EXPLORING THE USE OF COMPUTER SIMULATIONS AS A TECHNOLOGICAL PEDAGOGICAL REASONING TOOL IN THE TEACHING AND LEARNING OF ELECTROMAGNETISM IN A WHOLE-CLASS RURAL SETTING

By

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PROMOTER: PROF. JEANNE KRIEK

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DEDICATION

To

my wife Isabel

and our three children

Christine Makanakaishe, Lesley Mufarowashe and Makomborero

DECLARATION

I MAXWELL TSOKA hereby affirm that the research report titled: **EXPORING THE USE OF COMPUTER SIMULATIONS AS A TECHNOLOGICAL PEDAGOGICAL REASONING TOOL IN THE TEACHING AND LEARNING OF ELECTROMAGNETISM IN A WHOLE-CLASS RURAL SETTING** submitted in accordance with the requirements of Doctor of Education is my own work and that it has not been submitted for examination for a degree at this university or any other university. Furthermore, all the sources that I have cited have been recognised by means of complete references

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SIGNATURE   DATE

(Maxwell Tsoka)

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Abbreviations

AR	Action Research
CAPS	Curriculum and Assessment Policy Statement
CK	Content knowledge
CS	Computer simulations
DBE	Department of Basic Education
FET	Further Education and Training
GET	General Education and Training
ICT	Information Communication Technology
PD	Professional Development
TCK	Technological Content Knowledge
TK	Technological Knowledge
TPCK	Technological Pedagogical Content Knowledge
TPK	Technological Pedagogical Knowledge
TPR	Technological Pedagogical Reasoning

Abstract

This study, *Exploring the Use of Computer Simulations as a Technological Pedagogical Reasoning Tool in the Teaching and Learning of Electromagnetism in a Whole-Class Rural Setting*, documents a journey of a digital immigrant, physical sciences teacher in a secondary school in a rural area who sought to integrate computer simulations as reasoning tool to enhance instruction and learning. The study employed an action research methodology and used Smart's model of technological pedagogical reasoning and action (MTPRA) as a theoretical framework to guide the processes of teaching. The study utilised multiple methods of data collection: the documentation of my planning for teaching the topics of magnetic field and electromagnetic induction, reflective journals, feedback from critical friends, video-recordings of my lessons and focus group discussions with learners. Findings from the study revealed teaching with technology is a paradigm shift, change of mindset and culture that requires teachers to consider how the affordances of technology can be harnessed to create opportunities for learners to engage in meaningful learning. These opportunities for learning are created through the matrix of interaction between the teacher, learners, content and computer simulations as informed by the teachers' technological pedagogical reasoning (TPR) sub-process (i.e., comprehension, transformation, instruction, and evaluation). Each TPR cycle was a professional learning experience which meant that the teacher collected data that could be used to frame and reframe his practice. The process of learning was interactive and facilitated by reflecting on how the elements (content, learners, computer simulations, the teacher) interacted with the actions of comprehension, transformation, instruction, and evaluation.

The study found evidence to suggest that computer simulations had an influence on what was learnt, how it was learnt and the effect of these on the learners. Thus, computer simulations can be used as a curriculum resource/material to create potential learning experiences that have cognitive, affective, and conative dimensions. The learning experiences were among others, influenced by the following factors: context, prior learning experiences and the perceptions of the learners. The cognitive dimension resulted in the learners attaining knowledge of the relation between electricity and magnetism and the application of electromagnetism. The affective dimension created in learners a sense of enjoyment, wonder(surprise) and practical relevance of the lessons while the conative dimension created interest in the subject and learning in general.

Chapter 1

1.0 Introduction

When I began teaching in South Africa in 2008, I was hired at a rural secondary school as a physical science teacher, teaching both physics and chemistry in the further education and training (FET) band, Grades 10-12. This context was now different from my home country and I needed to change my approach to teaching. The system of education and the culture (especially the language) were new to me. Whilst I was comfortable with the language of teaching and learning (LOLT), to learners it was struggle. In Zimbabwe I had trained as a science teacher but then specialised at the university to teach physics. I taught physics at the advanced (A) level (Form 5- 6) and physical science at the ordinary (O) level (Form 3-4) students in Zimbabwe at an urban school, which was relatively resourced. The learners in physical sciences at O level were streamed based on their form 2 results where only those who had performed well were selected to do the subject. The students who managed to get good grades at O level would then proceed to do physics at A level.

The classes were generally manageable with learners averaging 45 at O level and about 15 at A level. As a teacher I was able to know all the learners and their weaknesses. When I came to South Africa it was a different case. Every learner was allowed to choose to do physical science irrespective of his or her ability in the subject. Some of the learners in physical sciences have been progressed to the next grade without having passed the subject at either grade 9 or grade 10. A new policy was introduced by the Department of Education (DBE, 2015). The Department of Education defines progression as "…the advancement of a learner from one grade to the next, excluding Grade R, in spite of the learner not having complied with all the promotion requirements" (DBE, 2015). The policy stipulates that no learner is supposed to spend more than four years in any particular phase and therefore may only fail one grade once. Thereafter, the learners are advanced to the next grade even if they fail to meet the promotion requirements. Hence, those learners who repeated a grade more than twice have been "qualified to progress" (QP) to the next grade. In Zimbabwe learners' performance was based on their final examinations which did not include any other assessments. However, in South Africa assessment is inclusive of continuous assessments and the final examination mark. The classes are usually overcrowded (Marais, 2016; Sethusa, 2015) averaging 60 learners due to high enrolments caused by the Education Laws Amendment Bill (DBE, 2005) which legislates that in impoverished schools should be declared as 'no-fee' paying schools. Accordingly, many learners are attending school in rural areas (Gardiner, 2008; Mabila, van Biljon & Herselman, 2017). The consequence of these large learner enrolments is the inadequacy of teaching and learning resources and facilities because they are disproportionally overwhelmed. Thus, the provision of quality education in quintile 1-3 schools at no cost to parents and communities is constrained, greatly compromised and difficult to attain.

Limpopo province, where I taught has been identified as predominantly rural and one of the least developed provinces in the country (Gardiner, 2008). Approximately ninety per cent of the population in this province live in rural areas (Risimati, 2007). Therefore, it follows that the majority of learners attend schools in rural areas. It was also established that the province has also the largest concentration of low-quintile[1] rural schools. However, some communities lack school facilities and learners have to travel long distances to access education (Abotsi, Yaganumah, & Obeng, 2018; Singal et al., 2015). Because of the low socio-economic statuses of the communities where these schools are located, learners are usually provided with daily meals during break time.

Most schools in this province have found to be constrained in terms of teaching and learning resources. Statistics from the National Education Infrastructure Management System (NEIMS) show that of the 3833 schools in the province only 230 (6%) have science laboratories, while 548(16,17%) have computer laboratories and 150 schools have internet connectivity for teaching and learning ,while 240 have functional libraries (NEIMS, 2019). Besides the lack of science and computer laboratories the schools do not have enough classrooms, have poor access to services such as water and electricity, and have no connectivity to the internet and very few school libraries (Gardiner, 2008). Research has shown that rural schools have the highest percentages of schools that still do not have access to the internet (Hepp & Laval, 2002; Sanchez & Salinas, 2009). Howie, van Staden, Draper and Zimmerman (2010) note with concern the increasingly lack of/or cultivation of a culture of meaningful learning within schools in rural areas. It is reported that Limpopo is among the provinces that have high levels of innumeracy and illiteracy (Haddow-Flood & Wiens, 2013; Moloi & Chetty, 2010).

