate to real life and should not only be pursued at the end of a study unit when mathematical content must be 'applied' (Van den Heuvel-Panhuizen, 2005). Instead, reality can be a rich source for learning *and* applying mathematics. Early experiences in which first-year students engage in real-world applications of mathematics can instill an appreciation of mathematics as an enviable tool in the bioengineering field.

New innovations and technological advancements, coupled with a greater awareness of the benefits of a healthy lifestyle, create a demand for different knowledge and skills in the biomedical technology industry (Magjarevic, Lackovic, Bliznakov, & Pallikarakis, 2010). This industry-driven mandate requires innovative models of learning. Besides traditional approaches, learning should include: authentic tasks (Harris, Bransford, & Brophy, 2002); problem-oriented learning (Magjarevic et al., 2010); information and communication technology (Mantas, Ammenwerth, Demiris et al., 2010); and small-group collaborations (Khan, Desjardins, Reba, Breazel, & Viktorova, 2013) to enhance problem-solving and decision-making competencies (Huang, 2007). In South Africa (SA), there is scant research on the competencies needed in the biomedical sciences and the specific contribution from the Mathematics discipline.

The mathematics curriculum for biomedical students at UJ is to a large extent based on "contrived" word problems instead of genuine real-world problems (Gravemeijer, Stephan, Julie, Lin, & Ohtani, 2017, p. 110). However, the overarching aim of the biomedical technology programme at the University of Johannesburg (UJ) is to train students to perform laboratory tests on human body fluids including blood, urine, body tissue and bone marrow (UJ, 2017). Using sophisticated procedures and equipment, biomedical technologists have to *analyse* data

#### Contribution of this paper to the literature

- Students are exposed to contextualised real-world problems for the first time to elicit mathematical competencies more in line with workplace skills.
- Modelling tasks were divided into subtasks, each eliciting specific modelling competencies.
- Error analysis revealed that atomistic modelling tasks attracted less errors in competencies embedded in the early phases of the modelling cycle.

samples in a laboratory with mathematical precision and accuracy; these include tests to determine blood types, drug levels and identification of bacterial or viral infections. Furthermore, the *interpretation* of test results must be precise and reliable. *Reports* that summarise test results must be scientifically accurate and are vital to medical practitioners who will base their diagnoses and subsequent treatments of patients on these reports. To this end, Humphrey, Coté, Walton, Meininger, and Laine (2005) acknowledged the benefits of a mathematical modelling approach in biomedical sciences: students can be exposed to the collection, analysis and interpretation of real-world data by working collaboratively. Alas, biomedical students at UJ are still unexposed to mathematical modelling and do not reap these potential benefits.

This apparent gap signaled the need for a dynamic interplay between mathematics as core discipline in the biomedical sciences and suitable problem-solving activities with embedded industry-based competencies. The overarching aim of this research was to investigate the type of modelling task that may be aligned with industry-imposed competencies as alluded to above. The inquiry also necessitated insight into the types of errors made in different types of modelling tasks. The research was thus motivated by a desire to inform a pedagogy that could strike a balance between curricular imperatives and industry requirements.

## BACKGROUND

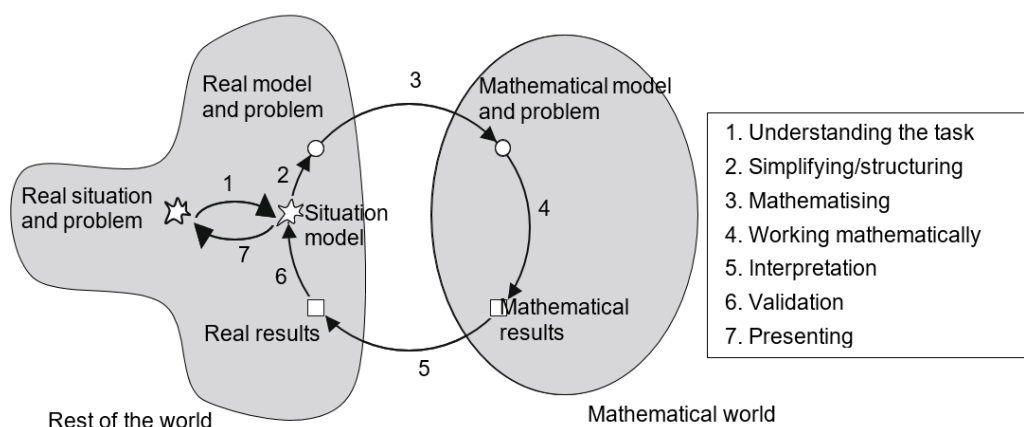
Biomedical technology students register for a semester module in mathematics during their first year of study at UJ. Although the teaching and learning style remained largely traditional, Kotze, Jacobs, and Spangenberg (2015) reported that students in a pilot study at UJ were enthusiastic to learn in a mathematical modelling environment that offered greater articulation of skills in biomedical contexts. Students who register for the biomedical technology programmes at UJ come from diverse geographic, socio-economic, cultural and academic backgrounds. UJ continues to attract students from across the African continent. For most students, English is a second or even third language. An entry requirement into the biomedical technology programme at UJ is proficiency in English, the language of instruction and learning.

In 2014, the use of tablets/laptops became compulsory in classroom teaching and learning at UJ. By 2015 when a pilot study was undertaken, it became evident that the broader availability of hand-held electronic devices created scope for modelling activities that utilise real-world data. A *laissez-faire* approach to the use of technology in the mathematics classroom also seemed to stimulate inquisitiveness among students. On one occasion, some students expressed their curiosity about theories that could explain the disappearance of Malaysia Airlines Flight 370. This discussion diverted to the mysterious Bermuda triangle which was subsequently used as inspiration for a modelling task.

## LITERATURE PERSPECTIVES

Mathematical modelling is the process whereby a real-life phenomenon is translated into a mathematical problem with the aim to find a realistic solution for the real-world situation (Blum & Leiß, 2007). Although these protagonists of a mathematical modelling approach advocated its implementation at all levels of mathematics education, mathematical modelling is still a novel undertaking for most students at UJ and indeed elsewhere. Often, classroom activities focus more on abstract mathematical concepts and principles with little regard for their applicability, usefulness and connections with real life.

The modelling cycle (Blum & Leiß, 2007, p. 225) is shown in [Figure 1](#). To transition from one phase of the modelling cycle to the next requires certain modelling competencies as indicated on the right in [Figure 1](#).



**Figure 1.** The mathematical modelling cycle (Blum & Leiß, 2007, p. 225)

The modelling cycle originates in the physical world and relates to a real-world problem. A non-mathematical situation must be abstracted as a situation model; this helps to untangle and *understand* the reality-based problem. By *simplifying* the situation model, only relevant information is retained such that the situation model develops into an idealised real model. The real model is then translated into a mathematical model; Freudenthal (1991) labeled this process *mathematising*. In the next phase of the modelling process, the mathematical model must be manipulated mathematically. By *working mathematically*, all relevant mathematical domains and applicable skills, algorithms, processes and calculations are employed to produce a mathematical solution. The mathematical solution must then be *interpreted* in relation to the real model. To ensure that the mathematical model make sense in real-world terms, the solution must be *validated*. It may be necessary to repeat the modelling cycle if the mathematical solution is in conflict with the real-world situation. The modelling process concludes with the *presentation* of results. As an indispensable component of the modelling process, contexts allow for greater flexibility in the modelling cycle and add an open-ended character to the modelling process (Freudenthal, 1991).

Mathematical tasks, situated in contexts that students can easily relate to, have the potential to enhance students' sense-making of problems (Wijaya, van den Heuvel-Panhuizen, Doorman, & Robitzsch, 2014). Context-rich tasks can even be relatively simple problems, as long as contextual settings contribute to learning and a deeper understanding of concepts. Students are likely to show more interest in tasks with contexts that draw on their own everyday experiences and curiosities (Wijaya et al., 2014). Contexts can be created by way of stories, illustrations, pictures and maps. Contextually rich settings can provide information, serve as a problem-solving stimulus, elicit model-building and support the validation of processes and solutions. Blomhøj and Jensen (2003) differentiated between two types of modelling: holistic modelling and atomistic modelling. In a holistic approach, students work through *all* modelling phases (Figure 1) but in an atomistic approach, only certain modelling phases are prioritised. Although it may be tempting to endorse only the atomistic approach due to its resemblance to traditional classroom strategies, Blomhøj and Jensen (2003) argued that these two approaches contribute in different ways to the modelling agenda.

Van den Heuvel-Panhuizen (2005) distinguished between contextually rich problems – where contexts should be mathematised – and word problems – where contexts do not matter. Newman (1977) identified five categories of errors to analyse students' difficulties when solving word problems; these are reading, comprehension, transformation, mathematical processes and encoding. Wijaya et al. (2014) pointed to remarkable similarities between the Newman error categories – associated with word problems – and errors made in the modelling processes as described by Blum and Leiß (2007). According to Wijaya et al. (2014), difficulties in context-rich modelling tasks relate to four competencies, namely, understanding, translating the real-world situation into a mathematical problem, working mathematically and interpreting the mathematical solution in real-world terms. Arguably, reading is part of understanding and therefore, Newman's reading and comprehension categories can be merged (Wijaya et al., 2014). The studies of Newman (1977), involving 11–13 year-old Australian students and that of Wijaya et al. (2014), involving 14–18 year-old Indonesian students, revealed similar results: low-performing students experienced difficulties with understanding and translating word problems or modelling tasks. Consequently, students in these two studies struggled to progress to the phase where mathematical work must be performed. Taking heed of these outcomes, this study investigated errors made by biomedical technology students in atomistic and holistic modelling tasks. The following research questions are posed: *Which competencies attract the most errors in an atomistic modelling task? What are the differences between error trends in atomistic and holistic modelling tasks?*

## RESEARCH DESIGN AND METHODOLOGY

Supported by a contextualist world view (Schraw, 2013), this study is predicated on knowledge that is not only applicable to real-world contexts, but is acquired from settings where new facts can collectively be debated. Within this paradigm, lecturers act as facilitators to promote learning experiences wherein students can negotiate a “consensual reality within a specific context” (Schraw, 2013, p. 3). Lave (1996, p. 155) considered the practices of tailor apprentices in Liberia and law students in Egypt to be grounded on “learning as [a] socially situated activity”. In other words, informal but contextually rich practices as encountered in daily life characterise all learning activities.

The participants in this study were a 50-strong cohort of first-year biomedical technology students at UJ. The demographics of the cohort revealed more female students (56%), representation from five of the nine provinces in SA while two students came from other African countries. Students’ ages ranged between 18 and 21 years and 87% of the cohort’s home language was not English. For the modelling tasks, students were divided into ten groups of four to six students per group. Using recent semester test scores, each group included low, middle and high performers. With this group structure, it was hoped that low performers would be more inspired, and high performers would demonstrate and articulate their ‘better’ abilities. This was students’ first exposure to a mathematical modelling approach.

Over the course of a semester, students were exposed to four mathematical modelling tasks. For each of the four tasks, a newspaper article was sourced that described a real-world problem. Task 1 was based on a community project in the Eastern Cape province of SA. The narrative described a project wherein children could exchange recyclables for ‘Moolas’ (a made-up currency). In turn, Moolas could be accumulated over time to be exchanged for ‘treasures’ such as stationary and food items. The task challenged students to design a poster that could be used as a guide for trading different types of recyclables (e.g. plastic, glass) for different types of ‘treasures’. In Task 2, students had to construct a realistic three-month budget with which to create a garden with plants, trees and lawn. The budget, to be spend at a Garden center, also had to accommodate discounts on certain items during certain months. Task 3 related to the mysterious disappearance of boats and airplanes over the Bermuda Triangle and was analysed in this study. Task 4 described an experiment on Mount Everest that related to the oxygen levels in human blood at different altitudes as reported in Kotze et al. (2015).

All tasks were designed to elicit mathematical modelling competencies as suggested by Blum and Leiß (2007). Using this framework, the modelling process could be critically analysed by identifying errors in each phase of the modelling cycle. Also, the framework helped to detect whether required competencies were attained in each transition. Galbraith and Stillman (2006) suggested the use of subtasks to help trace performance at different phases of the modelling process. It was important to anticipate students’ approaches to the task and the types of errors that could be made. In designing the tasks, it was also necessary to ensure that all relevant mathematical knowledge and technological skills required to perform the task were already considered in prior study units.

Each custom-designed task was completed within a scheduled 90-minute tutorial period. Task 3 was dubbed the Bermuda Triangle task and this triangle is shown in [Figure 2](#). A narrative described the enigmatic disappearance of aircraft and ships over the triangle ([Appendix A](#)). To assist students with the progression through the modelling cycle, the task was delineated into five subtasks. Although the model for the area of the triangle was given, it still had to be analysed and interpreted in terms of the real-world contexts. Students had to use hand-held technology to source the global positioning system (GPS) coordinates of the vertices of the Bermuda triangle. In effect, each different set of GPS coordinates would result in a different area. This freedom of choice facilitated the open-endedness of the modelling task.



**Figure 2.** The Bermuda Triangle map

All students had the opportunity to participate in the modelling task. To encourage students' attendance and participation, the task contributed to the semester mark. Each group submitted a completed worksheet which was assessed by the researcher and moderated by another subject expert. The inter-rater reliability of the task was measured with Cohen's kappa ( $K=0.81$ ). Stoddart, Abrams, Gasper, and Canaday (2000) proposed that kappa values between 0.21–0.40 reveal poor agreement between raters but values between 0.41–0.75 indicate a moderate to good agreement. As such, the agreement between raters for the Bermuda triangle task was excellent. A pilot study was conducted the previous year which confirmed the content validity of the task.

## DATA ANALYSIS

Group documents were analysed with content analysis. Following Wijaya et al. (2014), **Table 1** aligns the Newman (1977) error categories in column one with the mathematical modelling competencies as described by Blum and Leiß (2007) in column two. However, *mathematising* and *interpreting* were further sub-divided to allow for more nuanced analyses of these two important but difficult competencies in the modelling cycle (Blum & Leiß, 2007). This brings the number of modelling competencies in column two to six. In scoring the task, all six modelling competencies were considered equally important. For each competency, a zero score was awarded for an inappropriate response or a score of one for a relevant response; therefore, the maximum score that could be awarded for the task was six. Since there were ten groups, the total number of possible errors made in the task amounted to 60. Overall, 21 errors were recorded in the task. The most common errors appear in the third column of **Table 1**. The last column reflects the specific subtask related to the Newman error category, modelling competencies and related errors.



**Table 1.** Newman's error categories, modelling competencies and typical errors in the Bermuda Triangle task

Newman's error categories	Modelling competencies (% errors)	Errors	Subtask
Comprehension	Understanding (0%)	<ul style="list-style-type: none"> <li>No errors were made as all groups could fully understand the task and source omitted data (GPS coordinates)</li> </ul>	a. Source the omitted GPS data by using technology
Transformation	Mathematising_1 (GPS coordinates) (23.8%)	<ul style="list-style-type: none"> <li>Incorrect conversion of GPS coordinates from degrees minutes and seconds (DMS), to decimal degrees (DD)</li> <li>Incorrect positioning of GPS coordinates on vertices of triangle</li> <li>Unable to associate North and East with positive coordinates and South and West with negative coordinates</li> </ul>	b. Convert GPS coordinates from DMS to DD
	Mathematising_2 (set up determinant) (0%)	<ul style="list-style-type: none"> <li>No errors were made in representing relevant vertices of the triangle in order to set up the appropriate determinant</li> </ul>	c. Calculate the area of the triangle using the given formula
Process skills	Working mathematically (9.5%)	<ul style="list-style-type: none"> <li>Using wrong co-factor expansion in the evaluation of the determinant</li> <li>Calculation mistakes in evaluating determinant</li> </ul>	
	Interpreting (23.8%)	<ul style="list-style-type: none"> <li>Mistaking <math>\pm</math> signs in given determinant model for <math>\pm</math> signs associated with longitude or latitude</li> <li>Confusing <math>\pm</math> sign in given model with <math>\pm\sqrt{\quad}</math> (as in taking the square root)</li> </ul>	d. Explain the meaning of $\pm$ sign in given formula
Encoding	Validating and presenting (42.9%)	<ul style="list-style-type: none"> <li>Presenting area as a negative value</li> <li>Unrealistic answer given in km instead of km<sup>2</sup></li> <li>Unable to judge correctness of Bermuda triangle area</li> <li>Presenting area in degrees (without converting to km<sup>2</sup>)</li> </ul>	e. Convert the calculated area of the triangle from degrees to km <sup>2</sup> using $1^\circ = 111.701 \text{ km}$

The task was firstly analysed according to the modelling competencies of Blum and Leiß (2007) where errors were not allowed to accumulate. For example, a wrong conversion of the GPS coordinates was not again penalised in follow-up calculations. The task was secondly analysed according to Newman's (1977) error categories.