Teaching learners “to experience the richness and excitement of knowing about and understanding the natural world” (National Research Council, 1996:13) in rural settings was truly challenging endeavour for me, it was a struggle[2] in such a deprived context. The curriculum policy was highly prescriptive making it difficult for teachers to practice more

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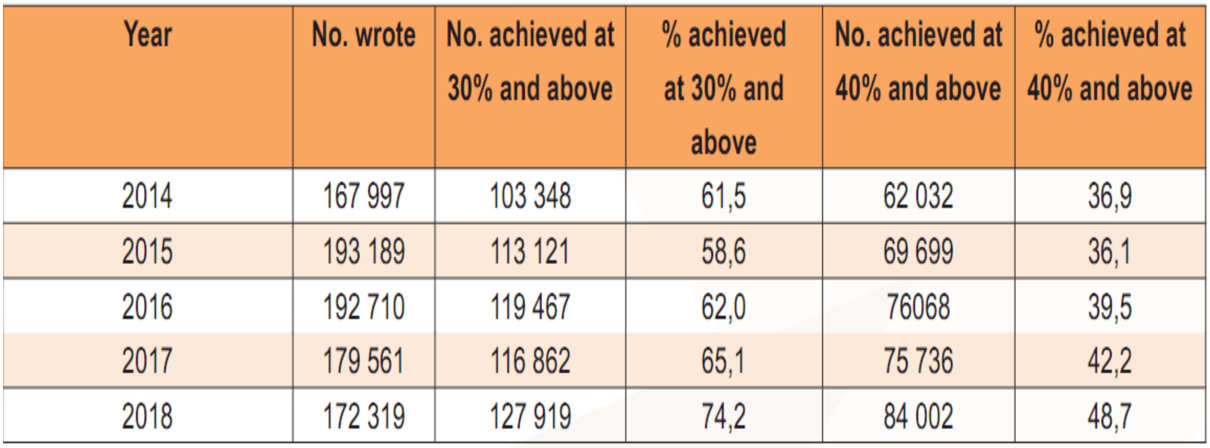
[1] South African’s government schools are divided into five quintiles based on the prosperity of the area they are situated in. Schools in quintiles 1-3 (low-quintile) provide free access to primary and secondary education. Schools in quintiles 1-2 are usually located in urban areas and parents have to pay school fees.

[2] Peercy, Martin-Beltran, Yazan and Destafano (2017) define struggle as instances of frustration and uncertainty while the teachers were grappling with the authentic challenges that arose during the lessons.

professional autonomy when making decisions about pedagogy and content (Priestly, Biesta, & Robinson, 2015). It does not allow the teachers freedom to decide the order of teaching the topics depending on their level of difficulty or abstractness. In Zimbabwe, I had the opportunity to choose which topic/concept to start teaching depending on my judgement of its difficulty or otherwise. However, in South Africa, I felt powerless even to execute my professional judgement in things which affected my practice. The question was now, what should I do to survive in this context without compromising the ethos and ethics of teaching that I had been immersed and cultured in in Zimbabwe. I did not want to perform the least possible in this challenging working context as an adaptive action. On the contrary, the ability to thrive in challenging contexts contribute to positive emotions, feelings of professional success, satisfaction, and a sense of agency. Researchers (Eick, 2002; Kelly, Gningue & Quian, 2015) have reported that science teachers experienced diminished professional satisfaction if they felt that they did not impact their learners learning.

1.2 Background of the Study

There is a concern with the ‘low’ and ‘poor’ quality of passes in physical sciences which continues to attract attention from government, academia, industry and civil society. Good performances by learners at the matriculation level in physical sciences is still low (Mudadigwa & Msimanga, 2019) with severe gaps in knowledge being identified. At the same time the number of learners doing physical sciences nationally is declining, while the number of passes above the 50% mark is lower than 50% of the total number of learners who sat for the examination (Table 1.1).



Year	No. wrote	No. achieved at 30% and above	% achieved at 30% and above	No. achieved at 40% and above	% achieved at 40% and above
2014	167 997	103 348	61,5	62 032	36,9
2015	193 189	113 121	58,6	69 699	36,1
2016	192 710	119 467	62,0	76068	39,5
2017	179 561	116 862	65,1	75 736	42,2
2018	172 319	127 919	74,2	84 002	48,7

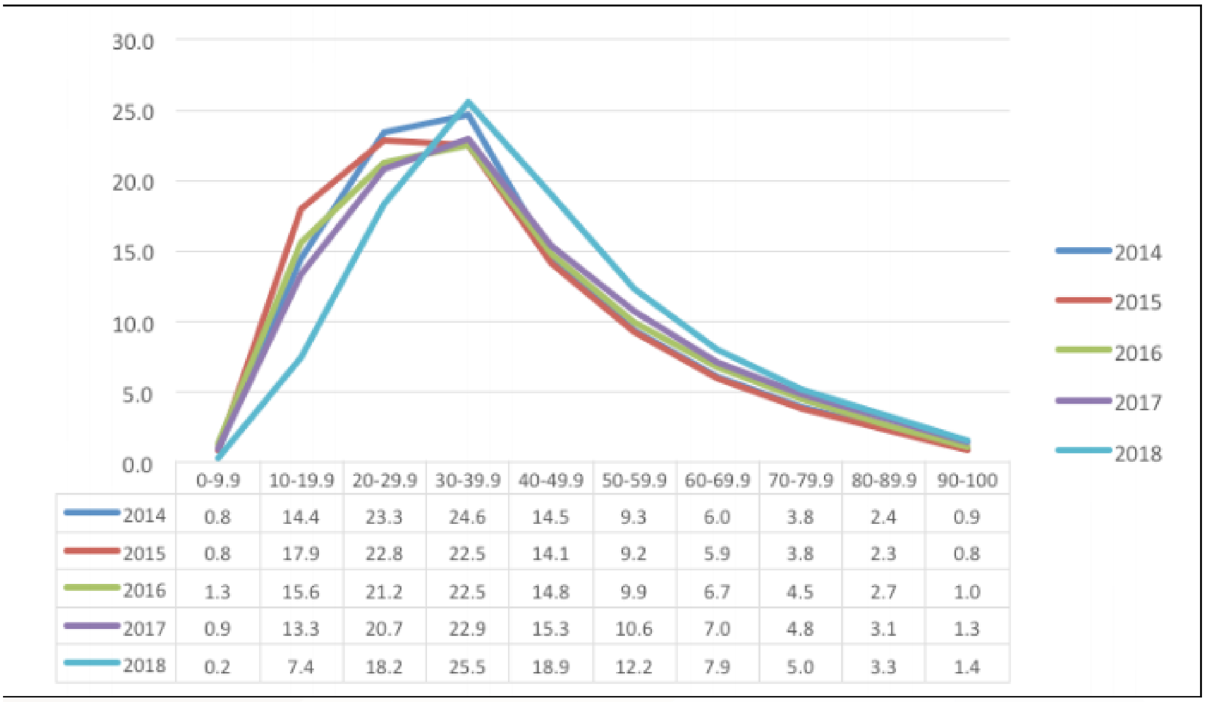
Table 1.1 Overall achievement rate in physical sciences (DBE, 2018:153)

Figure 1.1 is distressing considering government expenditure in education in comparison with other countries that are comparatively poorer than South Africa. According to World Bank Report (2016), the government spends about 18% of its budget on education. The country allocates a higher proportion of its budget towards education than the United

States, United Kingdom and Germany. Despite government increases in spending on science and mathematics education, there hasn’t been a corresponding increase in better learner performances in these subjects (Moloi & Chetty, 2010; Spaull, 2013). There is a lower number of learners with high enough scores who are able to proceed to university to pursue careers in science and technology. Fewer than 30% of learners managed to get marks of 50% and above while the majority are performing at the 30% which is the minimum mark by the South African standards. In the five consecutive years (2014-2018), the performance in physical sciences at the national level has not significantly changed/improved (see Figure 1.1). In Limpopo province where the study was conducted, the overall performance by learners in physical sciences has successively lagged all the provinces along with Eastern Cape (see Table 1.2) even though many learners who wrote the national examinations were coming from this province along with Eastern Cape and KwaZulu-Natal. The overall performance in physical sciences has been declining.

This situation will negatively impact the development of the country considering that economic and social welfare and overall improved living conditions are strongly connected to successful learning (Salavati, 2016). In South Africa, education has been thrusted as a developmental tool for redressing colonial imbalances created by apartheid as well as alleviating extreme poverty of the black majority who live in rural areas. It has been suggested that improved access to school and the attainment of good educational outcomes is corelated with the lessening of generational poverty as a result of increased income and ability to make a livelihood, and those positive effects grow generationally (Sabates, Westbrook, & Hernandez-Fernanez, 2012). On the other hand, poor passes have also been linked with diminished labour force participation, exacting a high economic toll on society (Muennig, 2006).

The large number of learners failing physical sciences are from rural schools since the majority of them have been reported to be ineffective (Moloi *et al*., 2010). It is reported that about eighty percent of South Africa’s dysfunctional schools are located in townships and rural communities (Mlachila & Moeletsi,2019). Meanwhile, children in rural schools are believed to be at risk of becoming school dropouts, and they have limited opportunities to participate in higher education (Abotsi *et al*., 2018).This view corroborates with the findings of Scott(2017) who documented that the majority of learners entering higher education institutions from rural secondary schools are underprepared to undertake studies at that level.



	0-9.9	10-19.9	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	90-100
2014	0.8	14.4	23.3	24.6	14.5	9.3	6.0	3.8	2.4	0.9
2015	0.8	17.9	22.8	22.5	14.1	9.2	5.9	3.8	2.3	0.8
2016	1.3	15.6	21.2	22.5	14.8	9.9	6.7	4.5	2.7	1.0
2017	0.9	13.3	20.7	22.9	15.3	10.6	7.0	4.8	3.1	1.3
2018	0.2	7.4	18.2	25.5	18.9	12.2	7.9	5.0	3.3	1.4

Figure 1.1 Performance distribution curves in physical sciences (DBE, 2018:154)

The Department of Basic Education (DBE) reports that learners are struggling with questions that requires them to reason by constructing scientific explanations (DBE, 2015). These concerns have been noted down in diagnostic reports of every national matriculation examination (see DBE, 2015, 2016, 2017, 2018), concluding that learners are not critical thinkers. The reports for the years 2014 to 2018 all said: “In many cases, candidates appear to cope only with questions involving application of routine procedures that have been taught in the classroom, and struggle with those that require more independent or creative thought” (DBE, 2018:15). The concerns have become perennial and with the suggestions being made nothing much has changed. Researchers (Hobden,

Province/year	2014	2015	2016	2017	2018
Western Cape	82.2	84.7	87.7	82.7	81.5
Eastern Cape	65.4	56.8	63.3	65	70.6
Northern Cape	76.4	69.4	82.2	76.6	73.3
Free State	82.8	81.6	93.2	86.1	87.5
KwaZulu-Natal	69.7	60.7	69.5	72.9	76.2
North West	84.6	81.5	86.2	79.4	81.1
Gauteng	84.7	84.2	87	85.1	87.9
Mpumalanga	79	78.6	81.3	74.8	79
Limpopo	72.9	65.9	68.2	65.6	69.4

Table 1.2 Provincial achievement rates in physical sciences (Business Insider,2019)

2016; Macufe, 2019; Stott, 2018) have identified that even extra teaching[3] has not translated to a better matric pass rate in physical sciences. Ramnarain and van Niekerk (2012) suggest that the problem emanates from the strong focus at school on solving problems by the direct application of previously learned algorithms. However anecdotal evidence reveals a heavy emphasis that the national examination place on tasks which requires learners to use learnt algorithms. Teachers appear to have mastered the format and routine type of questions from the recent past examination papers (Munsamy, 2014) and thus teaching and assessment is approached from this end. There are little variations in the manner the questions are set. Therefore, much time and effort are exhausted on solving quantitative problems while problems that require learners to engage with concepts in qualitatively manner are given scant opportunities.

Kriek and Grayson (2009) note with serious concerns about the state of physical science teaching in South Africa. The quality of teaching and learning in schools is poor (Desta et al, 2009) as reflected by the low and poor performances in the subject. A common thread among the research on the state of teaching and learning in South Africa is that teachers are inadvertently teaching to the examination (Macufe, 2019; Munikwa, 2016). The pressure on them is to pass as many learners as possible, at all costs. Provincial education departments are spending money on organising weekend schools and camps so that learners are coached and drilled for the final examination. Teachers are not teaching learners to understand or to become thinkers, but rather how to pass the final examination. The way the curriculum is structured, for example through pacesetters[4], means that teachers have to cover the work in the prescribed time so that learners are ready for the common assessment tasks or tests. Teaching is teacher-centred in order to meet the requirements of the curriculum (and not the needs of the learner). Such teaching practice fails short of positioning learners to construct knowledge and understanding through inquiry, investigation, problem solving, collaboration, planning, decision making, and connecting science to practical uses in the real world (NRC, 2013).Thus, they enculturate and entrench poor learning behaviours and constrain epistemic access. Consequently, meaningful learning does not take place. Therefore, many learners emerge from their study of physical sciences with serious gaps in their understanding of important topics (McDermot & Redish, 1999). This situation concurs with the findings of study by Ramnarain and van Niekerk (2012) which revealed that learners have a naive, superficial

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[3] Learners attend weekend schools, winter, autumn and summer camps held during the school vacation

[4] Pacesetter is a document that provides guidelines for the teacher to pace the progress of topics per term as per policy requirement.

and fragmentary understanding of scientific phenomena which according to researchers (Russ, Hammer & Mikeska, 2008) affects their mechanistic reasoning.

For example, the World Economic Forum reported in 2014 that South African learners ranked last in the performance of Mathematics and Science education. Research shows that science subjects in general are becoming less popular and interesting for learners (Osborne &Dillon, 2008; Saleh, 2012). Suggestions have been made as to how the subject should be taught to be meaningful to learners. What is clear from all the suggestions proposed and research is that teaching should be learner-centred (DBE, 2011; Msonde & Msonde, 2019). Within the science education literature, prominence has been given to the teaching of physical sciences through inquiry. Inquiry-based instruction is promoted in science education because of the need to have learners learn how scientific knowledge is constructed (Fogleman, McNeill, & Krajcik, 2011).

1.3 Rationale of the study

In order to provide high-quality learning opportunities, teachers need to create conditions for learners' meaningful and rigorous engagement beyond teacher talk and note taking. Therefore there is need to seek innovative instructional ways to engage learners in sense-making and co-constructing their own learning of science. There is evidence that learners are being taught in a superficial way which is deficient for encouraging integrated knowledge that permits learners to draw upon prior understanding to learn new ideas (Krajcik, Codere, Dahsah, Bayer, & Mun, 2015). In literature, engagement is considered to have behavioural, affective and cognitive components. (O'Toole & Due, 2015). Fredricks *et al.*, (2004) view behavioural engagement as participation in both academic and social activities associated with learning. Cognitive engagement is conceptualised as the 'expenditure of thoughtful energy needed to comprehend complex ideas in order to go beyond the minimal requirements' (Finn & Zimmer, 2012:102). Affective engagement refers to feelings of identification and belonging experienced by the learner in the learning setting (Appleton *et al*., 2006). These are generic features to instructional practices that have been found to support learning in any learning area. It has been suggested that learners make many interconnections in their developing brain that enable them to accelerate learning and development when teachers combine social, emotional, affective, and cognitive development together (Berger, 2020).