Analysing the task according to competencies suggested by Blum and Leiß (2007), the first transition evoked *understanding*. Students had to read the narrative and understand *what* to do in terms of the contextual setting of the task. The task involving the Bermuda triangle map (Figure 2) probed students to visualise the task and aimed to stimulate a sense of familiarity with the real-world contexts of the task. The subtasks (Appendix A) were designed to stimulate understanding and help students to structure, simplify and delineate processes (Blum & Leiß, 2007). Since all groups could successfully source the omitted data (GPS coordinates) with technology and acquired a full understanding of the task, no errors were recorded in *understanding*. In the modelling transition that elicited *mathematising* for the first time, students had to apply their prior knowledge of longitudes, latitudes and GPS coordinates to convert their real-world data from degrees, minutes and seconds (DMS) to decimal degrees (DD). Analogous to Cartesian coordinates, a point on the longitude-latitude grid is positive if it lies North of the Equator (the latter represents an East-West axis or 0° latitude); alternatively, a point is negative if it lies South of the Equator. Similarly, a point is positive when it lies East of the Prime Meridian (representing a North-South axis or 0° longitude) and negative if it lies West of the Prime Meridian. For example, the DMS coordinates (32°18'28,08"N; 64°45'1,8"W) of St George in Bermuda had to be converted to DD coordinates (32,3078; -64,7505°). Altogether, 23.8% of all errors were made in the first instance of mathematising, that is, mathematising of the real-world data. On the contrary, no errors were recorded in the second round of *mathematising*. This means that all groups could accurately present their assumed GPS coordinates in terms of the given determinant – which represented the mathematical model to calculate the area of the Bermuda triangle. *Working mathematically* seemed to be an easy part of the task. Procedural errors in this competency amounted to 9.5% of all errors made in the task; these included calculation mistakes and using incorrect co-factor expansions to evaluate the determinant. Errors in *interpreting* the solution were also 23.8% of all errors made; thus, the second highest alongside the first *mathematising* process. The plus-minus sign in the determinant was incorrectly interpreted by five groups. Group 8 spontaneously associated the plus-minus sign with the quadratic formula – this perhaps being the *only* instance where students have encountered this dual sign before – and trustingly computed the square root of the area. Three other groups confused this plus-minus sign with signs associated with the directions North, East, South and West. Unexpectedly, the *validating and presenting* competencies amassed most errors (42.9%). Since the Equator is divided into 360 degrees on the longitudinal axis, each decimal degree on the equator represents approximately 111,701 km. A conversion was therefore required to present the area of the Bermuda triangle in square kilometers. Most groups



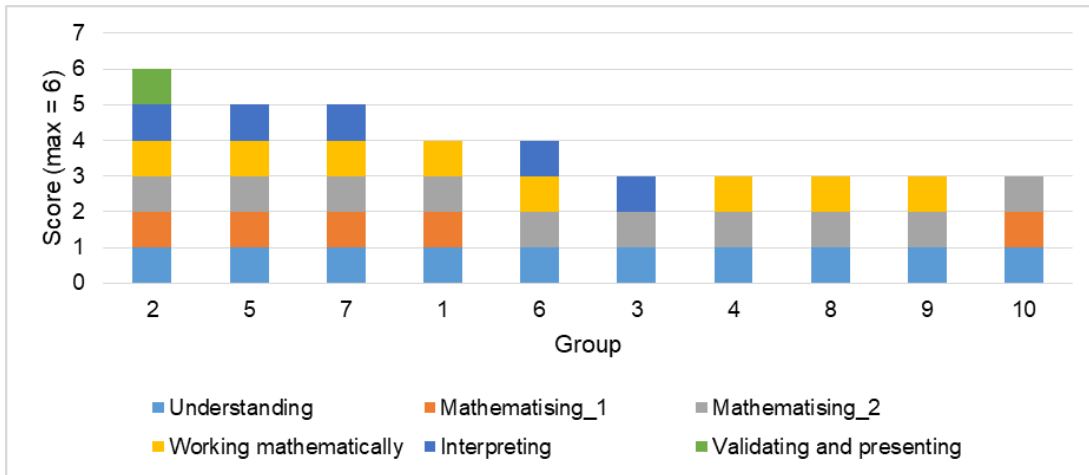


Figure 3. Percentage correct responses of ten groups

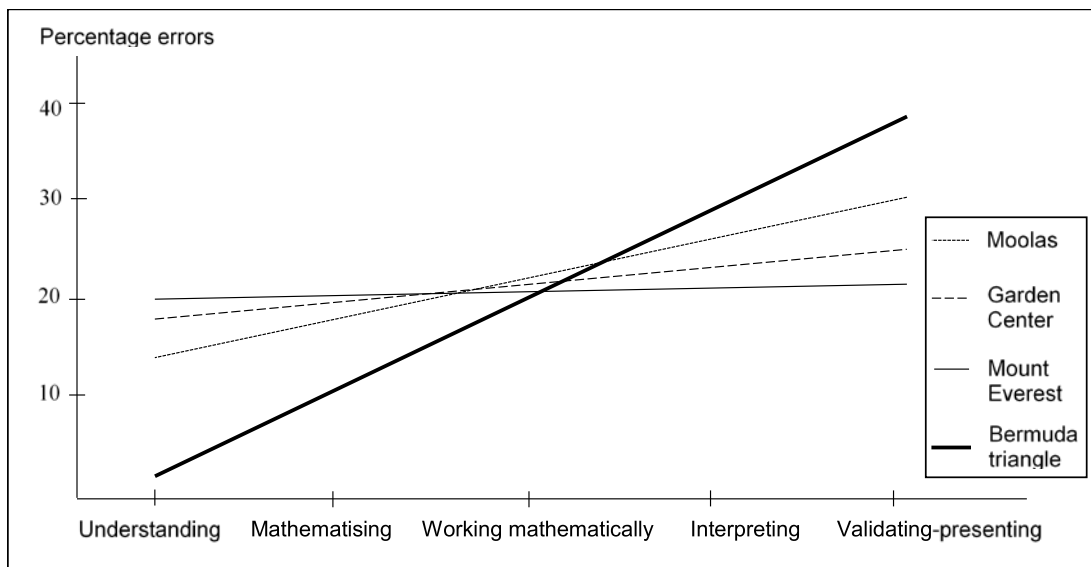
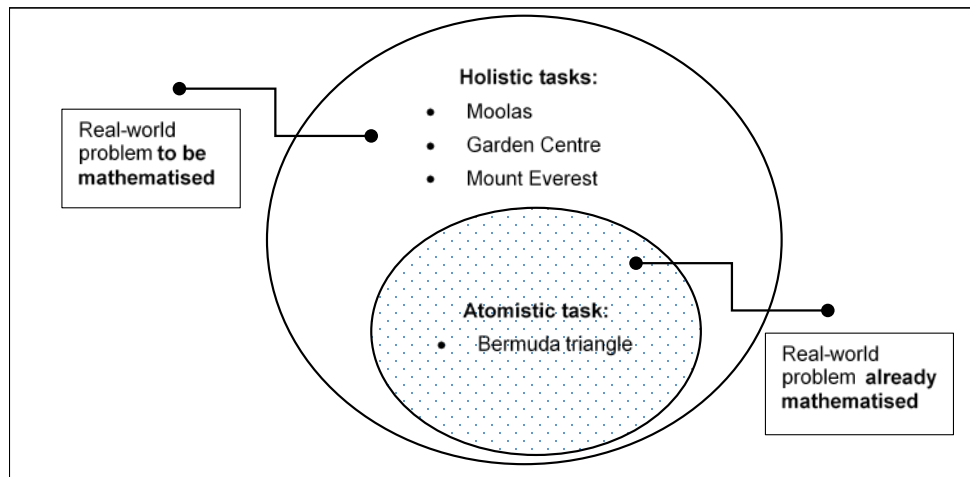


Figure 4. Trendlines showing percentage errors in the four modelling tasks

erred by multiplying the area by 111,701 km instead of  $(111,701 \text{ km})^2$ . In a former study unit, students were fluent with comparable conversions such as from m/s to km/h. If the *interpreting* step is combined with the *validating and presenting* steps, this collective category (labelled *Encoding*, according to Newman, 1977) accounted for 66.7% of all errors made in the task. Figure 3 shows the correct responses in each modelling competency for each group. Only Group 2 obtained the maximum score (six) while five groups succeeded in only three of the modelling competencies.

Overall, the four modelling tasks differed substantially in terms of the competencies which attracted most errors. While the Bermuda triangle task was nearly free from errors in the first three competencies embedded in the modelling cycle, competency errors in the other three tasks (Moolas, Garden center and Mount Everest) were mostly stable across all the modelling phases. In order to compare the trend in errors across all four tasks, the other three tasks were also analysed according to five modelling competencies namely *understanding*, *mathematising*, *working mathematically*, *interpreting* and *validating-presenting*. Figure 4 presents the trendlines of the four tasks and shows the percentage errors in the five modelling competencies. The trendlines suggest that errors in the Moolas, Garden center and Mount Everest tasks are mostly clustered about the 13–25% error levels.

Interestingly, the trendline for the fourth task (Mount Everest) almost levels out into a flat line, meaning that errors in modelling competencies were constant across this task. In fact, the Mount Everest task attracted the least number of errors overall, which could indicate that students were getting more accustomed to the modelling approach. It could also be that this task, with its direct links to the biosciences (modelling oxygen levels in blood at



**Figure 5.** Holistic versus atomistic modelling tasks

different altitudes), allowed students to make better connections between mathematical symbols and real-life contexts.

In contrast, the trendline of the Bermuda triangle in [Figure 4](#) confirms that few errors were made in *understanding, mathematising and working mathematically* while most errors occurred in the competencies of *interpreting and validating-presenting* (compare [Table 1](#)). The reason for this contrasting trend could possibly lie in the nature of the tasks. The main difference between the four modelling tasks in this study is that the mathematical model was *provided* in the Bermuda triangle task, meaning that the actual *mathematising* transition as suggested in [Figure 1](#) was largely bypassed; therefore this task can be classified as atomistic. In the other three tasks, students had to *mathematise* the real-world problem and construct a mathematical model *themselves*; these three tasks were therefore holistic (Blomhøj & Jensen, 2003). [Figure 5](#) illustrates the comprehensive nature of the other three holistic tasks – which involved all modelling phases – while as an atomistic task, the Bermuda triangle task can be regarded as a subset of the holistic approach since *mathematising* was avoided.

## DISCUSSION

According to Schoenfeld (2001), mathematics in contexts relate to the use of ordinary tools and skills in new contexts. The Bermuda triangle contexts encouraged students to source missing data, mathematise global coordinates of real-world places and transfer data to an unfamiliar model (area of the triangle). Students had to exhibit ownership of prerequisite knowledge and technological skills to make sense of the task. The task commanded various mathematical concepts – areas, determinants, coordinates, conversions between DMS and DD, the dual meaning of the plus-minus sign in the given model and conversion from DD to  $\text{km}^2$  – to be integrated into new contexts.

Results indicated that students could fully *understand* the intention of the task which eased the way for five groups to *mathematise* the real-world data without errors. On the one hand, it was possible that the earlier impromptu conversation about the missing Malaysian flight 370 – and widely publicised media coverage of subsequent search efforts by the international community – helped to promote a deeper understanding of the task. Specifically, media reports captured the extent of the search area which possibly helped students to picture distances travelled in an airplane, though it is likely that most students would not been in an airplane before. On the other hand, since the detailed worksheet ([Appendix A](#)) was not handed out immediately, additional time was allowed for informal group discussions which may have helped students to intuitively understand the goal of the task. Students would typically communicate in their native tongue during these discussions. However, many English terms are not necessarily easily translated, and are often adopted in a mode mixed with African languages; for example, concepts such as 'iPad', 'triangle', 'area' and 'GPS' remained untranslated. This was the third modelling task and students seemed to be more familiar with their group dynamics. By now, it was practice for students to work in their respective groups, even during traditional lectures. Throughout the Bermuda triangle task, the classroom mood was notably informal, talkative and animated.

The given mathematical model for the area of a triangle was a novelty; yet all groups could correctly transfer their mathematised data to the model. *Mathematical work* was performed with prudence and errors were only observed in Group 3. Up to this point in the task, a mere 33% of the total amount of errors were noted. Most likely, this acclaimed success can be ascribed to the design of subtasks that had a scaffolding impact on students'

modelling processes; in particular the modelling competencies of *understanding*, *mathematising* and *working mathematically*. The error ‘slips’ that would occasionally occur due to negligence could probably be resolved through the collective input of the group. In this sense, the heterogeneous composition of groups might have contributed to these gains. As a result, students were mostly successful in applying relevant mathematical concepts and coordinating mathematical tools to the contexts of the Bermuda triangle (Schoenfeld, 2001).

This outcome is contrary to the findings of Wijaya et al. (2014) who reported that most errors were made in *understanding* and *mathematising*. However, the study of Wijaya et al. indicated that fewer errors were made in *working mathematically* and *interpreting* the solution. A major concern was students’ inability to take the contexts of the Bermuda triangle problem into account in the *final* phases of the task which had to be supported by *interpreting*, *validating* and *presenting*. This unexpected finding is in contrast with Newman (1977) and Wijaya et al. (2014) who found that younger children in their respective studies mostly encountered problems with the *earlier* phases of the modelling cycle. These differences may be due to the atomistic nature of the Bermuda triangle task and the specific structure of subtasks which elicited one modelling competency at a time.

Gainsburg (2013) believed that atomistic tasks may be desirable to underscore and lay the foundation to holistic modelling. By focusing on strategic modelling competencies in atomistic tasks, students can be prepared for more comprehensive modelling tasks. Gainsburg (2013) refers to an atomistic approach as learning to model piece-by-piece. As such, atomistic tasks can help with the development of specific modelling competencies. For biomedical technologists, the *interpretation* and *validation* of laboratory data that culminate in report-writing (*presenting*) are important modelling skills that can be learned through atomistic tasks. The Bermuda triangle task was atomistic by nature since the mathematical model (area formula, given as a determinant) was provided. Although *mathematising* was side-stepped, this task contributed in a different but arguably also important way: it presented opportunities to focus more on the critical and quantitative analysis of the *given* model, its real-world meaning, interpretation and ultimately, the usefulness of the mathematical concept at hand. Blomhøj and Jensen (2003) also believed that a holistic approach to mathematical modelling is indeed time-consuming and that students need ample time to adjust to a modelling environment. Another complication is that *mathematising* is widely regarded to be cognitively challenging. For biomedical technologists who have a high-school modelling deficiency and only one semester of university mathematics, the atomistic approach may be more suitable to attain competencies in line with workplace demands.

Arguably, the competencies embedded in the final phases of the Bermuda triangle task – *interpreting*, *validating* and *presenting* – required students to build up considerable understandings from symbols to reality. However, students struggled to coherently unite their mathematical work with real-world contexts. This finding also suggested that students were able to accurately calculate the area of a triangle but fell short of interpreting the symbolic significance thereof in the real world. One reason for this apparent divide between mathematics and reality may be that most students seemed to be reluctant – or perhaps unused – to reflect on contexts in order to ‘find truth’ in their answers. This reluctance may even suggest that *interpreting*, *validating* and *reporting* on the task, which accumulated 66.7% of errors, were not part of students’ standard classroom repertoire. Classroom practices which rarely stimulate these modelling competencies where errors predominated, may induce difficulties to reason meaningfully about solutions. As Schoenfeld (2001, p. 53) pointedly stated, all that is often required of students is “to draw a box around the correct answer”. Rightfully, there should be reservations whether the notion of area was truly contextualised given that most groups failed to present their answers in square units. Whereas students were more fluent with individual concepts – such as area and converting in-between different units – in earlier study topics, the same concepts, when intertwined into one task, could not be connected coherently. This failure is evidence that conceptual understanding and fluency in the earlier phases of the modelling cycle could not secure a real-world interpretation, validation and presentation of a real-world problem.

When the Bermuda triangle task was analysed according to the Newman (1977) error categories, errors were considered to be hierarchical and were allowed to accumulate from step to step (Wijaya et al., 2014). Per illustration, students in Group 3 used incorrect signs when they converted their GPS coordinates from DMS to DD; consequently, they obtained a negative area for the Bermuda triangle. This error was however ‘fixed’ in the next subtask when they correctly interpreted the plus-minus sign as a means to eliminate the negative value obtained for the area. This amendment is evidence that contexts were employed even though errors were made in previous steps. Even so, relatively few errors (39%) were made in the Newman error categories of *comprehension*, *transformation* and *process skills*. It therefore seems that errors identified with the modelling framework of Blum and Leiß (2007) were consistent with the Newman analysis. Again, specific subtasks served as a diagnostic tool to identify weaknesses in specific Newman categories.

The modelling competencies of Blum and Leiß (2007) are considered to be more suitable to analyse a modelling task, which ultimately, is more concerned with a meaningful solution than with adequate procedural processes. Clearly, more research is needed to find a balance between atomistic and holistic modelling within specific educational and curricular constraints (Blomhøj & Jensen, 2003).

## CONCLUSION

The aim of this article was to investigate the potential of different mathematical modelling tasks that could underscore competencies suitable to the biomedical industry. To this end, error types and trends were explored in both atomistic and holistic modelling tasks. By aligning subtasks with specific phases of the modelling cycle and embedded competencies, error analyses of modelling tasks could reveal students' strengths and weaknesses throughout the modelling cycle. Research question one was:

*Which competencies attract the most errors in an atomistic modelling task?*

The contextual setting of the Bermuda triangle task demonstrated that when students understand the meaning of real-world contexts, they are more likely to be successful to *operate*, *transfer* and *model* with real-world data. While the conversion from real-world data to mathematical symbols attracted minimal errors, most errors occurred in the reverse direction: converting mathematical results in a meaningful way to real world results. Students were mostly unsuccessful with the phases in the modelling cycle which elicited *interpreting*, *validating* and *reporting*. This deficiency may be an indication that these competencies do not receive the attention it deserves in traditional classroom practices. As such, mathematical results remained largely unconnected to the real world.

Research question two was:

*What are the differences between error trends in atomistic and holistic modelling tasks?*

When the atomistic task was compared with the holistic tasks, the most dominant errors in both types of tasks occurred with *interpreting*, *validating* and *presenting*. This means that in both types of tasks, students struggled most to convert mathematical results to reality. Furthermore, in the holistic tasks errors tended to be more equally distributed across all modelling competencies. This means that, even though the atomistic task side-stepped the initial phases of the modelling cycle – regarded to be a considerable cognitive barrier – difficulties were still more prevalent in the latter phases of the modelling cycle which probed competencies involving *interpreting*, *validating* and *presenting* of results.

The implications for practice are unambiguous. Biomedical technologists will need to interpret laboratory data, validate results and write reports, all of which are important modelling competencies which can be learned via atomistic modelling tasks. Students were unaccustomed to contextually rich tasks and need more opportunities to crisscross the divide between their own world and the formal world of mathematics. Available evidence of specific shortcomings coupled with target educational goals and workplace imperatives can guide the design of a more desirable classroom pedagogy. After all,

*errors are seen not only as natural, inevitable and [an] integral part of learning but are also regarded as valuable sources of information about the learning process; providing clues that researchers and teachers should take advantage of in order to uncover current students' knowledge and how they come to construct such knowledge" (Makonye, 2011, p. 19).*

## LIMITATIONS AND RECOMMENDATIONS

A limitation of the study was that only one of the modelling tasks was atomistic in nature. There is potential for future research to find a balance between atomistic and holistic modelling tasks. The sample was restricted to a relatively small cohort of 50 biomedical students studying towards a National Diploma in Biomedical Technology and can therefore not be generalised to all biomedical technology students. How students will respond to a task with a more local context may be an area for further investigation. As mathematical modelling is still in its infant shoes in SA, there is a need for further research on error analysis to help structure more suitable pedagogies for biomedical technology students who have to face a world of work with twenty-first-century demands.

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## APPENDIX A

### The Bermuda Triangle Task

Handout one (the narrative and map): The Bermuda triangle is a region of the north-western Atlantic Ocean in which a number of aircraft and surface vessels are alleged to have disappeared under mysterious circumstances, all of which fall beyond the boundaries of human error, pirates, equipment failure or natural disasters. Some writers attributed the disappearances of aircraft and boats to UFOs. This idea was used by Steven Spielberg for his science fiction film *Close Encounters of the Third Kind*, which features the lost Flight 19 as alien abductees. Others believed that the Bermuda Triangle is a wormhole (a gap in space and time). Plan a strategy to approximate the area of the Bermuda triangle.

Handout two (the worksheet):

- Search for the GPS coordinates of St George in Bermuda, San Juan in Puerto Rico and Miami in Florida.
- Convert these GPS coordinates to decimal degrees.
- The area of a triangle with vertices  $(x_1, y_1)$ ;  $(x_2, y_2)$  and  $(x_3, y_3)$  is given as

$$A = \pm \frac{1}{2} \begin{vmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ x_3 & y_3 & 1 \end{vmatrix}$$

Use this formula to calculate the area of the Bermuda triangle.

- What do you think is the meaning of the plus/minus sign in the formula given in Question c?
- Convert the area of the Bermuda triangle to square kilometers; assume 1 degree = 111,701 km.