Recent reforms in science education highlight the need for learner-centred approaches to teaching in school curriculum policy in South Africa (Buma & Nyamupangendengu, 2020). At the same time inquiry-based instruction has been highly advocated in K-12 science education (Cobern *et al*., 2010). Thus, science education literature advocates the teaching of (physical) sciences through learner-centred and inquiry-based instruction. The focus of reforming instructional practices is not to pass as many learners as possible but to enhance the learning and retention of science concepts by learners.There is an emphasis to present an image of science "as both a body of knowledge and an evidence-based, model-building enterprise that continually extends, refines, and revises knowledge" (National Research Council, 2007b, p. 2). Instructional practices of science teachers should engage learners and target the integration of scientific practices and habits of mind, and are mostly endemic to science classrooms, such as opportunities for students to design and conduct scientific investigations, analyse, and critique scientific data, and construct scientific explanations and arguments must be part of the science curriculum (Mikeska, Shattuck, Holtzman, McCaffrey, Duchesneau, Qi & Stickler, 2017).

Emerging research evince that teachers are not using learner-centred approaches in teaching physical sciences (Msonde, 2011; Nsengimana, Habimana & Matarutinya, 2017), while Mugabo (2015) reports that teachers have a shallow understanding of inquiry-based instruction. On the contrary the study by Navy, Luft, Toerien and Hewson (2018) revealed that teachers in South Africa are mostly using teacher-centred instruction in physical sciences. Teacher-centred methods that utilize lectures and textbooks alone may not likely support learners to develop a deeper understanding of complex scientific concepts (Karacop & Doymus, 2013). It is also recorded that learners have misconceptions about the concepts they are learning making it challenging to have a clear understanding of the phenomena under study (Bell & Trundle, 2008; Zacharia, 2007). Therefore, the use of teacher-centred methods such as lectures (Craig, Michel, & Bateman, 2013) and textbooks (Bell & Trundle, 2008; Hoeling, 2011) as the primary source of instruction may not be efficient to engage learners in meaningful learning to resolve their alternative conceptions (McDermott & Shaffer, 1992) considering the poor quality of learning experiences reported in rural schools (Mlachila & Moeletsi, 2019; Opoku, Asare-Nuamah, Nketsia, Asibey & Arinaitwe, 2020). Such instructional practices have failed to create interest of learners in class activities, producing instead poor responses to the teachers' instructions, dysfunctional and disruptive behaviour and infrequent school attendances (Balfanz *et al.*, 2007).

To assist teachers in transforming their instructional practices to become engaging, learner-centred, inquiry-based, technology is being suggested as an alternative and potential resource. Some researchers such as Codrington and Grant-Marshall (2011) posit that "technology is a huge driver of change" (p.86) of instructional practice to accommodate learners' of diverse backgrounds. Technology is even considered to be adding new variables and changing the existing condition in contemporary classrooms whereby “we now have a triangle, student-teacher-computer, where previously only a dual relationship existed” (Churchhouse *et al*., 1984:28). Technology has the potential to support didactical moves (Svensson & Johansen, 2017) that are learner-centred oriented in physical science classrooms (Czajka & McConnell, 2019; DBE 2004), thereby recalibrating the existing teacher and learner engagement and relationships. At the same time Chigona and Davids (2014) report technology as a potential catalyst for changing teaching and learning practices that addresses both the cognitive and social-personal needs of learners. As a result, teachers need to find more resources or adopt and adapt existing potential curriculum resources (such as technology) and learn to use them to enhance their instructional practice.

Despite the calls and investment in technology, research suggests that teachers are not integrating technology into their instructional practices (Utterberg, Lundin, & Lindström, 2017). In South Africa, concern has been raised about the low uptake and how information and communications technology can effectively be integrated into schooling (Meyer & Gent, 2016). Padayachee (2017) reports that the uptake in secondary education has been slow, with schools restricting their pedagogical use to engage learners in meaningful learning. The use of technology has not reached its full potential in order to impact practice significantly. Technology use has not endenized to become common to instructional practice of physical science teachers. Even experienced teachers have been described as digital immigrants as far as technology integration in their classroom is concerned (Prensky, 2001). There is however great concern over the trend that beginning teachers also make little or no use of technology in their instructional practice (Tondeur, Roblin, van Braak, Voogt & Prestridge, 2017). For many in-service teachers who have acquired some degree of comfort in their teaching practice, teaching with technology provokes a possibility for a new equilibrium (Zbiek, 2001), the attainment of which entails disruption of the routine. This situation is also echoed by Laborde (2002:285) who opine that that the introduction of technology in the complex teaching system produces a perturbation which requires teachers to seek a new equilibrium. The presence of technology in the classroom disrupts the status quo and challenges the established norms and procedures of doing things in the classrooms (Fullan, 2007) and instructional decisions (Opfer & Pedder,2011) applied in teaching and learning.

So, there is a need for teachers to be responsive considering the evidence from research highlighting the efficacy and potential of technology to mitigate the perennial challenges that continue to plague to schools in rural areas. Responsiveness is a quality that characterises all living organisms in response to events or stimuli. It is a reflex action. Teachers need to be responsive to the stimuli brought by technology to transform their practice. Actually, collective responsiveness is necessary to improve teaching that has prioritises learners at the heart of professional learning. We concur with Kincheloe (2012) that collective responsiveness requires teachers with a willingness and responsibility to reinvent themselves via classroom inquiry and knowledge production. Teaching with technology or TPR is the sine qua non for the 21st century teacher.

1.4 Context of the Study

My desire to want to teach with technology was not informed by policy but the need to mitigate the challenges that I faced in my practice. The antecedent to my desire was my previous experience with learning with technology in university. Before me was presented, in the form of ICT, an array of cognitive resources and materials for creating learning environments with a potential to overcome the limitations and scope of instructional technologies now being used in schools in rural areas. Nevertheless, my professional training was inadequate to support meaningful utilisation of technology to "promote learning in a pedagogically grounded manner" (Sipilä, 2014:235). Means and Olsen (1994) asserted that:

> What technology will not do is make the teacher's life simpler. The kind of teaching and learning ... [that regularly integrates technology] requires teachers with multiple skills to thoughtfully select and integrate the technology into educational practice (p.18).

Despite my master's degree in science education, I lacked a practical knowledge of teaching with technology. I had no experiential knowledge of teaching with technology though I had watched and experienced lecturers using technology in teaching when I was in university. However, Mishra and Koehler (2008) proposed through their model TPACK, the knowledge domains required by teachers for them to successful integrate technology into their practice. They further assert that TPACK is developed in practice as teachers use technology in their classes. Unfortunately, Krumsvik (2008) argued that it was a challenge for teachers to develop competence in using technology through conventional training because new knowledge and practices are difficult to adopt when separated from the authentic teaching situations. At the same time, researchers (Hyo-Jeong & Kim, 2009) argue that typical once-off training workshops are the most available professional development for in-service teachers. In these trainings, technology is studied in isolation from pedagogy and subject content, making it a challenge for teachers to integrate technology effectively into their classroom practice. Teachers are only provided with knowledge of technology minus the pedagogical knowledge for teaching with technology within the particular contexts in which they work.

The workshops or training seminars that I have attended unfortunately did not address the challenges that I faced in my practice. All of the workshops that I attended were designed to develop the content knowledge (CK) for teachers in rural schools. There is research to suggest that physical sciences teachers lack content knowledge in South Africa (Kriek & Grayson, 2009; Taylor, 2008; Manqele, 2017). Scott, Mortimer and Ametller (2011) however argue that for the effective implementation of teaching and development of scientific conceptual knowledge, teachers need to be experts in the CK. Researchers (Seeley, Etkina & Vokos, 2018) have identified the different kinds of CK (i.e., foundational content knowledge and elaborative content knowledge) that teachers need to have to help students learn.Foundational content knowledge is the knowledge of facts,theories,principles,methods,skills,terminology and modes of reasoning that are essential to the understanding of the subject.Elaborative content knowledge is the knowledge that teachers can use to compensate for lack of content knowledge if they are skilled in science practices.Thus, providing training workshops for developing knowledge for teaching with technology (TPCK) to teachers is secondary and not urgent considering the need to develop the content knowledge of teachers is necessary. However, on the other hand, teachers need to be up to date with new and innovative teaching approaches that integrate technology to develop scientific conceptual knowledge to prepare learners for the examination (Jeff, Marshal, Smart, & Alstone, 2017). They need to develop a robust pedagogical content knowledge (PCK) enables them to move from ‘knowing what to do’ (knowledge manifesting in planning), to ‘doing what you know’ (knowledge manifesting in classroom enactment) with the intention to benefit learners’ understanding within their local context (Mavhunga & van der Merwe, 2020). Such is the conundrum that some teachers are facing: the challenges that are given preference for professional development are not the same challenges affecting their practice. To address challenges that affect their practice (including how to integrate technology into teaching), researchers (Arrifin, Bush & Nordin, 2018) advice that teachers should incorporate action research in their classrooms. Researchers (Burke & Kirton, 2006; Gray & Campbell-Evans, 2002; Henderson, Meier, Perry & Stremmel, 2012) concur that teachers can execute their role effectively when they become (action) researchers.

By researching how to integrate technology into my practice I intended to develop models of utilisation through practice by “turning confusions into questions, trying something out and studying the effects, and framing new questions to extend one understanding”

(Feiman-Nemser, 2001:1030). This is critical as the need to promote effective, efficient and enjoyable learning that is facilitated and/or enhanced by the technologies available to the teacher, the learner and the school (Kirschner 2015) is urgent. As suggested by Gonczi, Maeng, Bell and Whitworth (2016) practice is desirable because it fosters automaticity and psychological ease which can increase the likeliness of teachers to incorporate and make the use technology in their practice a regular and standard practice. Practice also eliminates the fear of taking risks in the classroom. It serves as a catalyst for teachers to experiment and explore new alternatives thereby reframing their practice. According to Thierry *et al*. (2009:1), ICT integration is defined as the appropriate, consistent and sufficiently regular use of ICT that produces beneficial changes in educational practices and improves students' learning. Thus, the integration of technology into teaching and learning requires a developed repertoire of pedagogical and technological skills or what Mavhunga and van der Merwe (2020) calls prudent practical wisdom (p.66) that provide specific guidance as to how teachers can learn to integrate technology effectively in the classrooms.

Studies (Chan & Yung, 2015; Mavhunga & van der Merwe, 2020) have revealed how the practical wisdom of teaching develops in practice but not many studies have researched on how teachers in schools in rural areas develop the *phronesis* of teaching with technology, especially in the absence of formal professional development.

1.5 Aim of the Study

The use of technology in teaching and learning is a global phenomenon affecting our classrooms in direct and indirect ways. Teachers are not excused in this phenomenon. The pervasiveness of technology is insidiously pushing for technology in teaching and learning to become a *de facto* curriculum material. The boundary between technology in the world outside the school and the world of the school is becoming blurred. Technology is now an *invasive species* in the school ecosystem which is changing the social and learning milieu. Its presence in our classrooms is no longer obtrusive to teaching and learning especially to the present generation of learners. One outstanding characteristic of the present generation of learners is that they were born and are growing up enmeshed in technology. They are digital-cultured. Therefore researchers have called for reforms in science teaching advocating for technology-supported teaching practices that foster deep and integrated understanding of important ideas, engaging all learners in learning science, supporting all learners in developing important scientific practices and 21st century competencies, supporting all learners in using their knowledge in science, mathematics and engineering arts to solve problems and making decisions and think innovatively

(Krajcik, 2016). An alternative to the use of and dependence on textbooks is thus being suggested in the form of technology. Technology is becoming the new textbook for the 21st century classroom with a potential to transform the way teaching and learning is currently occurring in science classrooms. It has been observed that many schools in rural areas are exposed to the teaching and learning challenges that can be mitigated by technology use (Nkula & Krauss, 2014; Sánchez & Salinas, 2009). In order to successfully integrate technology into their practice, teachers are required to develop a robust technological pedagogical reasoning (TPR) (Smart, 2016). TPR develops in "ecologically embedded settings of real classroom practices, real students and real curricula- elements that teachers define as central to their profession" (Confrey, 2000:100). However, in the absence of formal professional development, teachers need to carry out their own action research on how they can integrate technology into their practice. Teaching with technology is "wisdom of practice" (Shulman, 1986) which is developed in practice and thus teachers are challenged to find idiosyncratic ways that each technology shapes their practice. The way that technology shape and affect each individual teacher is unique and context dependent. Thus, the general 'spray and stick' approach to professional development (PD) where teachers are usually *sprayed* with information with the hope that it will *stick* in their minds commonly used to capacitate teachers will not be effective in developing competence in their use of technology. According to Huang, Spector, and Yang (2019) competency is a collection of related knowledge, skills, and attitudes (KSAs) that enable a person to perform a particular task. To engender digital competence, PD should involve activities that address KSA in the context of real classrooms. Smith-Senger (1999) suggests that the effect of decontextualised, in-service PD is "fragile and transient (p. 201).

Therefore, the aim of this study is the digital immigrant teachers' use of computer simulation as a technological pedagogical reasoning (TPR) tool in the teaching and learning of electromagnetism. In that regard Smart's (2016) model of TPR (figure 2.7) is used as theoretical framework (see section 2.8). Can the sub-processes of this model be applied to describe the teacher's instructional practice in a resource-constrained context? Is the model malleable to address all the different contexts of teaching, especially in developing countries where the challenging working conditions impact on teachers' instructional effectiveness, sense of accomplishment, and commitment to the profession (Isenbarger & Zembylas, 2006)?Can the model be employed to develop a robust understanding of content, ways to effectively represent scientific ideas to enhance understanding and pedagogical approaches to engage learners in classroom activities? Answers to these questions are pragmatic and have implications for professional development especially for teachers in contexts still to integrate technology in ways that allow for professional growth as well as to engage learners in co-constructing their own learning of science in innovative ways. To seek answers to these questions, the study aims to employ action research as the methodology. As suggested by Avgitidou (2020) the key inherent tenet of action research is that pragmatic knowledge to address contextual needs of teachers can be generated by testing an action or intervention (in this case the use of technology as informed by Smart's model) and then reflecting upon it in a community of practice.

1.6 Significance of the study

This study is significant for teachers, school managers, and teacher educators.

Johnson, Monk, and Hodges (2000) liken the environment in South African low-quintile schools to that of a desert, where few pedagogies can survive, as opposed to the tropical rainforest of the classrooms found in developed countries. Extant research and anecdotal evidence suggest that there are myriad barriers that teachers in rural areas have to contend with in their work (De Lange, Mitchell, Moletsane, Balfour, Wedekind, Pillay & Buthelezi, 2010; Gardner, 2008; Opoku et al., 2020). In these environments characterised by lack of basic infrastructure, materials and resources, physical science teachers are constrained to orchestrate the least kinds of teaching practices possible. Their pedagogical reasoning-the ability to plan, design, implement and evaluate meaningful learning experiences for learners, is severely hampered in ways that would not allow for professional growth. Luft and her colleagues (2003) assert that science teachers pedagogical reasoning is the most affected by barriers especially in resource-deficient contexts. They suggest that science teachers encounter have added challenge of "implementing inquiry lessons, planning and managing laboratory instruction, and fostering an understanding of the nature of science among students" (Luft, Roehrig, & Patterson, 2003:79).Teachers are often operating in a position of isolation, which compounds the several difficulties they face when trying to be innovative and improve their teaching practice in ways different from how they were taught. Most teachers teach alone in isolated classrooms and there are no opportunities to observe other teachers or reflect on their own practices (Remillard, 2005). This study is significant for teachers in that it seeks to explore how the use of technology (computer simulations in this case) can aid/enhance the pedagogical reasoning process in a resource-constrained environment to implement learner-centred, inquiry-based learning. The research is important to determine and explicate how teachers transform their CK with the support of technology into powerful representations to support learning of different topics in physical sciences (Abell,2008; Aydin, Friedrichsen, Boz & Hanuscin,2014).