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# In Search of a Working Strategy: The AHA... Moment in the Teaching of Science Subjects at Two South African High Schools

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Received 24 January 2018 • Revised 5 May 2018 • Accepted 9 May 2018

## ABSTRACT

The purpose of this study is to interrogate a 'working' strategy established to improve and sustain learner performance by two Life Sciences and two Physical Sciences teachers of two best-performing high schools in the North West province of South Africa. The schools in this study have had a pass rate of over 90% for seven consecutive years in Physical and Life Sciences. Ausubel's (1963) constructs of Meaningful Reception Learning theory provided the conceptual framework for this study. The study was purely qualitative, employing an exploratory case-study approach. Purposive sampling was adopted to identify participants and research sites for the study. Data was generated through interviews, classroom observations and document analysis. The data were thematically analysed using open coding, axial coding and selective coding. Results of the study demonstrate that the *aha! moment* originated from the use of role-playing as a teaching strategy. Recommendations for policy and further research are suggested.

**Keywords:** aha! moment, case study research, learner performance, role-playing, meaningful reception learning theory

## INTRODUCTION

Physical Sciences as a school subject in South Africa is generally characterised by poor performance amongst high school learners (Mavhungu, 2016). Outdated instructional teaching practices and lack of basic subject content knowledge amongst teachers have resulted in poor teaching standards in the subject and the overall South African education system (Makgato & Mji, 2006). However, this is not the case in every public school. Mavhungu (2004) showed that the failure rate in Physical Sciences in most South African schools varies from region to region. According to BusinessTech (2018), education quality assurer uMalusi recently expressed delight that South Africa's science marks are improving; however, the actual numbers show that things are getting worse. Furthermore BusinessTech notes that the numbers are even more telling when looking at the passes in the ranges that give access to degrees that carry a high demand in the South African work space. Thus, the current trends are still prevalent in South Africa. The same can be said about Life Sciences. There has been a consistently poor record of performance in Life Sciences as a school subject in the past (Ferreira, 2011) with only some miniscule improvement reported. Similar trends still exist as noted by BusinessTech (2018) as Life Sciences is a science subject. Physical Sciences and Life Sciences are perceived to be difficult by South African learners as indicated by low performance (BusinessTech, 2018; Diagnostic report, 2017). The impediments to academic success and reasons for the poor performance are complex and only vaguely understood.

According to Kriek and Grayson (2009), some of the reasons include poverty, lack of resources, entrenched poor learning cultures, poor infrastructure in the schools, weak subject mastery amongst teachers, as well as insensitive regional distribution of Mathematics and Science teachers. Ramnarain and Fortus (2013) indirectly blamed teachers who lack specialist content knowledge and are incapable of implementing successful teaching strategies in their classrooms. Lee and Luft (2008) suggested that such teachers tend to rely heavily on textbooks, albeit without the necessary pedagogic strategies to stimulate receptive mastery of the concepts. With research suggesting that certain teaching practices seem to be more effective than others for particular learning domains, educational levels and

### Contribution of this paper to the literature

- Role-playing provided *the aha! moment* as a 'working' teaching and learning strategy in two subjects perceived difficult by Grade 12 learners where performance is below the national average in a majority of schools in the North West province.
- The use of role-playing not only showed deviation from routine and superficial approaches which explain why South African learners are not performing well in Physical and Life Sciences as compared to international benchmarks. It also prepared the learners for examinations and fostered growth of scientific conceptual knowledge.
- Role-playing increased learner participation and encouraged them to use their background knowledge to acquire new information.

specific learner populations (Seidel & Shavelson, 2007), a closer look at the *aha! moment* of Physical and Life Sciences teachers seems to be warranted. In most cases teachers clarify aims of their lessons, present the lessons and need to relate lesson content to their learners' prior knowledge. Teaching entails making the organisation of the new materials explicit, making logical order of the learning materials explicit. In all this, teachers should use examples and engage learners in meaningful learning activities to promote active reception learning. These are day-to-day duties of teachers. However, the *aha! moment* is when teachers are made aware of useful practices which they might not be practicing. According to Winfrey (2006):

*What's really outstanding about those moments is usually when you hear something like that, it's - it's - it's reminding you of what you already know. That's what the aha is, cause it feels like, 'I knew this; I just didn't know the words to put it,' you know? That's what's fabulous about it.*

In the same vein, the assertion by Winfrey (2006) relates to how the *aha moment* is operationalised in this paper. This paper reports on *the aha! moment* (a point in time when the teachers had sudden insight into a 'working' teaching and learning strategy, to improve and sustain learner performance in the two subjects that are perceived to be difficult by learners and where performance is below the national average in a majority of schools in the North West province. The two schools (study sites) are labelled best-performing because they are amongst the schools which obtain between 90% and 100%, despite not having enough resources just like the majority of South African schools. In the South African context, schools that perform at the 80–100% range per subject and the overall school's achievement are labelled best-performing.

## Background to the Study

In order to fully understand the background in which this study was undertaken, it is necessary to describe the context in which this research took place. Grade 12 examinations are set by the Department of Basic Education in South Africa. The term 'Department' is preferred and used in South Africa as opposed to 'Ministry'. Examinations are set according to the criteria outlined in the official curriculum statements. The Grade 12 examination are set by a group of selected subject specialists, some of whom are school-based teachers who have produced good results (80–100%) pass rate. The other examiners are the subject advisors (in South Africa, these refer to senior subject-specific education specialists). They are also known as office-based teachers who monitor curriculum implementation (Department of Basic Education, 2011a). These examinations are moderated by education officials responsible for curriculum monitoring, also known as provincial and national curriculum coordinators.

Each subject has its assessment requirements. In South Africa, Physical Sciences consists of two subjects which are Physics and Chemistry. In other African countries such as Zimbabwe and Malawi and European countries such as the United Kingdom, these two subjects are taught separately. The Physical Sciences examination consists of two sessions. Session 1 is Physics and session 2 is Chemistry. Each session's total is 150 marks as shown on **Table 1**. Each session has its specification of content, marks, duration and cognitive weighting. Duration for each session is three hours. As shown on **Table 1**, there are four content areas for session 1, whereas there are three content areas for session 2. Mark allocation for each content area is different, as shown on **Table 1**, with weightings of questions across cognitive levels (recall, comprehension, applying and analysing and synthesis). The distribution of marks for specific main knowledge areas is outlined in the 'pacesetters document' (guideline for the teachers to pace the progress of topics per term as per policy requirement). Syllabus coverage in the examinations is determined by the weighting of topics.

**Table 1.** Physical Sciences

<b>Physics (Session 1): Physics Focus</b>							
Content	Marks	Total	Duration	Weighting of questions across cognitive levels in percentages (%)			
				1	2	3	4
Mechanics	63	150 marks	3 hours	15	35	40	10
Waves, sound and light	17						
Electricity and Magnetism	55						
Matter and Materials	15						
<b>Chemistry (Session 2): Chemistry Focus</b>							
Content	Marks	Total	Duration	Weighting of questions across cognitive levels in percentages (%)			
				1	2	3	4
Chemical Change	84	150 marks	3 hours	15	40	35	10
Chemical Systems	18						
Matter and Materials	48						

Key: 1 = Recall; 2 = Comprehension; 3 = Applying and analysing; 4 = Synthesis

**Table 2.** Life Sciences Session 1

Content	Marks	Total	Duration	Weighting of questions across cognitive levels in percentage (%)			
				1	2	3	4
Meiosis	11	150	2 ½ hours	40	25	20	15
Reproduction in Vertebrates	6						
Human Reproduction	31						
Responding to be environment (humans)	40						
Human endocrine system	15						
Homeostasis in humans	11						
Responding to the Environment (plants)	11						
Human impact (Grade 11)	25						
<b>Life Sciences Session 2</b>							
DNA: Code of Life	27	150	2 ½ hours	40	25	20	15
Meiosis	12						
Genetics and Inheritance	45						
Evolution through Natural Selection	23						
Human evolution	43						

Keys: 1 = Recall; 2 = Comprehension; 3 = Applying and analysing; 4 = Synthesis

Life Sciences is known as Biology in the countries as stated above, excluding South Africa. In South Africa, the Life Sciences examination is written in two separate sessions, i.e. session 1 and 2 each carrying a total of 150 marks. As shown on **Table 2**, session 1 covers eight content areas and session 2 covers five content areas. Each session's total is 150 marks as shown on **Table 2**. Each session has its specification of content, marks, duration and cognitive weighting. Mark allocation for each content area is different. Duration for each session is two and a half hours. Both sessions have the same cognitive weightings for topics across cognitive levels (recall, comprehension, applying and analysing and synthesis). The distribution of marks for specific main knowledge areas is outlined in the 'pacesetters document' (guideline for the teachers to pace the progress of topics per term as per policy requirement). Syllabus coverage in the examinations is determined by the weighting of topics. The duration of each session is two and a half hours (Department of Basic Education, 2011b).

The examination marking is centralised. Each province arranges a number of venues at which the scripts are marked. The provinces collect papers from schools under tight security; these are sent to the provincial examination office for administration purposes and ultimately to the marking centres. The scripts are marked by selected teachers who have been teaching the subject for three years or more and have produced 80–100% pass rate in three consecutive years counting from the current year of teaching (Department of Basic Education, 2011b). The marked scripts are moderated twice, first by the senior marker followed by the chief moderator who forms part of the examiners for that paper. Umalusi is an independent body responsible for quality assurance of the examination process, including setting of examinations, distribution and authenticating the marking process. They oversee the whole process including the results. They work with the Minister of Education and the rest of the assessment team. This process involves only Grade 12. Amongst other responsibilities, Umalusi standardises the examination to

**Table 3.** Physical Sciences results since 2013 for the North West province

		Physical Sciences	
Year		No. of candidates	% of candidates
Nov. 2014	Wrote	8 191	
	Pass at 30%	5 243	64.01%
	Pass at 40%	3 012	36.77%
Difference Nov. 2013 & Nov. 2014	Wrote	-787	
	Pass at 30%	-1 443	-10.46%
	Pass at 40%	-1 170	-9.81%
Nov. 2015	Wrote	9 090	
	Pass at 30%	5 639	62.04%
	Pass at 40%	3 265	35.92%
Difference Nov. 2014 & Nov. 2015	Wrote	+898	
	Pass at 30%	+396	-1.97%
	Pass at 40%	+253	-0.58%
Nov. 2016	Wrote	8 593	
	Pass at 30%	5 984	69.64%
	Pass at 40%	3 699	43.05%
Difference Nov. 2015 & Nov. 2016	Wrote	-497	
	Pass at 30%	+345	+7.60%
	Pass at 40%	+434	+7.16%

Source: North West Provincial examination analysis report 2017

mitigate the effect of factors other than learners' knowledge and aptitude on the learners' performance and finally approves the results (Umalusi, 2014, p. 84). After approving the results, Umalusi issues the National Senior Certificate to successful candidates. The body consists of academics from various institutions of higher learning such as universities, colleges and Department of Basic Education (DBE) officials.

The Physical Sciences and Life Sciences results of 2012–2016 Grade 12 final examinations are not good. **Table 3** shows the Physical Sciences results since 2013 for the North West province.

From **Table 3**, the quantity of passes is determined by the number of candidates who made the 30%+ pass percentage and the quality passes are determined by the candidates who achieved 40%+ pass percentage. The 30% and 40% pass percentage is controversial; however, this is a South African standard outlined in the National Policy Pertaining to the Programme and Promotion Requirements of the National Curriculum Statement policy document (Department of Basic Education, 2013). As can be seen from **Table 3**, in 2016, in Physical Sciences 497 fewer candidates wrote the subject examination. According to Lehari (2017), Physical Sciences showed an excellent performance as 345 (7.60%) **more** candidates managed to reach the 30% pass criteria and 434 (7.13%) **more** candidates managed to achieve at 40%. There has been debate within the South African education context on the Grade 12 subject pass mark being pegged at 40%+ (Jansen, 2014). Some academics and teachers are overtly against the idea of giving a cut-off point of 40% as a pass. For example, Muller (2014) contended that pegging the pass mark at 40%+ is setting the bar too low. Each year, the Minister for Basic Education produces a strong defence about why the pass mark should be retained and maintained at 40% and not pushed to 50% or more (BusinessTech, 2018). The Minister's argument is premised on the National Development Plan (NDP) which directs the Department of Basic Education to mediate the high drop-out rate of learners from the basic schooling system by increasing learner retention rate (Wicks & Raborife, 2017). Dropping out from high school is associated with negative employment and life chances (Muennig, 2006). Young people who drop out of high school are unlikely to have the minimum skills and credentials necessary to function in today's increasingly complex society and technology-dependent workplace (Christle, Jolivet, & Nelson, 2007). The completion of high school is required for accessing post-secondary education and is a minimum requirement for most jobs (Child Trends Databank, 2015). Negative outcomes, such as drop-out status have been linked with poor health, including poor mental health along with diminished labour force participation, exerting a high economic toll on society (Muennig, 2006). A country would not want to see itself with a multitude of citizens who dropped out of school: so, political demands and whims have taken the lead and have advocated for 40%+ as a pass, however educationally unsound this might be. From a political standpoint, this trend suggests an improvement focusing on the 2016 class, but from an academic viewpoint, the quality of passes raises serious concerns about the competencies and skills the candidates exhibit. Life Sciences generally have similar profile.

There is a myriad of reasons behind such unsatisfactory performance, outlined by several researchers (Ferreira, 2011; Kriek & Grayson, 2009; Ramnarain & Fortus, 2013). It is not the purpose of this paper to get entangled in the enumeration of these reasons, but rather to explore the body of knowledge on the use of a 'working' strategy in

Life Sciences and Physical Sciences which could assist in triggering learners' understanding of difficult concepts, thereby constructing new knowledges as learners interact with one another and the subject content. Scott, Mortimer and Ametller (2011) noted that teachers need to be experts in the subject matter for the successful implementation of teaching and learning processes and the development of scientific conceptual knowledge. Teachers need to be acquainted with new and innovative teaching approaches that not only prepare learners for examinations, but also foster the growth of scientific conceptual knowledge (Jeff, Marshal, Smart, & Alstone, 2017). Routine and superficial approaches explain why South African learners are not performing well in Physical Sciences when compared with international benchmarks (Lehesvuori, Ramnarain, & Viiri, 2017). Instructional practices are often classified into two types – teacher-directed or constructivist – depending on whether it is the teacher (direct instructional practices) or the student (constructivist teaching practices) who plays the pivotal role in the learning process (Isac et al., 2015). The notion of a working strategy falls into the latter. This kind of pedagogic practice is characterised by weaker classification and framing, and logic of acquisition as a more progressive (learner-centred) 'invisible' pedagogy (Bernstein, 2000, p. 110). This paper reports on how role-playing was identified as the 'working' teaching and learning strategy.

## LITERATURE REVIEW

### Role-playing as a Teaching Strategy

Role-play is a pedagogical practice that has been used in a wide variety of contexts and content areas (Rao & Stupans, 2012). Derived from psychodrama, Craciun (2010) explained that role-playing could be used to help learners understand more subtle aspects of literature, social studies, and even some abstract aspects of science or mathematics. Role-playing is a basic engagement and should not be considered just as fun but as part of the learning process (de Medeiros-Silva, de Oliveira, & de Oliveira, 2017). Thus, role-playing as a basic engagement becomes a forum for learning and mastery of concepts. The school environment needs to be part of a social context that should provide meaningful, pleasurable and dialogical learning, encouraging learners to actively participate in the development of their own mastery of concepts (de Medeiros-Silva et al., 2017). Most of the studies on role-playing we cite in this section, though not from Africa, are from comparable developing contexts. Examples include de Medeiros-Silva et al. (2017, Brazil), Fogg (2001, Malaysia), and Khiri and Mohammadi (2016, Iran). Exceptional cases are the studies done by Bhattacharjee (2014, US), and Westrup and Planander (2013, Sweden). Our focus in such studies was mainly the benefits of using role-playing and we aimed at establishing if similar benefits could be realised in an African context using these pedagogic practices in the teaching of science subjects.

Fogg (2001) reported that learning through play raises learner interest in the topic. According to Poorman (2002), "integrating experiential learning activities in the classroom increased interest in the subject matter and understanding of course content" (p. 32). Learning through play provides the learners with the opportunity to construct knowledge in an interactive and participatory manner. New methods for teaching that incorporate play in order to improve both teaching and learning are seen by some as imperative (de Medeiros-Silva et al., 2017). Role-playing is a teaching strategy that fits within social family models (Joyce & Weil, 2000); part of this strategy is to emphasize the social nature of learning and promote cooperative behaviour as stimulating learners both socially and intellectually. Fogg's (2001) study also found that there is increased involvement on the part of the learners in role-playing lessons.

Westrup and Planander (2013) summarized the benefits as getting "students to apply their knowledge to solve a given problem, to reflect on issues and the views of others, to illustrate the relevance of theoretical ideas by placing them in a real-world context, and to illustrate the complexity of decision-making" (p.7). Craciun (2010) listed more benefits of using role-play pedagogy as developing the skills of initiative, communication, problem-solving, self-awareness, working cooperatively in teams, and teaching abstract phenomena in physics. During learning through role-play lessons, learners take an active part rather than being passive recipients of the instructor's knowledge. Poorman (2002) observed that "true learning cannot take place when students are passive observers of the teaching process" (p. 32). Besides being an active teaching strategy that promotes skill-based learning, Knowles, Holton, and Swanson (2011) asserted that role-playing as experiential learning offers a high degree of flexibility, creativity, and direct hands-on opportunity in the learning environment. Beyond learning the mere facts of the subject, role-play helps learners to be prepared in dealing with the challenges of the twenty-first century. Poorman (2002) also found "a significant increase among students in feeling another's distress as their own" (p. 34). Role-play has also been effective in reducing racial prejudice in plural societies (McGregor, 1993). Learning through play improves interpersonal skills, communication skills and enhances communication (de Medeiros-Silva et al., 2017). When used in a school setting, learning through play allows learners to extend their knowledge of a subject by researching the concept within a given topic. Using it as a teaching strategy which defines teachers' instructional practices, science teachers can come to realize that they are not just knowledge transmitters but facilitators who allow children to question, investigate and interact.

Although it is not a new strategy, role-playing has found a privileged place in only a few classrooms in which planning for role-play is a priority for the teacher (Rao & Stupans, 2012). Role-playing has been used as a pedagogical approach for many years, predominantly in sports education, theatre, history and other social science disciplines. Slowly, role-playing as a holistic teaching method that inculcates critical thinking, stimulates emotions and engenders moral values, and informs about factual data has found its way into the teaching of science subjects (de Medeiros-Silva et al., 2017). Khiri and Mohammadi (2016) found role-playing as a catalyst for problem-based learning which increases decision-making, interpretation and critical thinking. These are essential skills for learners who study science subjects. Using it as a teaching strategy which defines teachers' instructional practices, science teachers need to realize that they are not just knowledge transmitters but facilitators who allow children to question, investigate and interact. Bhattacharjee (2014) summed it all by noting that role-playing increases the efficacy of the learning experience, increases reliability of learners, thus enabling learners to think freely and deeply in a fashion that is more grounded in reality. There are quite a number of reasons why the focus of this paper is on role play as a working strategy for these two science subjects. According to Bhattacharjee (2014) role play provides learners an opportunity to build on their communication skills as well as synthesize the knowledge they have been taught and apply it. Being an active learning model, role-playing teaching encourages the learners for increased involvement. Zenda (2017) asserted that most South African schools (especially the ones in rural areas) do not have teaching and learning materials for science subjects. Strategies have to be established to self-motivate science teachers who have exposure to new teaching methods in science subjects. Zenda further states that strategies which need to stimulate scientific curiosity in learners through direct or indirect investigations of the natural phenomena in their immediate environments should be identified. It is therefore important that flexible teaching methods should be adapted to the needs of individual learners, hence role play was identified in this paper as the teaching strategy, following from Zenda's proposition.

In South Africa, role play is not new but has been used mainly in secondary schools as a tool to teach drama as Arts and Culture subject (Moore & Lemmer, 2010). Arts and Culture is a school subject in South African curriculum taught in Grades 4 to 9 to primary and middle school learners. In the South African context, role play is used in kindergartens and to teach all the subjects offered in primary schools. According to Bhattacharjee (2014) there is a dearth of studies where role play is used in high schools. Thus, this paper tries to create awareness that this strategy can be used in the high the school teaching, particularly in science subjects. In European countries, for example, role play has been used in behaviour change (Kaloyirou & Lindsay, 2014), in teaching science topics such as analytical chemistry where learners have been reported to have acquired a good understanding of the workings of the analytical technique through role-playing as parts of a mass spectrometer (Perry, 2007; Rao & Stupans 2012). In this context, role-play aligns with concepts for motivating learning approaches, with possibilities for capturing student attention and through emphasis of the relevance of the tasks in debrief. There are also acknowledged benefits for learners of approaching ideas from multiple perspectives (Merrill, 2002). In sum, it can be inferred that role-playing has not been used much in the South African context in secondary schools when compared to other third world countries such as Brazil and European countries. In European countries, role-play is considered to be effective in achieving a broad range of learning outcomes, and is indeed able to address cognitive, affective and psychomotor domains of learning as described in Bloom's taxonomy (Rao & Stupans, 2012). In the South African context, not much effect of role-playing in secondary schools has been reported. The paper reports on *the aha!* moment (a point in time when the teachers had sudden insight into a 'working' teaching and learning strategy), to improve and sustain learner performance in the two subjects that are perceived to be difficult by learners and where performance is below the national average in a majority of schools in the North West province.

## Research Questions

The central research question is: *What spawned the aha! moment for the teachers during the teaching and learning process, in their bid to improve and sustain learner performance?* The focus of this question is limited to four teachers of the best-performing schools in the two subjects perceived difficult by learners. Two sub-questions which the study focuses on are: (i) What is the relevance of role playing as the identified strategy in practice? (ii) How does role play in practice relate to teachers' pedagogic practices?

## Conceptual Framework

Ausubel's (1963) constructs of Meaningful Reception Learning theory provided the conceptual framework for this study. There are other theoretical or conceptual frameworks which could have been used, where the learner is embedded in the teaching and learning process. However, this framework was adopted because it points to the overarching principle that learning from instruction requires learners to play an active role in order to acquire new knowledge successfully (Shuell, 1988). The knowledge gained through meaningful learning applies to a new learning situation. Meaningful learning is active, constructive and long-lasting, but most importantly it allows student to be fully engaged in the learning process. Thus, it stays with learners for life. Reception learning



**Table 4.** Ausubel's Model of Meaningful Learning

Phase One	Phase Two	Phase Three
<i>Advance Organiser</i>	<i>Presentation of Learning task or Material</i>	<i>Strengthening Cognitive Organisation</i>
Clarify aim of the lesson	Make the organization of the new material explicit	Relate new information to advance organiser
Present the lesson	Make logical order of learning material explicit	Promote active reception learning
Relate organiser to students' prior knowledge	Present material in terms of basic similarities and differences by using examples and engage students in meaningful learning activities	

Source: Adapted from Ausubel (1968)

essentially means that learners receive information, think about it, make deductions and then apply such information to resolve a contentious problem. Within a classroom setting, this cognitivist theory brings about a holistic and collaborative learning and teaching approach. According to Haas and Parkay (1993), information is said to be meaningful if "it can be related in some way to the learners' present, past or future experiences" (p. 144). Ausubel contended that learning occurs because of the relatedness of what learners know and what they learn. In other words, learning proceeds in a deductive manner. For this study, Ausubel's learning model was coupled with role-play as a learner-centred pedagogy. Ausubel's theory consists of three phases and the main elements of Ausubel's teaching method are shown in **Table 4**.

Ausubel (1968) advocated the use of advance organisers to help link new learning material with existing related ideas and constructs. An advance organiser is information presented by an instructor (in this case a teacher) that helps the learner organise new incoming information (Mayer, 2003). This is achieved by directing attention to what is important in the coming material, highlighting relationships and providing a reminder about relevant prior knowledge (Woolfolk, Winne, Perry, & Shapka, 2010). Advance organisers make it easier to learn new material of a complex and difficult nature, provided the learner processes and understands the information presented in the organiser (Kumagai, 2013; Woolfolk et al., 2010), as this increases the effectiveness of the organiser itself. Furthermore, the organiser must indicate the relations among the basic concepts and terms that shall be used. Ausubel distinguished between two kinds of advance organisers, *comparative* and *expository*. Comparative organisers act as reminders to bring into the working memory of what one may not realise as relevant. In contrast, "expository organisers provide new knowledge that students would need to understand the upcoming information" (Woolfolk et al., 2010, p. 289). Essentially, expository organisers furnish an anchor in terms that are already familiar to the learner. As mentioned earlier, coupled with role-play, as the practice of having learners take on specific roles – usually roles they are not familiar with – and act them out in a case-based scenario for the purposes of learning course content and understanding "complex or ambiguous concepts" (Sogunro, 2004, p. 367).

## METHODOLOGY

The study was purely qualitative, thus employed exploratory case-study approach. According to Saunder, Louise and Thornhill (2012) exploratory research is conducted in order to determine the nature of the problem but merely explores the research topic with varying levels of depth. Exploratory research also "tends to tackle new problems on which little or no previous research has been done" (Singh, 2007, p. 64). For these reasons, an exploratory case study was adopted, which according to Basit (2010), supports the production of detailed accounts and deeper consideration of actions, experiences and perceptions.

### Sample

*Participants.* The sample consisted of four Further Education and Training (FET) teachers of two best-performing public high schools and one of their Grade 12 classes. Since 2013, both schools have had a 100% pass rate in Life Sciences. This is high compared to 70.4% national pass rate for Life Sciences. For Physical Sciences both schools have had a minimum of a 98% pass rate. This is high compared to the national pass rate of 58.6 % for Physical Sciences. Regarding the quality of learner performance, at both schools and in Life Sciences, the average score is 78%; for Physical Sciences, the average score is 75%. Comparing the Physical Sciences average score of these two schools and the ones on **Table 3**, it can be inferred that these two schools are performing well. Each school had one Grade 12 class specialising in Physical Sciences and one class specialising in Life Sciences. The other classes specialised in other subjects such as History, Geography and Accounting. **Table 5** summarises the distinct features of the two schools in this study.

**Table 5.** Summary of the distinct features of School A and School B

Features	School A	School B
Distance from researchers' area (Mmabatho)	60km in the outskirts of the capital city of the province in a small town.	Within the capital city of the province in a suburban area.
<b>Physical Sciences</b>		
Teacher's population group	White	Black
Teacher's pseudonym	Natalie	Modise
Teacher's gender	Female	Male
Age	33	44
Number of learners in class	26	33
Learners' gender	12 males and 14 females	18 males and 15 females
Learners' population group	8 Black, 12 White and 6 Indians	33 Black
<b>Life Sciences</b>		
Teacher's population group	White	Black
Teacher's pseudonym	Lizanne	Kelebogile
Teacher's gender	Female	Female
Age	47	43
Number of learners in class	32	36
Learners' gender	19 males 13 females	14 males and 22 females
Learners' population group	10 Black, 15 White and 7 Indians	36 Black

The two schools sampled had moderate class sizes. The Life Sciences classes had 32 and 33 learners whilst the Physical Sciences had 25 and 26 learners. In South Africa, the majority of classes are overcrowded with up to 55 learners in a class which is beyond the national Department of Education's teacher to learner ratio. Thus, the two schools in the study are described as having moderate class sizes. All the four teachers had a Bachelor's teaching degree in either Physical Sciences or Life Sciences. Natalie was studying towards an Honours degree in Physical Sciences and Kelebogile had completed her Honours degree in Life Sciences and was now studying towards her Master's degree. The sample was purposively selected from one district of the North-West province of South Africa which was deemed to be performing well and contributing significantly to the overall performance of the province in matriculation examinations. Purposive sampling is a non-probability method whereby only those two schools consistently producing a pass rate of over 90% were selected.

The Grade 12 learners are between 16 and 18 years of age. The average age for the learners who took part in this study is 17 years. The teachers were purposively sampled and each teacher had one Grade 12 class. This group of learners became automatically purposefully sampled. Fortunately enough, all parents and the learners gave consent to take part in the study as these was a provincial Department of Basic Education's (DBE's) intervention programme. This was a study requested by the Department of Basic Education, after it had issued ethical clearance. One of the Grade 12 Physical sciences class has 25 learners (12 males and 13 females). Of the 25 learners, 12 were Black (4 male and 5 females), 8 were White (4 males and 6 females) and 5 were Indians (4 female and 2 males). The other Physical Science class had 26 learners. All the 26 learners were Black (10 males and 16 females). For Life Sciences, one of the Grade 12 classes had 32 learners (14 males and 18 females). Of the 32 learners 10 were Black (3 males and 7 females), 14 were White (6 males and 8 females) and 8 were Indians (5 males and 3 females). The other Life Science class had 32 learners. All the 32 learners were Black (12 males and 20 females).

## Research Methods

In order to capture the lived experiences, perspectives and knowledge generated by the four teachers – Natalie, Lizanne, Kelebogile and Modise – classroom observations and semi-structured interviews as 'extended conversations' (Holland & Ramazanoglu, 1995) were organised on a regular basis (one interview per three weeks) over a school term period (three months) resulting in sixteen interviews (four with each teacher) in all. The learners for each class were interviewed twice, immediately after the first and last classroom observation sessions. Learners' interviews took the form of focus-group interviews with five learners in each group. Both teachers were asked to randomly select any five learners from the participating class. Teachers purposively selected the learners, targeting those who could express themselves confidently. The focus was on how learners viewed the role-playing teaching strategy and its relevance in their learning process. Natalie, Lizanne, Kelebogile and Modise aimed to sustainably improve learner performance (in tests and the examination), protect time for teaching and learning, improve support for teaching and learning and increase effort on time-on-task as these were areas of difficulty which most significantly impacted on learners' success. These are also DBE's 2015 National Strategy for Learner Attainment (NSLA) framework objectives. Learners' work samples, photographs and comments provided sources of additional

**Table 6.** Three stages of coding

Stages of Coding	Type of coding	Process involved
First stage	Open coding	Initial themes and codes were assigned to the data in order to condense the mass of data into categories. Codes were identified based on questions from the diary entries, observation schedule and interview schedule, which were designed with the research question in mind
Second stage	Axial coding	The codes were organised, linked and key analytical categories discovered
Third stage	Selective coding	Previous codes were examined to identify and select data that would support the conceptual coding categories previously developed

Source: Adapted from Neuman (2011)

**Table 7.** Table displaying techniques this study used to establish trustworthiness

Aspects of trustworthiness	Criteria	Techniques used to achieve trustworthiness
Credibility	Confidence in the 'truth' of the findings	Triangulation through multiple data sources
Transferability	Showing that the findings have applicability in other contexts	Thick description of empirical evidence based on details of the schools
Dependability	Showing that the findings are consistent and could be repeated	Maintaining an audit trail and the use of quotes to discuss findings
Confirmability	Extent to which the findings are shaped by the respondents and not researcher bias, motivation or interest	Maintaining an audit trail and the use of quotes to discuss findings

Source: Adapted from Lincoln and Guba (1985)

and complementary data. Thus, data was generated through interviews, classroom observations and document analysis.

## Data Analysis

Open coding, axial coding and selective coding were used to thematically analyse the data (Neuman, 2011), as shown in [Table 6](#). This analysis was guided by an analytical tool which was derived from the conceptual framework. For example ([Table 4](#)), in the phase three construct, 'promote active reception learning', the analytical tool had points such as: focus on discovery and exploitation, student-centred, high collaboration amongst others. For phase one, the construct 'clarify aim of the lesson' on the analytical framework focused on an analogue as an introduction, stating of lesson objectives or emphasising on the purpose for the lesson amongst others. This helped organise data into conceptual categories and themes whilst also assisting in the development of several core generalisations. This was then used to identify patterns across data and develop tentative explanations. Pattern-matching assisted in making comparisons (Schwandt, 2001) and looking for outliers (Yin, 2003), thereby assisting in a better understanding and analysis of data. The results of the study demonstrate the effort these four teachers put in to establish a 'working' strategy of teaching that resulted in improvement and sustained learner performance in Life and Physical Sciences.

The three stages of coding are shown in [Table 6](#).

## Trustworthiness

Lincoln and Guba's (1985) concept of trustworthiness was used to strengthen the quality of findings and enhance trustworthiness of the study. The four aspects of trustworthiness are described in [Table 7](#). The following was done to show the validity of the data obtained. To ensure credibility, triangulation through multiple data sources such as, classroom observation, interviews and analysis of learning materials were used. Thick description of empirical evidence, based on details of the schools, was used to ensure transferability. Maintaining an audit trail and the use of quotes of participants' responses in verbatim to discuss findings ensured dependability. We maintained an audit trail by utilising the peer debriefing and support strategy to ensure that the quotes used to discuss findings were accurate.

As shown on [Table 8](#), in the first phase, advance organisers, three themes with two codes for each theme were generated, giving a total of six codes. For the first phase, the three quotes were selected from both teachers and learners on the condition that at least all the six codes were represented in the quotes. The second phase, relating to presentation of learning task or material, also had three themes. Like the first phase, two codes were generated for each theme. However, for the learners, only two quotes were selected. The rationale for the selection was grounded on the fact that the two quotes were inclusive of all six codes. The third phase relating to strengthening cognitive organisation had two themes and each theme had two codes. Five quotes were selected, one from a learner and one from each of the four teachers. In a way, the quotes were selected on the basis of how each teacher explained

**Table 8.** Examples of themes and codes

Phase	Themes	Codes
Phase 1 <i>Advance organiser</i>	clarifying the aims of the lesson	i. Trial and error; I like trying new teaching methods (teacher interview) ii. Teacher giving direction to the lesson (observation)
	presenting the lesson, and	i. Teacher states aim and asked learners to group themselves (observation) ii. learners prepare and present the coming lessons using role-playing (teacher interview)
	relating the organiser to learners' prior knowledge	i. role-playing in a way they understood the new incoming information (observation) ii. prior knowledge was used as a basis of what the learners were doing (observation)
	<i>Category: common human experience of suddenly understanding a previously incomprehensible problem</i>	
Phase 2 <i>presentation of learning task or material</i>	making the organisation of the new material explicit	i- teacher prepares ahead for us and we play a game based on the topic she has to teach (learner interview). ii- we act role assigned, e.g. in electricity if you are a conductor, you will have to behave like a messenger (learner interview).
	making logical order of learning material explicit,	i- play (act the path of current flow when it is connected in parallel or in series) opened my mind rather than reading the books or listening in class all the time (learner interview) ii- learners apply all their skills in a realistic, nonetheless safe setting (learners' work samples)
	presenting material in terms of basic similarities and differences by using examples, and engaging students in meaningful learning activities.	i- learners used simulations first to demonstrate similarities and differences between parallel and series circuits before a group presenting this topic offered it through role-playing (observation) ii- learners had consulted with their teacher during preparation time (teacher interview)
	<i>Category: relevance of imagined ideas by placing them in a real-world context</i>	
Phase 3 <i>Strengthening Cognitive Organisation</i>	Relate new information to advance organiser	i- teacher clarifying certain concepts after group presentations (observation). ii- ensuring group presentations were not introducing misconceptions and also addressing [providing the] missing conceptions (teacher interview).
	Promote active reception learning	i- learners' second language learning enhanced (observation) ii- ensuring new knowledge was linked to what the learners already knew and preparing for the learners for the new content (teacher interview)
<i>Category: role-playing is a basic engagement and should not be considered just as fun but as part of the serious learning process</i>		

the relevance of the identified strategy in practice. Furthermore, selection of the quotes was envisaged to reveal how the identified strategy in practice related to teachers' pedagogic practices in a bid to improve and sustain learner performance. Each set of codes for each theme formed a set of categories for each phase that summarises the ideas in the codes together.

## RESULTS AND DISCUSSION

In this section we introduce the cases for the two best-performing schools (and their four teachers) by presenting data based on themes around the three phases and main elements of Ausubel's teaching method. Phase one relates to the advance organisers; phase two relates to presentation of learning task or material; and phase three relates to strengthening cognitive organisation. The generated resonances were linked to DBE's (2015) NSLA framework objectives of sustained improvement in learner performance, role of teachers, improved support for teaching and learning, and increased efforts on time on task, making high learner attainment.

The three themes based on the first phase are: clarifying the aims of the lesson, presenting the lesson, and relating the organiser to learners' prior knowledge. With a minimum of at least ten years in their teaching profession, the four teachers had their common human experience of suddenly understanding a previously incomprehensible problem [*the aha! moment*] through trial and error. This was in a bid to improve learner performance and ensure that they sustain their effort. This study identified what they called a 'working' teaching strategy which is role-playing. During interviews, the teachers had this to say:

*I am a teacher full of energy. I like trying new teaching methods. My learners generally are not that bad but I used to do a lot for them. More-or-less like spoon feeding, you understand ... I just decided someday to try role-playing as a teaching method. I had done an assignment for my Honours*

*assignment on it and I really doubted if it would work at FET level. Mine was to give the aim after one of my normal lessons, I asked the learners to put themselves in groups of fours as they were going to prepare and present the coming lessons using role-playing. That is how I introduced it to my learners. My aha! moment was when I put the method to test and it worked when revising the topic electricity (Natalie, School A).*

Kelebogile's narration was almost similar to that of Natalie. She says she has a lot of work to do. This is her response:

*I attended a Professional Support Forum (PSF) meeting. Then I had an informal chat with a colleague from another school teaching a similar grade. Then she suggested to me this teaching method to me. I told her openly that it was possibly going to work with lower grades, for example, kindergarten. She told me to try it. When I got to school, I asked my learners to role-play the lesson on body organs and show how they maintain a constant body temperature (Kelebogile, School B).*

One of Kelebogile's learners had this to say during focus-group interviews: "Playing *Pancreas* helped me to actually understand how this organ contribute in regulating blood sugar level. My friend was "Liver" and I can never forget how I and her worked together to maintain the internal body environment".

As can be inferred from the learner's description of events in the role-play lesson, the presentation of the lessons is solely the responsibility of the learners. Interestingly, the advance organiser was just clarifying aims of the lesson by the teacher and giving direction to the lesson (Kumagai, 2013). The rest was left to the learners to use role-playing in a way they understood the new incoming information. In a way, all the learners were doing was related to their prior knowledge. This is related to the comparative organiser (Woolfolk et al., 2010).