School managers need to encourage their teachers to conduct action research of their classes while also plan for professional development opportunities to capacitate teachers to carry out action research. Volk (2009) asserts that action research has been recommended as a necessary part of the professional portfolio and skills of teachers. Kincheloe (2003) envisions all teachers being researchers and urged that “teachers must join the culture of researchers if a new level of educational rigor and quality is ever to be achieved” (p.18). Therefore, this study will possibly provide suggestions to teachers on how to do action research in their classrooms to solve critical problems in their practice.

At the university level action research should be introduced to pre-service teachers at an early stage. Pre-service teacher education should provide experiences in action research both for academic and professional reasons Teachers need to develop research skills in order to carry out action research early in their careers. Kincheloe (2003) stated that “if students are not introduced to the power of practitioner [action] research during initial teacher training, chances are they will never be involved in it” (p. 37).

The findings from this study have significance in that they expand our knowledge about how individual teachers in resource-constrained contexts are learning to using technology to teach in their classrooms in the absence of formal professional development. This is critical considering the theory-practice divide that has been raised as a challenge among teachers (Mavhunga & van der Merwe, 2020). Data from this study can inform policy makers and administrators on how to plan professional development interventions for teachers on how to use technology in their classrooms in rural areas.

1.7 Research Questions

Guided by the theoretical framework adopted from Smart (2016), this study seeks to answer the following research questions:

1. Can the sub-processes suggested by the model of technological pedagogical reasoning (TPR) be used to describe a teachers’ technological pedagogical reasoning when using computer simulations (CS) in the teaching of electromagnetism to students in grade 11?
2. What are the cognitive, affective and conation experiences of learners when the selected computer simulations are used in the teaching of electromagnetism to students in grade 11?

1.8 Definition of Terms

For the purpose of this study the following definitions will be adopted.

Action research

Action research is defined by Arif (2002:43) as "a form of research in which teachers do research in their own classrooms for the purpose of improving practice."

Teaching and learning

According to the Higher Education Quality Committee (HEQC) (2002:14) framework for improving teaching and learning in South Africa, the concepts teaching, and learning should not be separated; they are two sides of the same coin, an interactive process that requires the active cooperation of both learner and teacher. The manual further explains that teaching might be the inspiration and facilitation of learning, whilst learning is explained as the conceptual and cognitive change as a result of direct or indirect interaction with a more knowledgeable and experienced other. For the purpose of this study, teaching and learning are defined broadly to include not only the actual teaching and learning within classrooms but also procedures and activities that teachers undertake to provide for learners the conditions necessary for learning to take place, that is, in terms of knowledge and skills development.

Technology

Kelley and Ringstaff (2002) broaden the view to define technology as a variety of digital devices, from computers to digital cameras to software. For the purpose of this study, the term technology will include all devices that are connected to and with the working of computers such projector, white screen application software, and digital devices, such as digital cameras, digital microscopes, and digital video cameras. In addition, for some of the devices were used in this study the focus was on computer simulations.

Computer simulation

A computer simulation is defined as a "computer-based model of a natural process or phenomenon that reacts to changes in values of input variables by displaying the resulting values of output variables" (Spector *et al.* 2008:457).

Technological pedagogical reasoning (TPR)

According to Shulman (1987), pedagogical reasoning and action comprises a cycle of cognitive actions that a teacher undergoes during the teaching process include: comprehension of subject knowledge, transformation of subject knowledge into teachable representations, instruction, evaluation of students' learning and teacher performance, reflection and new comprehensions. Therefore, TPR is the integration of technology in carrying out pedagogical reasoning and action.

1.9 Summary

This introductory chapter describes the genesis of the study. It outlines the background and statement of the problem, objectives, research questions, significance, and finally key terms/phrases of the study.

Chapter 2 Literature Review

2.0 Introduction

The purpose of this literature review is to ground this study in a strong theoretical base while at the same time seeking to fit this work with what has already been done. Therefore, a discussion on the instructional practices adopted by teachers to promote the learning of physical sciences will be made and how it relates to this study.

2.1 Instructional practices in physical sciences

Instructional practices are crucial to learning in any subject. Generally, these are the various and idiosyncratic ways in which teachers interact with learners to engage procedurally and conceptually with content. They are pedagogical mechanisms intended to position learners in the space where they can engage and interact with the designed learning experiences successfully. Under this process, teachers need to design the tasks, environments and resources that enhance learners' experiences in engaging with scientific concepts as outlined in the curriculum in a manner that "help students learn to think and act like scientists" (National Research Council, 2007b, p. 13). In other words,
an instructional practice is the planned curriculum for a particular context.

Science education literature has categorised the instructional practices adopted by teachers as either teacher- or learner-centred. However, these instructional practices can be conceptualised as falling on a continuum with the two approaches occupying the opposite ends of the continuum as shown in Figure 2.1.

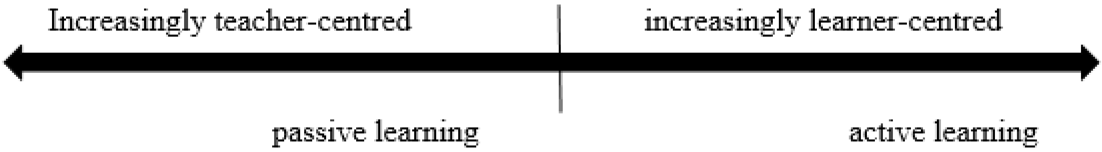

Figure 2.1 Continuum of instructional practices

From a developing country perspective, Okebukola (1997) succinctly describes the scenario of what happens in teacher-centred science lessons in Nigeria when he observes that:

> The science class begins with a brief chat as an introduction. This is followed by the reading of notes by the teacher to the students (learners). At the end of the lesson, the left-over notes on the topic is given to the class captain (prefect). In the free time, the class captain (prefect) copies the notes on the board or models the teacher by reading the notes for other students (learners) to copy (p.32).

From a developed country perspective, Martin Haberman (1991) has provided further details of activities in a teacher-centred approach as follows:

> Certain acts constitute the core functions of (urban) teaching at all levels and in certain subjects: giving information, asking questions, giving directions, making and reviewing assignments, monitoring seatwork, giving and reviewing tests, assigning and reviewing homework...Taken separately, they may be nothing wrong with them. Taken together and performed to systematic exclusion of other acts, they are the pedagogy of poverty--what teachers do and youngsters expect and what parents, the community, and the public assume teaching to be (p.290).