*The second phase, presentation of learning task or material, had three themes. These are: (1) making the organisation of the new material explicit; (2) making logical order of learning material explicit; and (3) presenting material in terms of basic similarities and differences by using examples, and engaging students in meaningful learning activities. All four teachers planned for the lessons well, making sure that the new material to be taught was made explicit. This is what one learner from Modise's class said during a focus-group interview:*

*Our teacher prepares ahead for us to play a certain game based on the topic she has to teach. One time she came to class with soccer/ netball balls pasted with instructions to follow. She threw the ball randomly at anyone, when you catch the ball you have to act what is written and the whole class will follow and identify what part of the topic you are acting or simply who you are and your role, for example in electricity if you are a conductor, you will have to behave like a messenger. Taking current from the source of energy to the appliance stated. My friend was a radio (laughed), and it was such fun (Learner 1, Modise's class, School B).*

Logical order of learning material was made explicit. A second learner from Modise's class had this to say:

*We also had to act the path of current flow first when it is connected in series. The way the current flows was well explained during role play and discussion time. After the series circuit, role play moved to parallel circuit illustrating the way in which current flows. In both instances the effect of resistance when high or low was discussed. That was a play that opened my mind rather than reading the books or listening in class all the time (Learner 2, Modise's class, School B).*

Regarding presenting material in terms of basic similarities and differences by using examples, and engaging learners in meaningful learning activities, the role-playing teaching employed by teachers facilitated it well. As witnessed during classroom observations of Modise's lessons on electricity, the learners used simulations first to demonstrate similarities and differences between parallel and series circuits before a group presenting this topic offered it through role-playing. However, it was evident that the group learners had consulted with their teacher during preparation time. In a way the learning process was significantly dependent on the teachers as also shown by Kumagai (2013).

*Two themes were formulated from the third phase dealing with strengthening cognitive organisation. The two themes are; relating new information to an advance organiser and promoting active reception learning. The first theme can be illustrated by what was observed in Lizanne's classes. Lizzane could be seen following sessions where learners had role-played with keen interest. She was also seen clarifying certain concepts after group presentations. Asked why she was doing that during interviews, she had this to say:*

*I wanted to make sure that group presentations were not introducing misconceptions and also addressing [providing the] missing conceptions. So, I was trying to concretise what the learners were already familiar with. Given that group presentations were more or less like play but serious content*

*delivery, I wanted to ensure that in a way I was emphasising how relevant this information was for the learners to remember. In a nutshell, I was ensuring new knowledge was linked to what the learners already knew and preparing for the learners for the new content which was yet to be presented in future.*

This finding confirms de Medeiros-Silva et al. (2017) findings which showed that role-playing is a basic engagement and should not be considered just as fun but as part of the serious learning process.

Having sat in all four teachers' classrooms during teaching and learning sessions, a question asked to all four teachers towards the end of the study was "what is the use and relevance of role-play in practice?" Natalie responded:

*By simulating a scenario during acting [and] role-playing, it allows my learners to practise newly developed skills where that skill may be required which is close to the real experience of the learners. Learners' second language learning is enhanced, and it motivates them to research for specific topics.*

Lizanne's response to the question was:

*During role-playing, learners apply their knowledge to a given problem and at the same time illustrate relevance of imagined ideas by placing them in a real-world context through reflecting on issues and the views of others. There is however a point I would like to make clear, as part of the paramount practices, as a teacher, I think deeply about the learning goals of the role-play and choosing a case that best reaches those goals.*

Modise's response was skewed towards that of Lizanne. He said,

*The teacher just like the learners has to be adequately prepared with instance materials and familiar with the pedagogy. The learners apply all their skills in a realistic, nonetheless safe setting. However, I would [like] to point out that as you saw me doing, I allowed for sufficient and appropriate feedback and debriefing of the entire exercise. This is so important if use of this method has to be a success.*

Kelebogile responded to the question by saying,

*All I can say is that through use of this method, learner interest in the topic is raised, there is increased contribution on the part of the learners in role-playing lessons and learners use their background knowledge in addition to acquiring new information. I must however, point out that, a teacher needs to have about both the content and the pedagogy because the amount of time taken to properly prepare for the lessons and the amount of knowledge is quite a lot. If one takes time to prepare, indeed the benefits far outweigh the effort.*

This also affirms Khiri and Mohammadi's (2016) observations, which showed that role-playing is a method of problem-based learning which increases the ability of learners in decision-making, interpretation of situation and critical thinking.

An inference can be made from the teachers' responses to questions posed and recollecting some events which took place during the teaching and learning process, in answering a question such as, how does role-play in practice relate to your teachers' practices? What is clear is that the teachers do know the pros and cons of such a teaching strategy. For example, Kelebogile said,

*Role-playing for me is a make-up procedure, and improvisation which requires a feeling of relative safety for the learner. The teacher engaging learners in groups, should ensure that they get to know each other in a more trusting fashion and become involved in the theme [or topic] to be learned. The introduction is more important. I can use the analogy of a surgeon knowing how to prepare a patient for an operation. Otherwise, it will be play for the sake of play.*

## CONCLUSIONS

From the results presented and discussed, the eureka effect (aha! moment) was that moment when all four teachers who took part in this study identified role-playing as a teaching and learning strategy amongst other strategies chosen to bring about a desired future, such as achievement of a goal or solution to a problem. In this study, the desired future was to improve and sustain learner performance by the four teachers of the best-performing schools in both Life and Physical Sciences, two subjects perceived difficult by learners who perform on the average to low in a majority of schools in the North West province. Another finding was that teachers were well-informed regarding the use and relevance of role-play in practice. Learner interest in the topic was evidently raised as was observed in the case study. There was also increased contribution on the part of the learners in role-



playing lessons and learners' use of their background knowledge in addition to acquiring new information. Phases of the conceptual framework were evoked in describing the findings. Play in practice was related to teachers' pedagogic practices by emphasising the fact that planning is important, just like the introduction where the aims of the lesson are clarified. This study demonstrated that constructs of Ausubel's Meaningful Reception Learning theory were coupled with role-playing to describe the experiences of teachers in narrating their teaching practices.

## RECOMMENDATIONS

The study recommends that teachers who are keen to establish uncommon teaching practices, such as the ones in this study, should share them with their colleagues who are in schools which are not doing as well as them. Further research could be done when teachers, such as the ones described in this study, are paired with their colleagues from poor-performing schools for improved results in the latter. The study also recommends that curriculum designers attach certain teaching strategies to some topics in the policy documents for the teachers to implement. This may assist teachers who might not be aware that certain teaching strategies such as role-play may be the answer in topics that they struggle to impart successfully. Lastly, it is also recommended that education planners should focus on encouraging and updating teachers' classroom practices by all possible means. This might gradually create a ripple effect on improving learner performance in science subjects.

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APPENDIX A



**Education and Sport Development**  
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Departement van Onderwys en Sport Ontwikkeling  
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**OFFICE OF THE SUPERINTENDENT-GENERAL**

Enquiries : Mr L.H. Modisane  
Telephone: (018) 388 3432

To: Prof N Diko  
Research Professor  
North West University  
Faculty of Education and Training

From: Dr I.S. Molale  
Superintendent General

Date: 30 September 2015

**SUBJECT: REQUEST TO CONDUCT PROJECT: PROF N DIKO**

Kindly note that permission is hereto granted for you to go ahead with the project.

Wishing you well in your endeavour to realise a successful project.


Kind regards

  
DR I.S. MOLALE  
SUPERINTENDENT GENERAL





APPENDIX B



**Education and Sport Development**  
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**NGAKA MODIRI MOLEMA DISTRICT**

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Enquiries    S.O. Molete  
 Telephone    018 - 388 - 3383

To            :    All Area Managers  
                       Ngaka Modiri Molema District

**Attention    :    School Managers of Secondary Schools**

From         :    Mr B.E. Monale  
                       District Director

Date         :    01 October 2015

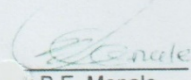
**Subject       :    Permission to conduct a research in Secondary Schools**

Permission is hereby granted to at team of Professors from North West University, under the leadership of Professor Nolutho Diko, to conduct a research on **“Grade 10 – 12 teaching and learning improvement in Ngaka Modiri Molema District”**, during vacation camps.


Schools are requested to cooperate with them during this project and provide them with necessary support.

Your cooperation and support in this regard is highly appreciated

Yours in education



Mr B.E. Monale  
 District Director



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**“Towards Excellence in Education”**





# Understanding Science Teachers' Classroom Practice after Completing a Professional-development Programme: A Case Study

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Received 31 January 2018 • Revised 23 March 2018 • Accepted 1 May 2018

## ABSTRACT

This article reports a study aiming to understand the classroom practice of four grade 7 science teachers following an in-service teacher-development programme. Such studies are needed to contribute to knowledge about the effectiveness of professional development programmes. Clarke and Hollingsworth's model of professional growth was used as a theoretical framework. Data were collected by means of interviews, lesson observations and document analysis. It was found that each teacher experienced professional growth in a personalised way, such as increased confidence, improved content knowledge, teaching strategies, practical skills, and valuing professional collaboration. All the teachers reported that their classroom practices have improved. Lesson observations revealed that three of the four teachers were enthusiastic and engaged their learners in practical work. Challenges such as lack of resources, poor language skills, and lack of higher cognitive levels in activities and questions were observed for all the teachers. An adapted model of professional growth has been proposed to represent the professional development of science teachers in poorly resourced schools.

**Keywords:** teacher professional development, science teaching, classroom practice

## INTRODUCTION

The ultimate goal of teacher-development programmes is the enhancement of learner outcomes through improved teaching practices (Desimone, 2009; Supovitz & Turner, 2000). This is in agreement with the views of Darling-Hammond, Hyler, and Gardener (2017, p. 12) when they defined effective professional development as "structured professional learning that results in changes to teacher knowledge and practices, and improvements in student learning outcomes". The emphasis on improving classroom practice is based on the strong relationship found between classroom practices of teachers and learner outcomes (Wenglinsky, 2002).

In South Africa (SA), professional development of science teachers is a priority, in view of poor learner performance in international assessments, poor Grade 12 results, the effects of curriculum changes since 1994, and the heritage of inadequate teacher training in the apartheid era. From 2003, a professional-development programme, the Advanced Certificate in Education (ACE), was introduced by Higher Education Institutions in SA. The purpose of the ACE programme was to upgrade and re-skill teachers (Department of Education [DoE], 2000). There was a rapid increase of ACE programmes on offer, though not in the subjects where it was needed most. The extent of this increase led to a review of the ACE programmes (DoE, 2007; Kruss, 2009). Consequently, it was replaced by a programme named the Advanced Certificate in Teaching (ACT) (Department of Higher Education and Training, 2011).

Despite the discontinuation of the ACE, there is a need to understand how it affected the practices of individual science teachers, as such studies are scarce (Avidov-Ungar, 2016). The current article contributes to the research literature by reporting a case study exploring four science teachers' views about how the ACE programme

#### Contribution of this paper to the literature

- The paper illuminates professional development from the perspective of science teachers in poorly resourced schools.
- Teachers experienced professional growth in personalised ways, such as increased confidence, improved content knowledge, teaching strategies, practical skills, and valuing professional collaboration.
- The paper presents a new model for professional development of science teachers, particularly in developing countries.

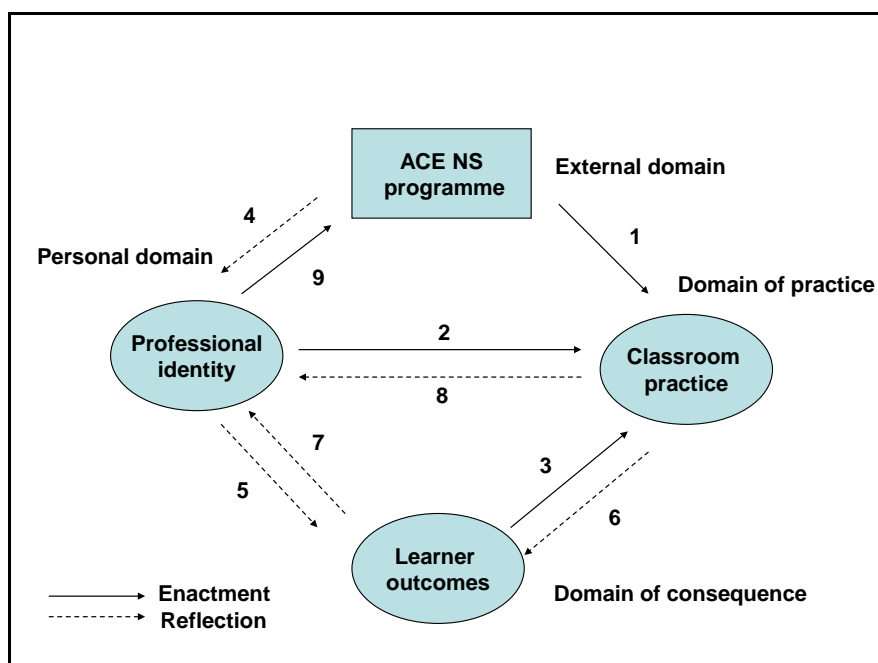
influenced their classroom practices. The aim of the study was to gain in-depth understanding of teachers' classroom practice after they completed the ACE programme. The following research question guided the study: How can the classroom practice of science teachers be understood after they completed an ACE Natural Science (NS) programme? Such understanding is vital to learn from the successes and challenges of the ACE programme when designing future professional development for science teachers.

### IN-SERVICE TEACHER PROFESSIONAL DEVELOPMENT

Teacher-development programmes are offered in different delivery modes such as certificate programmes, workshops, seminars, action research, coaching and mentoring (Loucks-Horsely, Stiles, Mundry, Love, & Hewson, 2010). Some of these modes of teacher development, like once-off workshops, are regarded as ineffective as they do not enhance learner performance (Borko, 2004; Darling-Hammond et al., 2017; Ono & Ferreira, 2010). However, it is acknowledged that workshops can serve a different purpose for example for the orientation of teachers on new policies. Desimone (2009), Guskey (2003), Garet, Porter, Desimone, Birman, and Yoon (2001), and Sandholtz and Scribner (2006) proposed some core features that should be taken into consideration when designing effective professional-development programmes: Firstly, programmes should be based on the analysis of learner performance and focus on what learners are struggling to learn in order to improve learner outcomes. Also, programmes should be school-based, ongoing, coherent and collaborative, and focused on teachers' needs for improving their practice. In the same vein, Darling-Hammond et al. (2017) proposed that effective programmes are content-focused, incorporate active learning, support collaboration, use models and modelling, provide coaching and expert support, offer feedback and reflection opportunities, and are of sustained duration. In the US, a large state-wide professional-development programme for mathematics teachers and administrators showed significant improvement of participants' knowledge and self-efficacy (Carney, Brendefur, Thiede, Hughes, & Sutton, 2016). These authors concluded that long-term, large-scale professional development may be more fruitful than intensive projects focused on smaller groups.

In South Africa, Aluko (2009) explored the impact of ACE in Educational Management on the professional practice of teachers. In this study the change in the teachers' professional practice was evaluated from the way teachers understood, interpreted and implemented educational policies after completing the programme. It was found that there was an improvement in the teachers' professional practice after completing the programme. Burton (2011) investigated teachers' perceptions about the use of a teaching strategy learnt in the ACE programme in the Eastern Cape. The strategy entailed using interactive notes on the website of the university. It was found that not all the teachers implemented the strategy as required, particularly the many teachers who resided far from the university who did not have access to the Internet.

Classroom practice is linked to professional identity (Beijaard, Meijer, & Verloop, 2004). Learners' responses on improved practice provide feedback that further improves teachers' identity. According to Desimone (2009), teachers' beliefs and attitudes need to be changed first before their classroom practice is changed, while Guskey (2002) proposed that improved learner outcomes precede changes in teachers' beliefs and attitudes. According to Avidov-Ungar (2016, p. 654): "Professional development is a process in which the professional identity of the teacher is formed, and implicit knowledge becomes explicit". Once implicit knowledge becomes explicit, it will permeate in the classroom. Subject knowledge is an important contributor to effective classroom practice (Garet et al., 2001; Harvey, 1999; Kruss, 2009; Mji & Makgato, 2006). It is widely accepted that learners understand science concepts better when they conduct practical work and observe real events (Millar & Abrahams, 2009). Mji and Makgato (2006) found that conducting experiments enhanced learner performance in science. Therefore, practical skill should be an important element in science teacher-development programmes. Burton (2011) found that the avoidance of practical work is caused by a lack of apparatus, while Muwanga-Zake (2000) found that it is related to a lack of teacher knowledge. The findings from these two studies indicate that, although lacking resources may sometimes be used as an excuse, the reasons for not conducting experiments may be multifaceted, including inadequate training of science teachers.



**Figure 1.** Theoretical framework based on Clarke and Hollingsworth's model of professional growth (2002, p. 951)

In South Africa, language skill is another important aspect of science classroom practice as classes are mostly taught in English, while English is not the first language of the majority of learners and teachers. Harvey (1999) recommended that language-skills development should be incorporated in the everyday classroom practice of science teachers. He further advised that teachers could develop scientific activities that would enhance learners' listening, speaking, writing and reading skills. However, Villanueva (2010) found in her study on integrated teaching strategies that science teachers were reluctant to address language skills in science.

Pedagogical skill is an important aspect of science classroom practice (Harvey, 1999). This includes the use of constructivist principles for teaching, use of discrepant events to explain science concepts, managing resources and learning activities in the classroom. General pedagogical skills support the understanding of deeper meanings of learner behaviour in the classroom by teachers (Stenberg, 2011) and their reaction in appropriate ways.

## THEORETICAL FRAMEWORK

Clarke and Hollingsworth's (2002) model of professional growth was used as a theory to frame the study. This model depicts the influence of a professional-development programme on classroom practice, professional identity and learner outcomes as a web of possible pathways of enactment and reflection. These alternative pathways make the model more versatile than the linear one-way model of Guskey (2003) and Desimone's (2009) linear two-way model.

**Figure 1** shows the framework, comprising of four interconnected domains, namely the external domain, domain of practice, personal domain and domain of consequence. In our study, these domains are represented by the ACE NS programme, classroom practice, professional identity and learner outcomes respectively.

The model makes it possible to describe how growth in any of the three internal domains influence each of the other domains through the processes of direct enactment or reflection. Specifically, teachers' classroom practice may be enhanced in three ways: direct implementation of something learnt in the ACE programme (arrow 1); planning and trying something new based on enhanced professional identity (arrow 2); and improved learner outcomes (arrow 3). Similarly, the teacher's professional identity may be enhanced by three influences: reflection on the ACE programme (arrow 4); learner outcomes (arrow 7); and classroom practice (arrow 8). Learner outcomes may be influenced by the teachers' professional identity (arrow 5); as well as classroom practice (arrow 6). Finally, enhanced professional identity may ultimately find expression in contributions to the external domain (arrow 9).