Haberman (2010) has rightly referred to the teacher-centred approach as the pedagogy of poverty. In both Okebukola and Haberman's descriptions I can characterise teacher-centred teaching as a 'sage on the stage' model of instruction, where teachers often and primarily present facts, concepts, and/or procedural knowledge in a way that relegates the learner to a passive observer (Handelsman et al., 2004). In such an approach to teaching, the teacher dominates the classroom activities to the exclusion of learners and in the teaching of physical science, the main focus is getting the learners to perform well on district or national assessments instead of assisting learners to construct knowledge and understanding of concepts. While others have reported advantages of this approach especially in university settings (Emaliana, 2017), there is still calls in higher education to "ensure that the programmes are delivered in a way that encourages students to take an active role in creating the learning process and that assessment of students should reflect this approach" (European Students Union, 2015, p.12). Thus, even in higher education, learner-centred approaches are being advocated to improve learning outcomes. One would then argue that at the secondary school level where learners need to develop a solid understanding of the rudiments of the subject, a learner-centred approach would be more appropriate and beneficial. What makes the approach more appropriate is the context and conditions of learning in schools in rural schools which affect the quality of learning. There is an increasing trend in the world that learning should focus more on the learner and to back up this with the necessary changes in policy and practice (Gover, Loukkola & Peterbauer, 2019).

The scenario described by Okebukola (1997) has also characterised classrooms in South Africa (see Ogunniyi & Rollnick, 2015; Zenda, 2017) and other developing countries (Hardy,2019). The practice has been reported to be prevalent in the majority of schools that are found in rural areas (Hardy,2019; Manqele, 2017; Ojo & Adu, 2017). Evidence attests to such practices as still dominating in most science classes globally (Bahou, 2017; DeCoito, 2006; DeCoito & Myszkal, 2018; Weimer, 2012; UNESCO, 2010). As depicted in Figure 2.1, learners are inadvertently forced to be passive recipients of information which is not a characteristic of today's learners: a generation of digital natives who are encultured with technology (Prensky, 2001).

A synthesis of literature review reveals organic differences that contrasts teacher-centred instruction from learner-centred instruction. Table 2.1 contrasts these two approaches.

	Teacher-centred instruction	**Learner-centred instruction**
Focus	Content/syllabus	Learners

Aim	Examination	Understanding
Learning theory	Behaviourist	Constructivism/Connectivism
Metaphor for learning (Sfard, 2006)	Acquisitionism	Participationism
Learning environment	Closed	Open
Degrees of freedom	Limited	Unlimited
Role of teacher	Directs learning/sage on the stage	Facilitates learning/guide on the side
Teachers’ view of learners	Empty vessels to be filled with information/knowledge	Individuals capable of constructing knowledge
Teachers’ concept of knowing	Product	Process
Teachers’ perceptions of their role in curriculum development	Curriculum transmitters	Curriculum makers/developers
Use of curriculum materials	Chalk and talk largely dependent on textbooks	Not restricted to the textbook only but other curriculum materials like the internet
Relation to technology (Prensky, 2001; Starkey, 2010)	Digital immigrants	Digital saviours
Teacher self-efficacy (Appleton & Kindt, 2002; Bandura, 1997)	Low sense of self-efficacy	High sense of self-efficacy
Positionings	Tend to be fixed	Are not fixed but tend to be changing
Professional development approach	One-shot workshops, seminars, etc	Long and sustained approaches that includes action research, lesson study

Table 2.1 Differences between teacher-centred and learner-centred instruction

The organic differences between instructional approaches have implications on how both the teacher and learners are positioned to engage procedurally and conceptually with content. Learners are inclined to think, feel and act differently depending on the instructional approaches used by teachers to engage them (Corso, Bundick, Quaglic, & Haywood, 2013). Thus, instructional approaches adopted by teachers have been described as determinants to the successful learning by learners than anything else that happens in the classroom (Delen & Krajcik, 2016). They influence the 'habitus'[5] or 'strategies of action'[6] learners will adopt which will determine their success or failure in learning Physical Sciences. The approaches to learning adopted by learners are not their characteristics but rather a "dispositional phenomenon" actuated more by the demands of particular learning environments (Rhem, 1995:200). Learners can either adopt surface or deep approaches to learning depending on the context in which learning is occurring. Learning behaviours are not static dispositions inherent in learners but behaviours associated with the learners' experiences, schooling processes and the broader contexts that shape learning. From the argument presented one would argue that learners adopt surface approaches to learning in teacher-centred classrooms. Conversely learners would likely to adopt a deep approach to learning in learner-centred classrooms. According to Gilmer (2010), the teaching practices teachers employ in teaching science classes affect the learners' understandings and their conceptions of science.

Despite reform efforts that tend to motivate teachers to reduce the time they spend lecturing and to engage learners more directly in the learning process by adopting learner-centred methods that integrates digital technologies (Garrison & Akyol, 2009), teacher-centred practices have become a deeply entrenched practice in schools in rural areas and has become the accepted norm(Zenda,2016). In the end, teachers tend to be recalcitrant resisting any attempts to changes in their routinized teaching practices (Henderson & Dancy, 2007).

2.2 Why teachers prefer traditional methods.

Why do teachers prefer traditional methods for teaching physical sciences despite convincing evidence from science education literature of the deficiencies of such approaches to enhancing learners' understanding of scientific concepts and develop critical thinking (Stohlmann, Moore, & Roehrig, 2012)? Are teachers aware/informed of the deficiencies of traditional teaching methods? What incentives can motivate teachers to change their instructional approaches from teacher-centred to learner-centred? Answers to these questions are critical in order to deepen the reform of class teaching and improve the quality of learning of physical science from its present state, especially in schools in rural areas. Despite the national and provincial governments reform initiatives in education to provide adequate, rigorous and engaging instruction to learners, traditional teaching practices are still prominent in schools. There is resistance to change by teachers

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[5] Bourdieu (1991), defines *habitus* as a "set of dispositions which incline agents to act and react in certain ways."

[6] Swidler (1986) defines strategies of action as "persistent ways of ordering action through time" (p. 273).

to adopt research-based teaching methods that offer meaningful educational experiences to learners, even though change can have positive effects for teachers overall (Emo, 2015). Lorsbach and Tobin (1997) admit that “traditional teaching practices are sometimes difficult to discard” (p.6). There is an unwillingness among teachers to adopt learner-centred approaches advocated by research-based reforms (Fullan, 2007). These practices have been institutionalised and regarded as legitimate, and they have become “the way we’ve always done things here” (Lockton & Fargason, 2019:470) in schools. Thus, schools are concerned with prioritising the maintenance of cycles and structures, rather than being open to change (Handy, 1995). Consequently, schools can be uncomfortable places for creativity and innovation even though there are well recognised exceptions to the status quo (Davies, 2013).

Tabulawa (1997:312) likens the resistance and unwillingness of teachers to change and adopt research-based reforms to “tissue rejection” arguing the expectation of a paradigm shift in education through top-down directives was always destined to fail. Indriganti (2018) concurs that this inertia is difficult to overcome and might call for multi-pronged, targeted action across the institutional hierarchy. One of the unwanted consequences of this inertia is that the quality of science teaching and learning has suffered and remained low as a result of traditional teaching practices. These traditional practices have contributed to a rising chorus of critiques of how this subject is taught (National Research Council, 2010). John Dewey (1910) has lamented over the manner science is taught over a century ago. He writes:

> Science teaching has suffered because science has been so frequently presented just as so much ready-made knowledge, so much subject-matter of fact and law, rather than as the effective method of inquiry into any subject-matter. (p.104)

A number of reasons have been suggested as to why teachers are deeply entrenched with traditional methods of teaching, despite their inefficiencies in positioning learners with epistemic agency to promote effective learning. A certain pragmatic value has been reported by teachers regarding teacher-centred practices, but the epistemic value of such practice is contested and has largely remained elusive (Artigue, 2002).