## METHODOLOGY

Searching for in-depth understanding of teachers' classroom practices requires an interpretative paradigm to enable the researcher to understand the situations and actions of teachers as viewed and experienced by the

**Table 1.** Overview of the themes and categories used for the analysis of interviews

Themes	Categories
Teacher's subject knowledge	Teacher's subject knowledge
Laboratory work	Practical skills
	Resource needs
	Improvisation
Pedagogical knowledge	Pedagogical skills
	Understanding learners
Learner outcomes	Learner outcomes
Professional identity	Teacher's belief
	Teacher confidence
	Teacher's attitudes
	Collaboration

participants. Therefore, a qualitative approach was chosen, employing a case-study design in the teachers' natural environment (Creswell, 2007).

The sample for the study was purposively selected, as is generally used for qualitative studies in order to ensure that participants meet predetermined criteria (Creswell, 2007). First and foremost, as the first author held office in a particular provincial Department of Education, a different province was selected for the study to ensure that issues of power relationships are avoided. To reduce travelling time and cost, a province relatively close to the first author's home was chosen. Teachers who have completed the ACE NS programme in a well-established, specific institution of higher learning were particularly targeted. The database of the teachers who completed this ACE NS programme and the profile of the schools were sourced from the Department of Education in the province. The list showed names of 28 teachers, all from schools in semi urban areas surrounding a large city. The first author approached the principals of the all relevant schools and found five teachers who were available and willing to participate. One of the teachers later decided not to continue. The principals and teachers were unknown to the researcher, ensuring that issues of power were not involved.

The participants completed the ACE programme two years prior to the study. The ACE programme was taught part-time over a period of two years. The programme included Natural Science content as well as pedagogy, offered as the following ten courses: Life and Living; Matter and Materials; Planet Earth and Beyond; Energy and Change; Curriculum in Context; Curriculum Development; Approaches to Learning and Teaching; Classroom Assessment; Learning and Teaching Science; Learning and Teaching Resources in Science. Detailed information about the ACE programme can be found from the Service Provider (Radmaste, 2013) as well as from the first author's PhD thesis (Kekana, 2015).

As indicated by Silverman (2014), for qualitative research, the researcher should have direct access to what is happening. In this study direct access to the classroom was realised by visiting teachers in their schools. Data were collected using interviews, observations and document analysis. Firstly, a semi-structured interview was conducted with each teacher; the interview protocol is available in [Appendix 1](#). The interviews were audio-recorded to ensure that no information was lost (Silverman, 2014). Secondly, for each teacher, six consecutive lessons were observed during a two-week period in the third term. The duration of lessons were about 40 minutes, amounting to a total of 16 hours of lesson observation for the four teachers. The teachers were asked to continue their normal routine during the observed lessons, following the curriculum as prescribed by policy, to ensure a natural classroom situation, rather than special lessons. A lesson-observation schedule was developed specifically for the study, based on important aspects of classroom practice described in the literature. The lesson-observation schedule is available in [Appendix 2](#). In particular, practical, pedagogical and language skills, subject knowledge, beliefs and attitudes were noted as the lessons progressed. Finally, the teachers' documents as well as learners' workbooks were analysed. Each teacher was asked to select three workbooks after completing the lesson observations; there was no particular instruction for how the books should be selected.

Qualitative content analysis was conducted, analysing each case separately. For the interview, categories were based on the literature and theoretical framework, and some emerged from the data. The transcriptions were initially coded by the first author, repeated by the second author and discussed to reach consensus where interpretations differed, thereby enhancing trustworthiness. Finally, the categories were grouped under the following themes: subject knowledge, laboratory work, pedagogical knowledge, learner outcomes, and professional identity, as shown in [Table 1](#). Lessons were analysed in terms of the observation schedule. Teachers' records and learners' workbooks were inspected to confirm evidence from other data sources, as suggested by Maree (2007). The schedule for document analysis is given in [Appendix 3](#).

The design of the study enhanced trustworthiness, using three data-collection methods to allow triangulation. To enhance credibility of data collected through lesson observations, six consecutive lessons were observed for each

**Table 2.** A part of Mr Wakithi's transcription including coding of his responses

<b>Excerpts from interview transcript</b>	<b>Category</b>
Researcher: Do you think that your classroom practice has changed?	Teacher's beliefs
Mr Wakithi: Ma,am, it has changed because now kids are more eager to learn science each and every day. Everyday learners do not want me to go out from their classroom sessions.	Learner outcomes
Researcher: What do you think is the best way for learners to learn science?	Teacher's confidence
Mr Wakithi: To make them aware that eh, without living organisms which are around us we cannot go anywhere. The environment, the ecosystem, go in pollution. I try to convince them that they must love nature like brothers and sisters.	Teachers' beliefs
	Pedagogical skills

teacher. Ethical research practices were followed to ensure that participants were not harmed physically and emotionally. Ethical clearance was obtained from the University and the Department of Education gave permission for data to be collected in schools.

## RESULTS

The participants are referred to by pseudonyms, Mr Wakithi, Mr Mashangura, Mr Zulu and Ms Ntombela. Each held a Senior Primary Teachers Diploma, while Mr Mashangura also held a two-year Further Diploma in Education. Ms Ntombela was the only teacher who had a science laboratory in her school while the other teachers had a few pieces of apparatus in their classrooms. Though all four teachers in this study believed that their classroom practice had changed for the better after completing the ACE programme, there were clear differences in how they perceived these changes.

The results are presented per participant, integrating the data from the different instruments, in order to gain in depth understanding of each participant's perspectives and practices. Each case is discussed in terms of the five themes identified from the literature.

### Mr Wakithi

Mr Wakithi presented four lessons on acids and bases, another lesson was used for assessment and the last was on introducing a new topic, 'energy'. Analysis of his interview showed that some responses often provided more information than asked for, and in such cases more than one code was assigned, as shown in [Table 2](#).

#### *Subject knowledge*

The lesson observations revealed that Mr Wakithi had sufficient knowledge to teach science in Grade 7. He explained that he learnt more during the ACE programme, referring to "... about the puberty age all in details", and "... more about the stars, some are gases some are liquids, there is one that is missing ...". Activities in learners' workbooks confirmed that he had adequate content knowledge, showing how learners' wrong answers were corrected. However, he mentioned that he needed more content knowledge about the 'Earth and Beyond' as well as about 'Matter and Materials' Natural Sciences knowledge strands.

#### *Laboratory work*

Mr Wakithi indicated that during the ACE programme they had opportunities to use apparatus they never used before, and that they had to perform experiments in front of colleagues. However, he believed that he still lacked practical competence in conducting experiments, saying: "I still need to improve and gain more practical skills. Hence I say I am not that good but I am trying." In spite of this, he successfully presented a demonstration and facilitated three practical sessions during the observation period, which indicated that he actually had adequate practical skills. In one of the practical sessions, he used some chemicals from the school's limited stock. He explained during the interview that he did not have sufficient apparatus and therefore he sometimes improvised. Improvisation was indeed observed when learners brought household substances which they tested for acidity.

#### *Pedagogical knowledge*

Mr Wakithi indicated that the ACE programme expected of teachers to make their "classrooms to be more friendly", and that they were "equipped with new strategies" and that learners need to "love science more". Teaching to care for the environment is demonstrated in his remark shown in [Table 1](#). He also mentioned that he learnt "the thing about hypothesising". He said learners who struggled to understand were assisted by using the strategy of group work; and that he used the "fast learners to assist those that are slow". Group work was indeed observed during the three practical lessons, but not in other lessons. Regarding language, he mentioned that some



**Table 3.** A part of Mr Mashangura's transcription including coding of his responses

<b>Excerpts from interview transcript</b>	<b>Category</b>
Researcher: Can you mention one science concept you think you learnt in ACE?	Laboratory skills
Mr Mashangura: Yes, oh, science concepts? Uhm, by doing experiments and by changing style of teaching, by doing experiments, investigations and also motivating learners to participate.	Pedagogical skills
Researcher: Can you give an example of subject knowledge in the syllabus that you struggle to teach?	Resources
Mr Mashangura: Eh! All I can say is acids and bases due to what? Lack of lab at the school.	

learners do not understand colours in their vernacular, "then you have to show them, they must see these colours ...". It was also observed that Mr Wakithi code-switched to explain to learners who struggled with English. He indicated during the interview that learners made use of a dictionary, and when necessary, he collaborated with other teachers who knew different languages.

### *Learner outcomes*

Mr Wakithi claimed that his learners enjoyed science since he completed the ACE programme, as illustrated by his remark in [Table 1](#). Later in the interview he elaborated, indicating that learner outcomes improved, saying "They now love this NS more than any learning area, because the results have improved dramatically since I completed ACE". Yet he later remarked that some learners were not co-operating: "... they write their homework in class, some they wait for you to give feedback and fill in work they were supposed to do at home."

### *Professional identity*

Mr Wakithi was confident when responding to questions and displayed a positive attitude towards the ACE programme. He indicated more than once that he learnt about "togetherness" of teachers: "The practice I learnt from ACE was this collaboration amongst ourselves." Not only did he mention that he sometimes asked for assistance from others, for example with practical work and language issues, but indicated that he was willing to contribute to the district cluster and that he aspired to be an examiner in the cluster. He added: "I can even see someone utilising my skills which I learnt from ACE." He displayed a positive attitude to teaching science, saying that he enjoys teaching more after completing the ACE. He referred to an incident in class where "I went an extra mile, I was going and going until I was stopped by another teacher" which revealed his enthusiasm and positive attitude. He explained that "the love of nature" is the best way for learners to learn science, revealing a wish to propagate a positive attitude to science. Overall, Mr Wakithi revealed that his professional identity was enhanced in terms of subject knowledge, practical competence, valuing collaboration and a positive attitude towards teaching science. By the end of the interview he indicated that teachers should be inquisitive and keep learning and sharing: "I have learnt as a teacher, not of science but a teacher in general. ... You must go and ask for more, you must share with other teachers. As I told you about the planets issue, some of us still think that there are nine planets while one is gone. You have to go deeper and seek more information. You must network as a science teacher."

### **Mr Mashangura**

Mr Mashangura presented four lessons on the separation of mixtures, one on forces and one on electricity, following the sequence prescribed by the curriculum. In his interview, his answers provided rich information, though not always focused on the questions, as illustrated in a section from the analysis shown in [Table 3](#).

### *Subject knowledge*

Mr Mashangura indicated during the interview that his subject knowledge has "definitely" improved during the ACE programme, though he did not mention specific topics or concepts. During the lesson observations, it was found that he presented and explained scientific content correctly. From the learners' workbooks, it was found that correct feedback was given to learners.

### *Laboratory work*

Mr Mashangura presented a series of well-planned practical sessions, supporting his claim that he learnt doing experiments and investigations during the ACE programme. He facilitated the sessions with confidence, engaging learners in hands-on activities. Learners worked in groups, making mixtures from substances they brought from home and later they separated these. Following up on the topic, learners collected trash from the school grounds and sorted it in another session. There was also a chromatography activity, where learners separated colours in ink. He improvised to demonstrate the separation of water and paraffin, using an empty bottle, upside down, instead



**Table 4.** A part of Mr Zulu's transcription including coding of his responses

Excerpt from interview transcript	Categories
Researcher: What do you think the University wanted you to learn from the ACE course?	Practical skills
Mr Zulu: You know ... they trained us more practical things, that we must apply because science is more practical, but it is difficult for us because of these challenges I have mentioned. We have overcrowding, lack of resources like laboratories, apparatus and all those things.	Resources
Researcher: How do you think your classroom practice was expected to change after completing the ACE program?	Teacher's beliefs
Mr Zulu: Ja, it does change on my side because I have learnt a lot about the practical part of science. I was not a fan before I attended the ACE. ...	Practical skills Teacher's attitude

of a separating funnel. In fact, he used improvised materials in all practical sessions except for a lesson on forces where he used magnets from the school's limited resources. In this lesson, he encouraged learners to handle the magnets to actually feel the forces of repulsion and attraction, in support of his stated belief that "touching and feeling" during practical work enable learning to take place.

### *Pedagogical knowledge*

Mr Mashangura indicated that during the programme he learnt to plan lessons, assess learners, motivate learners and change the style of teaching by doing experiments. Document analysis showed lesson plans in his files, confirming that he regularly planned lessons, using a template provided by the ACE programme. To help learners understand, he mentioned that he used teaching aids like diagrams and pictures as well as practical work. He claimed that his classroom practice had improved after completing the ACE programme, for example by referring to Vygotsky and social constructivism. In fact, the use of constructivism was evident in two consecutive practical sessions where learners first used familiar household substances to make mixtures, and had to separate these mixtures in the next lesson. Mr Mashangura displayed enthusiasm and patience during teaching. He clarified scientific concepts whenever the learners did not understand. For example, when he found that the learners gave incorrect answers during the lesson on attractive and repulsive forces, he repeated the explanations. He encouraged the learners to answer questions, to conduct hands-on activities, and to present their findings in front of other learners in the classroom. It was clear that he wanted his learners to participate, understand and enjoy science.

### *Learner outcomes*

Mr Mashangura believed that his learners' behaviour changed after he had completed the ACE programme, indicating that they want to understand science:

*"They want to concentrate ... in order to challenge the question asked in class and since they know in science we talk about true things, real things. You cannot say a child come from the ambulance, cannot say a child come from a river or aeroplane or ambulance. They have to understand that in reproduction the egg cell will meet the sperm cell."*

During observations, learners were co-operative and participated enthusiastically in the activities. The document analysis attested to this because the learners completed sufficient activities, as observed in their workbooks.

### *Professional identity*

Mr Mashangura displayed confidence and enthusiasm in the interview as well as during lesson observations. His beliefs about the value of engaging learners in practical work manifested in lesson presentation. This suggested that classroom practice improved in terms of improvement in his pedagogical knowledge, practical skills, confidence and enthusiasm to teach science.

### **Mr Zulu**

During the lesson observations, five of Mr Zulu's lessons were on the topic of 'Earth and Beyond,' and one was on mixtures. There were two practical activities conducted during the observation period. Mr Zulu often referred to the challenge of doing practical work due to the lack of facilities, as shown in [Table 4](#).

**Table 5.** A part of Ms Ntombela's transcription including coding of her responses

<b>Excerpt from interview transcript</b>	<b>Category</b>
<b>Researcher:</b> Can you explain how the ACE program has changed the way you view yourself as a science teacher?	Understanding learners
<b>Ms Ntombela:</b> Like I am brainstorming ACE. Other educators they must focus on various teaching methods. ... You can change the method. You can see like teaching grade 7A, B, C, D and E. On A the learners may understand more. You can change the method.	Pedagogical skills

### *Subject knowledge*

Mr Zulu displayed confidence, indicating that his subject knowledge "changed drastically" and later added "... now I am well equipped, I can answer any questions as far as science is concern". This belief was justified to some extent, as during the lesson observations, he presented and explained the scientific content correctly. The document analysis revealed that he gave learners correct feedback on the homework and classwork activities, indicating a sufficient command of subject knowledge.

### *Laboratory work*

He was of the opinion that the lack of apparatus limited his chances of practicing what he had learnt in the ACE programme, saying "... there is no problem as far as everything is concern in science, the only challenge that I have is experiment because here in our school we don't have a laboratory ...". He explained "I have to improvise practical so that they can be able to see". The lesson observations confirmed the data from the interviews because in the two hands-on activities conducted by the learners, the resources were brought by the learners from home; in one case they made volcanoes and in another case they separated mixtures. This improvisation indicates that he has adequate practical competence.

### *Pedagogical knowledge*

Mr Zulu indicated during the interviews that he planned his lessons using textbooks and the internet before teaching. He also said that he used different teaching strategies and that learners who struggle are given more activities while those who are "more intelligent" are given more challenging activities. Different teaching strategies were observed as he used demonstrations, presentations by learners, direct teaching, as well as incorporating group work. He also mentioned that he learnt "to allow learners to hypothesise, allow them to guess so that you can correct that guess thing".

### *Learner outcomes*

Mr Zulu was asked if his learners' behaviour in class changed after he had completed the ACE programme. He responded positively and further explained that previously, 60% of his learners obtained a "high mark", but after completing the ACE programme, he estimated it at "definitely 80 to 90". This indicated that Mr Zulu believed that his learners performed better.

### *Professional identity*

Mr Zulu indicated during the interviews that he was "excelling" as a science teacher after completing the ACE programme. He expressed confidence in teaching science and also indicated that he helped in training other teachers during district training sessions for the new curriculum. He also displayed confidence in the way he supervised the groups of learners during the practical sessions. Furthermore, he displayed a positive attitude towards the teaching profession when he honoured his appointment for lesson observation on a day when he was noticeably sick with influenza.

### **Ms Ntombela**

Ms Ntombela presented four lessons about 'Earth and Beyond', one lesson about mixtures and used one period to complete an assessment required by the school district office. She showed a lack of confidence during the interview, and gave mostly short answers. **Table 5** shows a section from the analysis of her interview.

### *Subject knowledge*

Ms Ntombela indicated that she had learnt subject knowledge during the ACE programme, especially about 'Matter and Material': "Like matter, I understand more matter, I did not understand before ...". It was noted during the lesson observations that she was comfortable teaching from the textbook or from the notes, but not confident in teaching without referring to these.

### *Laboratory work*

With regard to practical skills, Ms Ntombela indicated in the interview that she did not have sufficient practical skills to conduct experiments with learners. She also said that the laboratory was too far away and fetching apparatus wasted teaching time. During the six lesson observations, there were no experiments conducted, despite the fact that her school had a laboratory. In contrast to these remarks there was evidence that indicated that practical work actually did occur. There was an event where she allowed the learners to build circuits while she completed an administrative task during the lesson observation period. This suggested that the learners were actually familiar with the apparatus. Furthermore, the learners' books did show written work on some experiments conducted earlier in the year, suggesting that she actually did include practical activities as part of teaching. During the interview, when asked which experiences she thought enable learners to learn science, she responded, "I use science equipment, science equipment", which also suggests that she sometimes does conduct laboratory work. The conflicting data made it difficult to draw a conclusion about Ms Ntombela's practical competence. It is possible that she avoided practical work during the lesson observations due to a lack of confidence.

### *Pedagogical knowledge*

During the interview, Ms Ntombela indicated that she used different teaching methods to accommodate learners with different learning styles. In answering another question, she also mentioned that "you can change the method", similar to her response shown in [Table 4](#). She also claimed to use visual aids like charts and posters to support learning. This was actually observed in the second and sixth lessons. Across the six lessons that she presented for observation, it was found that she mostly used direct teaching from the textbook and notes, oral questions and having learners reading aloud all together.

### *Learner outcomes*

Ms Ntombela was asked about the learner outcomes, and indicated the learners enjoyed learning when she was "active", which seems to contradict her claim that she does not use practical work in lessons. She mentioned that there were still learners who were not well behaved, and during the lesson presentation she spent approximately ten minutes reprimanding learners on one occasion. Apart from the learners who were not cooperating, the analysis of the learners' workbooks revealed that they regularly did homework and classwork.

### *Professional identity*

Ms Ntombela's files and learners' workbooks indicated that she worked according to the departmental schedule. She indicated that she attends and enjoys cluster meetings and that the ACE programme contributed to develop her content knowledge. However, the interview and lesson observations revealed that she lacked confidence in her subject knowledge and her practical skills. Furthermore, her teaching style and reluctance to present practical lessons suggested a negative attitude toward science teaching. It seems that the ACE programme did not develop her confidence or attitude to provide positive learning experiences for her learners.

## DISCUSSION

To be able to understand and explain the teachers' classroom practices, lessons were observed, documents analysed and teachers were interviewed. The results indicated that classroom practices of Mr Wakithi, Mr Mashangura and Mr Zulu were indeed enhanced in terms of improved knowledge and practical skills, enjoyment of the programme, enhanced confidence and positive attitudes, as well as improved learner attitudes. It was also clear that the need for resources inhibited the improvement of classroom practice of these three teachers.

The results of this study should not be generalized, as it was a case study, searching to understand if, how and why these teachers' classroom practices changed following the professional-development programme. It should be noted that teachers' perceptions of their own practice and learners' outcomes may be misleading, creating an exaggerated impression of positive attitudes. However, the observation of six consecutive lessons for each teacher as well as analysis of learners' workbooks and teachers' files provided information about actual practice to enable

the researchers to form a holistic understanding of each teachers' individual experience and practice. Altogether, results clearly showed that this professional-development programme did not produce optimum outcomes for the teachers who participated in this study.

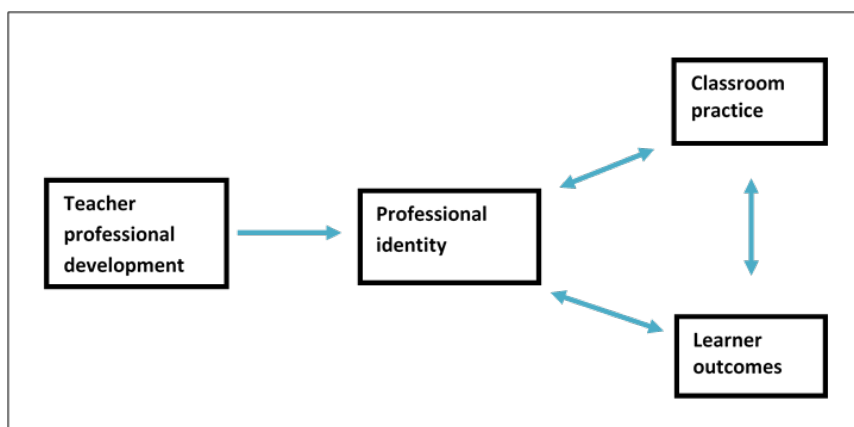
Three of the four participants were restricted by the lack of resources in their schools in implementing some of the knowledge and skills learnt. This is in agreement with Darling-Hammond et al.'s (2017) argument that lack of resources is a factor that can render a professional-development programme ineffective. Similarly, Buczynski and Hansen (2010) found that teachers struggled to implement knowledge and skills learnt in a professional-development programme. However, the ways in which teacher professional development occurred depends on the unique personalities and circumstances of the teachers. Confidence and positive attitudes to teaching seemed to enable three of the four teachers to grow as professionals. This is in agreement with what Borko's (2004) conclusion that teachers responded to professional development differently, claiming "some teachers change more than others through participation in professional-development programme".

The ACE programme did not fully develop the commitment of teachers to conduct practical work consistently. The analysis of documents revealed that most practical activities were conducted during the data-collection period, in fact, very little practical work was conducted during the semester prior to data collection. This may be an illustration of the Hawthorne effect (Wickström & Bendix, 2000). Therefore, it is possible that the practical work presented by three of the teachers during the study may gradually regress after the study (Leonard & Masatu, 2006). On the other hand, the experience of successfully improvising during the study may have good long-term results. It is argued that teachers in the current study may have realised their potential of conducting practical work when they were observed and they may be inspired to continue the practice. Furthermore, there was little indication of any direct implementation of what was learnt in the programme, except for one example where Mr Mashangura used the lesson plan template provided during the programme. Instead, the views expressed by the teachers indicated that changes in classroom practice were mainly caused by the changes in their professional identity.

According to the theoretical framework, improved classroom practice and improved professional identity both lead to improved learner outcomes. Although learner outcomes were not directly investigated, the views expressed by the teachers suggested that there had been an improvement in learner outcomes. It was not only the classroom practice that influenced learner outcomes but also the effects of enhanced professional identity. For example, Mr Wakithi reported that learners were more eager to learn science and ascribed it to his improved confidence. Therefore, results suggested that improved learner outcomes resulted from changes in classroom practices as well as professional identity. According to the theoretical framework, a professional-development initiative impacts on classroom practice by direct implementation, as well as indirect processes of enactment and reflection involving professional identity and learner outcomes. In the current study, little indication of direct implementation of the programme was found, contrary to Guskey's (2002) model. Rather, it was enhanced professional identity that contributed substantially to the growth of classroom practice, in agreement with Desimone (2009). Reverse processes were also found, indicating that the improved learner outcomes reinforced growth in classroom practice and teachers' professional identity.

## CONCLUSION

The results lead to a revised model of professional growth that represents professional development of teachers in poorly resourced schools where direct implementation is obstructed by lack of resources. This model is shown in [Figure 2](#). On the whole, in this model, science classroom practice and learner outcomes are observable outcomes of a professional teacher-development programme but these outcomes are the product of changes in professional identity, rather than from direct implementation. In addition, there is a positive feedback effect from improved learner outcomes reinforcing classroom practice and professional identity.



**Figure 2.** A suggested model of teacher development in poorly resourced schools

Although this was a case study, results support literature with regard to challenges regarding implementation of what was learnt in a professional-development programme. It is therefore recommended that in future programmes, support, including resources, should be provided to teachers after completing a teacher-development programme to re-enforce and implement new skills. Further research should be undertaken to investigate the applicability of the new model in other contexts.

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## APPENDIX 1

## Interview Protocol

1. Do you believe that you have sufficient subject knowledge to teach the syllabus? (If yes: Can you give an example of subject knowledge in the syllabus that you struggle to teach? If no: Are there any topics you struggle to teach?)
2. Do you believe that you have sufficient practical skills to do the prescribed experiments? (How often do you do experiments with learners; do you have enough apparatus to conduct experiments, If no, what is needed? Do you sometimes use improvised materials to do experiments? If Yes, can you give an example)
3. How do you plan lessons? (Can you name information sources you use to plan/prepare for each lesson?)
4. How do you decide which learning activities and instructional materials to use in a lesson (What do you do when learners are struggling to understand what you are teaching them)?
5. How do you accommodate learners with different learning styles?
6. How do you help learners to understand science when they have difficulty to understand the language?
7. What kinds of experiences do you think enables learners to learn science? (What do you think is the best way for learners to learn science?)
8. What do you think the department of education wanted you to learn from the ACE programme?
9. What do you think the university wanted you to learn?
10. How did you think your classroom practice was expected to change after completing the ACE program?
11. Do you think your classroom practice has changed? (If yes, which way? If no, what prevents you from changing your practice?)
12. Do you think your subject knowledge has improved? (If yes, can you name one science concepts you think you learnt in ACE? If no, why do you think you did not learn anything from ACE?)
13. Can you tell me about something you were taught in ACE which you are practicing in class? (Can you mention any best practice or experience you copied from ACE and you are implementing in class?)
14. Did your learner behaviour in class changed since you completed ACE? (If yes, in which way? If no, why do you think it did not change?)
15. Do you think learners are now enjoying science when you teach now that you completed ACE? (If yes, can you explain why do you think they are enjoying? If no, what prevent them from enjoying?)
16. Did you enjoy the ACE programme? (Can you name a specific concept that you enjoyed about ACE programme?)
17. Do you enjoy teaching science more than before you completed the ACE programme? (Can you mention a specific thing you enjoy in teaching science?)
18. Do you have more confidence in teaching science after completing the ACE?
19. Can you explain the effect of your learners' responses on your new classroom practice?
20. Would you be willing to share what you learnt in ACE in the cluster meeting? (Can you explain how the ACE NS programme has changed the way you believe and view yourself as a science teacher?)

APPENDIX 2

Lesson Observation Schedule

Elements of classroom practice to be observed	Question guiding observation
Teachers' subject knowledge	Is the content presented correctly?
	Is the content explained adequately?
	Does the teacher relate what he taught to real life examples?
	Is the teacher able to respond to learners' questions correctly?
Teachers' practical competence with experiments	Did the teacher select appropriate apparatus beforehand?
	Was the experiment suitable for Senior Phase? (comment on the relevancy of the experiment to the curriculum)
	Is the purpose of the experiment clearly stated?
	Were apparatus checked beforehand for functionality?
	Was there a worksheet or guideline on what to observe?
	What was the source of the worksheet or guidelines?
	Were learners clarified as to what to write on the worksheet?
	How was the practical work assessed or the experiment assessed?
	Did learners perform hands-on practical work?
	Did the teacher conduct practical demonstration?
	If it was a demonstration, was it visible to all the learners? Explain how
	What were the learners expected to do after seeing the demonstration?
	Were the learners assessed to find if they have learnt something from the demonstration?
Pedagogical skills	Is there continuous assessment?
	How is the classroom managed?
	Does the teacher link content to learners' previous knowledge and context?
	How is the interaction of the teacher with learners?
	How is learner participation, are they actively involved?
	Is there evidence of cooperative learning?
	Does the teacher use models/visual examples to explain science concepts?
	Are the various learning styles of learners accommodated in the lesson?
	Is the teacher aware of learners' typical misconceptions?
	Does the teacher use different strategies to teach? Which?
	Does the teacher ask learners questions that cater for the different cognitive levels?
Language skills	How much direct teaching does the teacher use?
	Does the teacher use the discrepant event to clarify further for learners?
	Do the planned learning activities accommodate language skills?
Teachers' beliefs and attitudes in teaching science	Does the teacher code switch appropriately?
	How confident is the teacher in teaching science?
	How is the enthusiasm of the teacher?
	Does the teacher inspire the learners?

## APPENDIX 3

### Document Analysis Guide

#### Learners' workbooks

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**CRITERIA**

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Activities based on practical work

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Frequency of written work

---

Accuracy of feedback or corrections given to learners by the teacher;

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Activities that require high order thinking

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Evidence of various forms of assessment given to learners

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#### Teacher documents and records (Work Schedule, lesson preparation and programme of assessment)

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**CRITERIA**

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Activities in teacher planning that involve practical work

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Science content covered for the grade in the planning

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Learners assessment records, planned for various learning styles

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Recording sheets for the learner performance

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<http://www.ejmste.com>



# Out-of-school Activity: A Comparison of the Experiences of Rural and Urban Participants in Science Fairs in the Limpopo Province, South Africa

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Received 25 January 2018 • Revised 9 May 2018 • Accepted 7 June 2018

## ABSTRACT

The paper compares the experiences of rural and urban learners who participate in Eskom Expo for Young Scientists science fairs in the Limpopo province of South Africa. Within an exploratory case study in the Limpopo province, a third-generation activity-theory framework was applied as an analytical tool to determine differences in activities between learners from rural and urban schools. To address triangulation, personal meaning mapping, interviews, focus-group discussions, and observations were used. The study involved eleven learners, six from rural schools and five from urban schools. Themes were identified to present the learners' view on science fairs and possible reasons for their performance or failure. The results revealed that the differences in activities of rural learners are due to: poor school facilities, lack of support, lack of mentors, lack of equipment, lack of computers and computer illiteracy. Two new areas are confirmed namely the level of attention with regards to learner's engagement and readiness to learn and depth of knowledge of learners – factors that were not identified in previous studies on science fairs.

**Keywords:** activity theory, out-of-school activity, personal meaning mapping, science fair

## INTRODUCTION

Some ethnic groups do not prefer pure sciences because to them they think they are for “white men” (Wong, 2015). However, out-of-school time programs such as science Olympiads, robotics and science fairs (Sahin, 2013) confirmed positive attitudes and achievements in science (Dabney, Chakraverty, & Tai, 2013). The out-of-school programs (Hayden, Ouyang, Scinski, Olszewski, & Bielefeldt, 2011; Robelen, 2011) have supported scientific literacy and well-planned out-of-school programs are able to “foster interpersonal competence, help define life goals and promote educational success” (Wirt, 2011, p. 48). While the learners are doing these activities, they acquire scientific skills, and improve communication skills and content knowledge (Fisanick, 2010; Tran, 2011). Involving learners in STEM (Science, Technology, Engineering and Mathematics) related out-of-school activities help in building STEM interest in learners and they will likely take up STEM careers (Sahin, 2013). In addition, learners find solutions to daily-life challenges in out-of-school settings and they will be able to construct their own meanings (Cicek, 2012).

These out-of-school programs offer a way by which learners can join science fairs (Sahin, Ayar, & Adiguzel, 2014). Science fairs are events where learners' science projects are shown and judged for prizes (Merriam-Webster, 2016). However, the original idea of science fairs is to enable citizens of a country to understand science and its role in society (Flanagan, 2013). In South Africa, the best-known science fair is the science expo and called Eskom Expo for Young Scientists. The purpose of this Eskom Expo is to provide a platform for learners to gain valuable work experience, to connect high-achieving youth to innovators, to enrich their skills, to inspire them to explore their passions and become more knowledgeable on the topic they are studying (National Research Council, 2012).

### Contribution of this paper to the literature

- Learners embrace the use of scientific methods of research however their understanding is very shallow due to lack of readiness and engagement.
- Learners in especially developing countries do not perform well in international science fairs due to lack of parental and teacher support – teachers indicate that science fairs are extra work for them and not part of the school curriculum.
- Rural schools do not have computers and those with computers do not allow learners to use them as this is after school and the teachers do not want to stay.
- Learners are supposed to learn from each other especially during science fairs, this study reveals that learners' levels of attention are low and they are distracted and not focused when projects are displayed at regional level.
- This study aims to fill the gap in out-of-school paucity of literature in Africa and to understand how the Eskom Expo for Young Scientists program contributes in this space.

A significant number of teachers believe that science fairs could help learners to develop skills, attitudes, and knowledge leading to a career (Czerniak, 1996). Therefore, schools, parents and science mentors should provide a platform for learners to explore their interests in a less formal environment to enable innovation and creativity in STEM (Wagner, 2012). There is also research evidence that learners who participate in science fairs improve academically (Kahenge, 2013).

In South Africa, the science-fair competitions are done from school level, regional or provincial level and, finally, national level. The learners participate from grade 5 to grade 12. The learners with the best science projects from the provincial competitions will proceed to the national science fair, which is normally held in the first week of October each year. In order for a project to win a gold medal, it must score 80% and above, a silver medal 70–79% and a bronze medal 61–69% as judged by adjudicators. For the past three years (2014, 2015 and 2016) learners in Limpopo province have not won a single gold medal at the national science fair.

Therefore, this study has two aims. Firstly, to determine the factors influencing the performance of learners at science fairs, and more specifically in the Limpopo province of South Africa. Secondly, to determine if there are differences among learners from rural and urban schools in terms of the factors. Rural schools are the previously disadvantaged schools (PDIs); poor schools with limited resources and urban schools are well-resourced schools (Ndlovu, 2015; Taylor, 2015). The research questions for this study are:

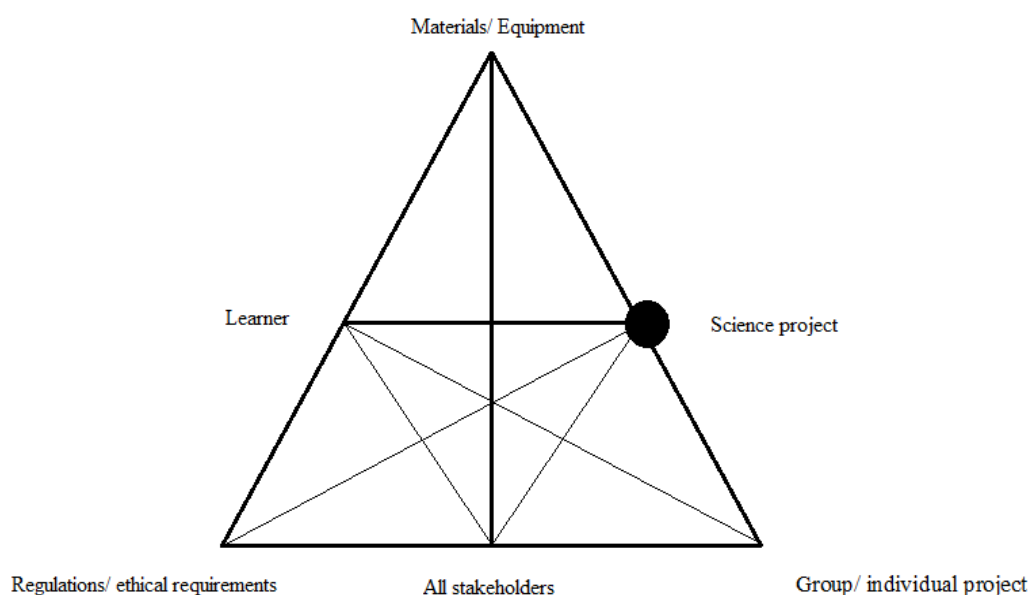
1. What are the issues influencing the activities of learners at science fairs in the Limpopo province of South Africa?
2. What are the differences among learners from rural and urban schools in terms of these issues?

## THEORETICAL FRAMEWORK

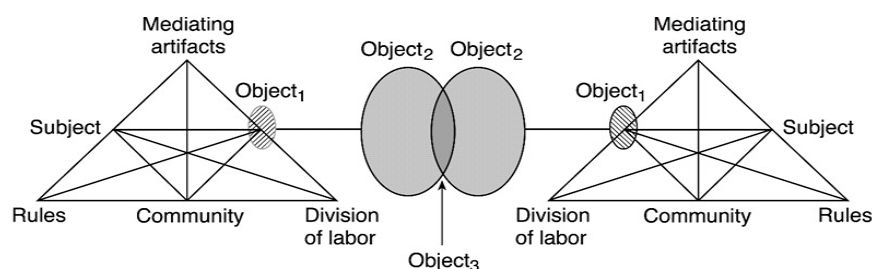
Activity theory, initiated by Lev Vygotsky, is a philosophical framework used to study human activity, practices and actions (Barab et al., 2002). Activity theory has been modified by having the two interacting activity systems with interacting objects to give rise to the third object (see [Figure 2](#)) and thereby to the third-generation activity theory, as it includes the interconnecting of individuals and the community as an analytical tool. This tool was chosen, firstly to analyze the factors which make up the components of activity and, secondly, to compare the two groups of participants, rural and urban learners.

Activity theory describes a triangular structure with six interdependent and related components (see [Figure 1](#))





**Figure 1.** Science-fair diagram in terms of this study (figure done by the researcher)



**Figure 2.** Two interacting activity systems with shared object as model for the third generation of activity theory (Engeström, 2001, p. 136)

The newly appeared ‘third object’ gives rise to a driving force for the transformation of the original activity system by means of feedback to the respective activity system, in this study the rural and urban learners.

The various components of the activity triangle (Engeström, 1987) are described below in terms of how it is implemented in this study:

- The **object** the purpose of the activity is the EE science fair, the school-based science fair (object 1) is improved to the regional science fair (object 2) which is later upgraded to the international science fair (object 3).
- The **subject** the individual actors in this study are the participating learners.
- The **community** the combination of all actors; in this study, the community refers to all stakeholders namely the learners, teachers, school administrators, department of education officials, science-fair personnel, judges, mentors, and parents.
- The **tools** the artifacts are what the learners, in producing their science projects, use; for example, laboratory equipment, materials, documents, etc.
- The **division of labor** refers to how the research projects are carried out; if it is a group project it must be clear who does what and using what.
- The **rules** all science-fair regulations and ethical requirements.
- The **outcome** this is the outcome of learner activity, the final research project and it also includes the result of the science-fair adjudication.

According to the activity-theory framework, learners’ science projects are to be taken as tools and have a mediating role between the outcome and the learner in the activity systems of research work (see **Figure 2**).

**Table 1.** Distribution of the sample

School location	Total number of learners	Primary school	Secondary school
Rural	6	2 females (both in grade 7)	2 males (grades 11 and 12) 2 females (grades 11 and 12)
Urban	5	2 females (in grade 6 and 7)	1 female (grade 10) 2 males (grades 10 and 11)

## METHODOLOGY

To gain an insider view (Creswell, 2014) of the factors influencing the performance of learners, constructivism and the interpretivist paradigm was taken as point of departure. An exploratory case-study research design was followed. An inductive analysis, which is the identification of patterns and themes in the data, was applied (Bertram & Christiansen, 2015; Creswell, 2014; Leedy & Ormrod, 2010; Nieuwenhuis, 2010). The information collected provided insight into the learners' view on science fairs and possible reasons for their performance or failure.

### Sampling

The sampling was purposeful and participants for this study were drawn from the four Eskom Expo districts of Limpopo province. A simple random selection procedure using project category numbers was utilized to select participating schools. The selected sample consisted of 11 learners (six from rural schools and five from urban schools) distributed in different grades taken from the regional science expo finalists (see [Table 1](#)).

### The Instruments

Activity theory is used as lens to collect and evaluate data to answer the research questions. Therefore, the instruments used to collect data were, personal meaning mappings (PMMs), interviews, focus-group discussions (FGDs) and an observation protocol. The PMMs, interviews and FGDs collect information on what the learners' view is on the EE science fair and possible reasons for their performance or failure. This will inform the activity-theory components; learners, materials and equipment, stakeholders and science project. The observation protocol was used to get information and to see if it was a group project or an individual project (division of labor). Permission letters to conduct research were obtained from the department of education, Eskom Expo for Young Scientists and from the school principals.

### Personal Meaning Mapping (PMM) and Interviews

Personal Meaning Mapping (PMM) was originally developed for museums, festivals or similar events in order to understand the experiences and knowledge of visitors or participants (Adams, Falk, & Dierking, 2003). Since then, PMMs have been used by proving a reliable instrument for learning assessment (Falk, Moussouri, & Coulson, 1998). For example, Lelliot (2014) used PMMs to understand how participants learn about gravity.

According to van Winkle and Falk, (2015) PMM is used by providing the participants with a blank paper on which a word, name or phrase is written at the middle of the page. They are then required to write around the phrase or word in the middle whatever comes to their minds. The researcher collects the papers and the participants are then interviewed based on what is written on the papers. After the experience or in the case of this study, after the science fair the participant is given back the paper to add more information using a different colour of ink. The interview is done again based on the changes made to the PMM. This enables the researcher to track changes in knowledge or attitudes of participants before and after the science fair.

The researcher used PMMs and follow-up interviews as a qualitative tool to have a better understanding of the learners' view on the EE science fair in general before and after the regional science fair. Therefore, the PMM provides a platform for learners to communicate their science-fair experiences, yielding descriptive qualitative data (Leftwich, 2012), and this provides a methodological tool to evaluate themselves in terms of type of experience and depth of knowledge.

### Focus-Group Discussion (FGD) Protocol

To elicit what learners' views are on the factors influencing their performance or failure in the science fair, eight questions were used as guideline, namely:

What are the reasons according to you for poor performance in science fairs?

What do you think is the expectations to achieve well from your school?

**Table 2.** Observation protocol

<b>Activity name or summary</b>	<b>Observer comments</b>
Learner distracted	
Learner focused	
Learner engaged	
Enthusiastic during judge interviews	
Self-confidence and body language	
Learner demonstrate understanding of his project in terms of content	
File and displays neatly and well organized	
Regulations and ethical issues	
Division of labor	

What are your views on your teachers` involvement with your research project?

What form of assistance do you expect from your school?

What would you expect your parents/guardian to do for you in order to assist you with your science project?

What are your views on the science-fair judges?

Do you understand the scientific method of doing a research project?

What should be improved on science fairs?

The FGD protocol was piloted with a group of five learners who were not part of the group under study. These students had to indicate any unclear questions that needs to be changed. There were 2 focus groups selected randomly from the 11 participants.

### Observation Protocol

An observation protocol was set up in terms of the level of attention shown by the participants throughout the science-fair activities. This was important as it could offer evidence on the focus and engagement of the learners during the science fair. Focused and engaged learners learn from other learners` best practices as well as from the judges, parents` and other stakeholders` positive comments. In addition, learner behaviors and activities in terms of interaction with other exhibitors, and, for example, the reading of display boards of other participating learners were noted. The last 5 aspects of the observation protocol were included because they are also part of the judges` assessment criteria. The observation protocol used is shown on [Table 2](#).

## DATA COLLECTION AND ANALYSIS

The learners completed their PMMs before and after the regional science fair and the answers to the FGDs were captured on a voice recorder. The researcher and two other volunteers completed the observation protocol. In order to ensure consistency an observation guide was used which indicated what was to be observed. In addition, the observers were trained and a pilot test observation was done. After the pilot, they discussed their notes noting that there were not significant differences in their interpretation.

### Data Analysis of the PPM

The analyses of the PMMs were done both within and across participants (Bertram & Christiansen, 2015). Based on the researcher`s experience the two categories - types of experience and depth of knowledge - where chosen in order to possibly extract factors that differentiate the urban and rural learners with regards to their performance at science fairs.

The learners` PMMs in terms of types of experience was analyzed using the four dimensions; object experience, cognitive experiences, introspective experiences and social experiences (Pekarik, Doering, & Karns, 1999). For example, object experiences entail "seeing "the real thing", while cognitive experiences describe the gaining of information or knowledge. The introspective experiences include imagining different places and times, and social experiences and entail the time spent with friends, family and include conversation with peers, teachers and others.

The learners` PMMs in terms of the depth of knowledge was analyzed based on the four-level categorization: recall, concept, strategic thinking and extended thinking (Webb, Alt, Ely, & Vesperman, 2005). These four categories are important in that they expose areas of weaknesses or strengths to the activities of learners. For example, urban learners exhibited high levels of strategic thinking as compared to rural learners.

**Table 3.** Dimensions for PMMs

<b>Dimensions</b>	<b>Rural learners</b>	<b>Urban learners</b>
object experience	80% of the learners do not understand the scientific methods of conducting a research and writing the report.	20% of the learners do not understand scientific methods of conducting a research project.
cognitive experiences	Not able to display higher level of thinking and planning using evidence	Showed no evidence of complex reasoning.
introspective experiences	Inspiring, encouraged to dream big, motivated, more confident.	Encouraged to become a scientist.
social experiences	Making friends, getting public opinion on their science project. Felt ashamed of poorly done project.	It's fun and cool, opportunities, making new friends, sharing information.

### Data Analysis of the Interviews

PMM was a qualitative tool that allowed the participants to express the knowledge and diverse meanings they on the science fairs. Learners were questioned on their understanding of science fairs in the semi-structured interview and further probing was followed in order to understand their responses.

### Data Analysis of the Observation Protocol

The levels of attention of the learners were evaluated by using the following categories: distraction, focus and engagement (Bitgood, 2010). Their engagement was analyzed by observing the learners' behaviors and activities in terms of how they interacted with other exhibitors and reading display boards of other participants. The observers looked into how the components of the activity triangle were interacting, namely; the materials/equipment, learners, ethical issues, stakeholders' division of labor and science projects.

### Data Analysis of the FGDs

The FGDs collected information on what the learners view is on the EE science fair and possible reasons for their performance or failure. This informed the activity-theory components: learners, materials and equipment, stakeholders and science project. As the FGDs provided information on what the learners' view is on the science fair and possible reasons for their performance, it was analysed in terms of the activity-theory components. The learners used materials and equipment for their science project. Thematic analysis was done by examining and recording the patterns across the collected data. The researcher identified constructs during and after data collection by analysis of words that is key-words in contexts and most repeated words or phrases. Therefore, by analyzing the FGDs thematically (Mayring, 2014; Seidman, 2012) it would not only give the science-fair organizers specific details on what influences the learners' performances at science fairs to make informed decisions about current and future science fairs but also inform the other stakeholders.

The FGDs were video-recorded and provided information on what the learners' view is on the science fair and possible reasons for their performance as it was analyzed in terms of the science-fair components. Transcriptions of the recordings were made. The learners freely gave information on the assistance they receive from their school or parents; "my parents were unable to buy for me the materials I needed for my science project so I had to change my initial project." Another learner from an urban school commented that "at our school there is a computer laboratory and we are allowed to use the computers for our research."

The researcher relied on detailed notes taken during the FGDs, and also replayed the videotape as needed. The nature of the analyses of FGD data was determined by the research questions of this study. There were two focus groups, the comments were rearranged to have answers together for each question. The researcher noted the main ideas in the answers and identified themes.

## RESULTS

### Personal Meaning Mapping (PMM)

**Type of experience** with regards to learner's engagement and readiness to learn.

An example of a PMM to illustrate the type of experience this learner had with the regional science fair (see [Figure 3](#)). The learners used red ink to write the PMM before the science fair and later they wrote in black ink.



Figure 3. Example of a PMM of a learner to illustrate his type of experience

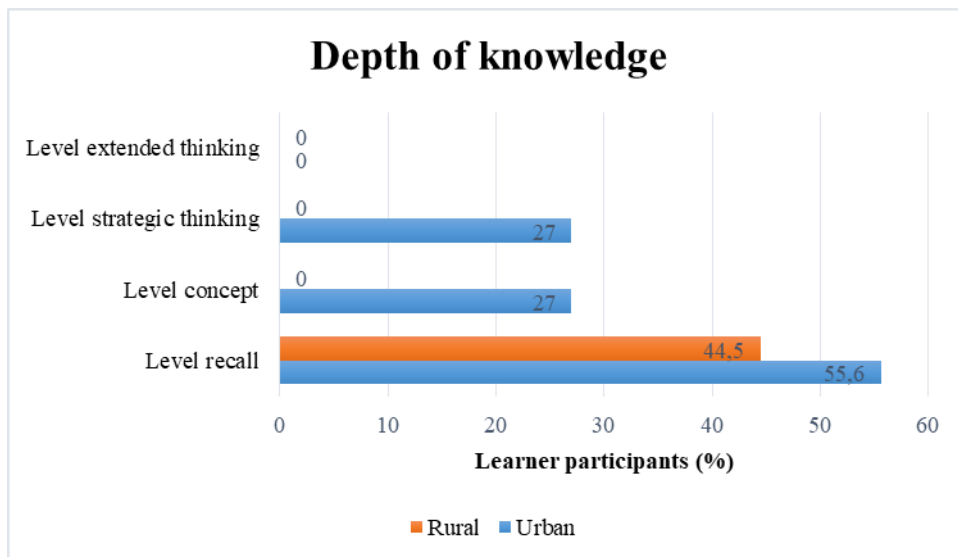


Figure 4. Depth of knowledge of learners

Each of the learners' experiences were analyzed using the four dimensions. The urban and rural learners' experiences are presented (see Table 6).

Observations were done by looking at the level of attention using the three categories (see Table 4) formulated by Bitgood (2010).

### Depth of knowledge

The rural and urban learners are compared in terms of their depth of knowledge in order to understand their scientific research skills, innovativeness and creativity. Each of the learners' depth of knowledge were analyzed using the four-level categories (see Figure 4).

From the results, it is evident that both our rural and urban learners' level of extended thinking is nonexistent. As for the rural learners, they lack strategic thinking as compared to the urban learners.

**Table 4.** The level of attention with regards to learner`s engagement and readiness to learn

Level of attention	Indicators
Distraction	Of the 11 learners under study, four learners (36,4%); three from rural school and one from an urban school, were distracted, not involved, they were talking, outside most times, and appeared to have a carefree attitude and playful.
Focus	Five learners (45, 5%); three from urban schools and two from rural schools were seen looking at other science projects in passing.
Engagement	Only two learners (18%) from urban schools were observed reading other displays and asking other learners, and teachers, or judges.

**Table 5.** Categories and Themes

THEMES	Theme 1 Communication		
	Theme 2 Support and assistance		
	Theme 3 equipment and computers		
Category 1	Category 2	Category 3	
Community	Tools	Division of labour	
learners	scientific skills	individual projects	
teachers	cognitive experience	group projects	
schools	introspective experience		
judges			
parents	social experiences		

### *The interviews*

The interviews were used to confirm the findings from the PMMs and to get more clarity on the participants' meaning mappings. The outstanding ideas and themes were incorporated in [Table 4](#).

### **Focus-Group Discussions (FGDs)**

Three themes emerged from the analysis of the FGDs, namely communication, support and assistance, equipment and computers. Rural learners said they were not getting information about science fairs on time and that support they get from their school, teachers and parents is minimum. Unlike rural learners, urban learners enjoy a lot of support and their schools have equipment and computers, which they use for their research. Categories and themes were formulated from the collected data and arranged (see [Table 5](#)).

## DISCUSSION

The purpose of this study was to identify the factors influencing the performance of learners at science-fair competitions in the Limpopo province and determine what the differences in performances are among learners from rural and urban schools.

The qualitative data from the FGDs, PMMs and the observation protocol were triangulated in order to validate results due to the small sample size. A third-generation activity-theory lens was used to interpret the data accordingly.

Data across all the three instruments indicate that the main reasons for performance of learners are as summarized on [Table 6](#).



**Table 6.** A comparison of the activities of rural and urban learners

	<b>Rural learners</b>	<b>Urban learners</b>
<b>Object</b>	<b>Regional Science fair</b>	<b>Regional Science fair</b>
<b>Subject</b>	<b>Six learners</b>	<b>Five learners</b>
<b>Community</b>		
Learners	Lack of needed materials and equipment, computers and printers, computer illiteracy among teachers and learners. Learners do not get information about science fairs on time. A significant number of rural learners were distracted and not focused during the fair. The depth of knowledge was significant on recalling of concepts but no evidence of strategic thinking and extended thinking during FGDs.	The schools have equipment. They get information from expo on time. Majority of learners were engaged during fairs. Depths of knowledge evident on level of recall, concept and strategic thinking but absent on level of extended thinking.
Teachers	Lack research skills and confidence and are unable to assist the learners fully. Teachers indicate to learners that its extra work for them and it's not part of the school curriculum.	Teachers indicate to learners that its extra work for them and that it's not part of the school curriculum.
School	Not very supportive and they do not give them prime time and dedicated rooms to do their work where they are not disturbed by other learners. No computers and laboratory equipment.	Some schools have computers but the learners are not allowed to use them.
Judges	Students view the judges to be incompetent and lack interest during judging, not friendly, harsh or rude, overly critical, they don't answer learners' questions. Judges are biased and favoritism is rife. Due to perceived lack of competence in the field their judging, they fail to offer constructive criticism.	Students perceive judges as lacking competence in the field their judging, thereby fail to offer constructive criticism. Lack competence and interest
Parents	Not very supportive in terms of finances, motivating and providing materials needed for the project. Some learners do not stay with their parents.	Parents are supportive. Some learners do not stay with their parents.
<b>Tools</b>		
Object experience	80% of the learners do not understand the scientific methods of conducting a research and writing the report.	20% of the learners do not understand scientific methods of conducting a research project.
Cognitive experience	Not able to display higher level of thinking and planning using evidence, no evidence of complex reasoning during FGDs.	Showed no evidence of complex reasoning. Learners say that the experience has expanded their knowledge of physics.
Introspective experiences	Inspiring, encouraged to dream big, motivated, more confident.	Encouraged to become a scientist,
Social experiences	Fun, receive awards, making friends, getting public opinion on my science project. Felt ashamed with my poorly done project.	It's fun and cool, opportunities, making new friends, sharing information, asking questions to scientists.
Division of labor	A maximum of two learners per project, this ensures that all are active participants.	A maximum of two learners per project
Rules	Eskom Expo science-fair regulations.	Eskom Expo science-fair regulations
Outcomes regional science fair	Gold: 1 Silver: 2 Bronze: 3	3 2 0

The differences in learners' views towards science fairs between learners from rural schools and those from urban schools:

- a. Learners in the majority of rural schools indicate that they are not supported by the school, teachers and parents.
- b. The communication of information about science fairs does not get to the rural schools on time.
- c. The urban learners' views science fairs as a link to becoming a scientist, meeting scientists and making new friends.

The lack of resources has been documented as disadvantaging learners (Flanagan, 2013; Gifford & Wiygul, 1992; Mbowane, Villiers & Braun, 2017). The results of this study concur with previous studies that the poor quality of judges affects their competence and that some judges are biased (Atkins, 2014; Bernard, 2011). The findings in this study show that teachers and parents are not supporting learners and these findings are consistent with previous studies (Betts, 2014; Finnerty, 2013; Kahenge, 2013; Naidoo-Swettenham, 2017). This study has further introduced

the aspects of level of attention and depth of knowledge of learners, which provided more insight into why learners fail to perform at science fairs.

With regards to the activity theory, all the facets of the activity triangle are interactive and interdependent giving rise to the science project. The quality of the science project is dependent on the contribution and positive interaction between these facets and stakeholders.

## SUMMARY AND CONCLUSION

The overall findings of this study show that while learners embraced the use of scientific methods of research, their understanding of the same is very shallow because they lacked readiness and engagement. Learners in the Limpopo province perform poorly in the international science fairs because they lack parental and teacher support; schools do not have computers and those with computers do not allowed learners to use them. Teachers indicate to learners that science fairs are extra work for them and are not part of the school curriculum. The learners view the judges at science fairs as incompetent and biased; hence poor-quality projects are allowed to sail through to national competitions. The learners are supposed to learn from each other during science fairs; this study has revealed that learners' levels of attention are too low and they are distracted and not focused during the science fair at regional level. The knowledge of challenges faced by rural and urban science participants will help all stakeholders to assist the learners leading to their gaining of lifelong skills. The science fairs could contribute to giving learners the skills and knowledge they need to have to be successful in their studies and in life by imparting them with technological literacy, transformative skills, problem-solving skills and critical-thinking skills.

As a way forward, the schools should make use of past successful science-fair participants to work with their learners and to motivate others sharing their practices. Science clubs could be established in schools giving a platform for learners to show and practice their innovativeness and creativity. Learners should not work in isolation, parents and teachers and science-fair organizers should work together not only to develop scientific knowledge but also to reflect on their work as well as for the advantages of social learning.

## FUTURE STUDIES

For future studies, this paper draws attention to three areas that could be investigated. Firstly, to investigate the effect of computer literacy and availability of computers with the carrying out of science fair projects. Secondly, to increase literature on the teachers' views and conceptions on science fairs since they are the ones mostly assisting the learners and finally to replicate this study in all provinces of South Africa.

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