Pleschovà and McAlpine (2016) state that learner-centred methods can be difficult to orchestrate by science teachers especially in developing countries. According to Aliusta and Özer (2016), shifting from teacher-centred to learner-centred instruction is a complex change process, which requires focusing both on the visible components and teachers. The difficulty arises from basically four factors that we have identified:

1. The deficiency/lack of quality (technological) pedagogical content knowledge (T/PCK) (Rollnick, Bennett, Rhemtula, Dharsey & Ndlovu, 2008),
2. The lack of teaching and learning materials exacerbated by overcrowded classes (Dudu, 2015; Makgato & Mji, 2006; Kriek & Grayson, 2009),
3. Teachers' concern about timely completion of the curriculum and getting credit for good examination results (Munikwa, 2016),
4. Pre-service teachers learning about teaching through observing and participating in activities that are done in the teacher education courses at university (Nyamupangedengu, 2016). Lortie (1975) describes this way of learning about teaching as "apprenticeship of observation". (p.28)

As a result of insufficient PCK, Qhobela and Moru (2014) have observed that science teachers in Lesotho have a narrow understanding of what constitute learner-centred teaching. This understanding is manifested in their pedagogical practices which reveal the deficiencies. This situation has also been confirmed in science teachers from Canada (DeCoito & Myszkal, 2018). These studies revealed that there is a gap between what teachers say constitute learner-centred teaching and what was happening in the classrooms. There is a mismatch between theory and practice. Teachers claimed to understand student-centred methods but in reality, they performed traditional roles where most class time is devoted to transferring knowledge with the textbook being used as the primary source of instruction (Aliusta & Özer, 2016; Mtika &Gates, 2010). Findings from the study by Nsengimana, Habimana and Mutarutinya (2017) revealed that learner-centred teaching is limited and reduced to oral questioning, group discussions, experimentation or doing exercises. Salavati (2016) reports that teachers with insufficient PCK seldom depart from teaching practices that are dependent and influenced by the textbook. Textbooks not only present the content knowledge that learners are supposed to learn but also suggest a teaching methodology for the teacher of how to treat the content. The approach to treat the content is suggested by the textbook author does not regard the background of learners nor the context of learning.

Many schools in rural areas suffer from the lack of basic teaching and learning resources which has remained a legacy of apartheid in South Africa. This deficiency has remained a perennial problem with low-quintile schools (Stott, 2018). Schools in rural areas in Limpopo are operating with a lack of basic textbooks, laboratories, science materials and equipment, lack of classrooms and computer rooms, no internet and few qualified science teachers (Sethusha, 2015; Zenda, 2017). At the same time, it has been documented that in many developing countries they have large teacher/learner ratio (Caillods &

Postlethwaite, 1989, Dahar & Faize, 2011). As a result of large classes, Thanh (2010) identifies this situation as one of the principal and motivating reason why teachers maintain the traditional teacher-centred approach in developing countries. Researchers have indicated that implementation of learner-centred approaches in the classroom in developing countries is problematic (Chisholm,2000; Chisholm & Leyendecker, 2008).

Science education literature substantiates that the lack of material resources and equipment seriously incapacitates the teaching and learning of science-related disciplines (Kasembe, 2011; Tesfaye & White, 2012). Resources provide structural capital for establishing professional standards and meeting them through purposeful actions (Allensworth, Ponisciak, & Mazzeo, 2009). Their deficiency contributes to the teaching of science in traditional ways that constrict the learners' opportunities to engage in science practices and processes, critical in developing a deep conceptual understanding of core science ideas. The cramped conditions created by large classes coupled with an under-resourced teaching and learning environment with an inflexible schedule make a learner-centred approach a mammoth task to implement (Davis & Broadhead, 2007:205). The lack of resources in low-quintile schools has prompted other researchers to suggest that teacher-centred approaches as a solution (Stott, 2018). While this suggestion is ideal, it is not congruent with current emphases in teaching and learning. From a constructivist perspective, learners are rarely positioned with the power to shape the knowledge and practices of their classroom community in teacher-centred classrooms (Stroupe, 2014).

Munikwa (2016) reports that teachers are interpreting the curriculum from an examination-focused perspective, incognito. This is rather forced insiduosly than intentional. Their teaching is focused on preparing the learners for examinations (teaching to the test) as opposed on conceptual understanding or creative thinking. Teachers said that they are not teaching learners how to access knowledge or to become thinkers, but rather how to pass examinations (Macufe, 2019). This focus on the grade 12 class to get good matric results means teachers have to rush through the curriculum to cover all the topics and ensure that learners write weekly tests on the topics. This is as per guidelines set by the districts. In a study by Zenda (2016), teachers revealed that if they adopted other teaching approaches other than teacher-centred, they will not be able to finish the syllabus in time for the examinations. Therefore, they (teachers) are preoccupied with the timely completion of curricula so that they can have time to drill the learners for the examinations. Teachers are thus pressured to cover the curriculum outcomes because of the schedules and administrative expectations put in place by the department. Stecher and Barron (2001) found that the teachers changed their classroom behaviours/activities to meet the targets of the examination. According to Chavunduka (2005), everything else outside the syllabus tends to be seen as "noise" that must be ignored (p.47). Teachers work to develop lessons that would deliver ideas specific to the examination. Confirmed by Buabeng *et al*., (2015), in examination-driven education systems, teachers spend a large amount of their time preparing learners for assessment. This preparation has even resulted in schools offering weekend or holiday lessons (Zenda, 2016). At the same time, the physical science curriculum can be viewed as "a mile wide and an inch deep" (Kim, 2017:312). It has been described by teachers as notoriously long especially for grade 11 (Kriek & Grayson, 2009). The physical science curriculum has been considered too congested and content heavy (Mudadigwa & Msimanga, 2019). If the syllabus is judged to be too long by the majority of the teachers, this perception may lead to rushed content knowledge coverage (Munikwa, 2016). Such a scenario may result in surface treatment of the content knowledge, creating a lack of deep understanding of concepts by the learners. School authorities and teachers who derive their credit from examination results would do all they can to maintain their credit (Munikwa, 2016).

Finally, another reason why teaching is dominantly teacher-centred emanates from the education that pre-service teachers receive in their training institutions. Teacher education programmes are largely conducted through large didactic lectures (Hall & Ivaldi, 2017; Gunes & Baki, 2011; Mangan, 2011); hence, these serve as their models eventually in their practice (Schweisfurth, 2011). This idea is supported by Adamson *et al*. (2003), arguing that new science teachers do teach as they were taught. Etkina (2010:3) advances the same notion that teachers tend to teach in the way they were taught. Therefore, an attempt to teach in ways other than how they were taught can be exceedingly difficult for teachers (Windschitl, 2003). According to Bourdieu's (1993) theory of social reproduction, a social system moulds people. Therefore, the system tends to reproduce itself; however, similarly to biological evolution, variation can occur (Gilmer, 2010). Because of these variations and other factors, researchers have asserted that teacher-centred practices are the main impediments to high quality learning (Biggs & Tang, 2007; Ramsden, 1992). Teachers who practice teacher-centred teaching tend to rely heavily and uncritically on textbooks (Lee & Luft, 2008) as they are incapable of orchestrating innovative teaching strategies. As suggested by Tallvid (2014), the textbook presents the teachers with well-framed, unquestioned, sequential organization of educational practice. As a result, they may not necessarily recognize the weaknesses of textbooks thus failing to make appropriate modifications that are necessary to helping learners achieve the learning goals.

2.3 Learner-centred inquiry-based instruction

Science education literature treats learner-centred and inquiry-based instruction separately. There is dearth of research that explores explicitly learner-centred and inquiry-based instruction combined in a developing country context, especially from a rural perspective. A variant of this approach is the Ambitious Science Teaching (see Windschitl, Thomposon & Braaten, 2018) which require that teachers respond to what learners do as they engage in problem solving performances, while holding them accountable to learning goals that include procedural fluency, strategic competence ,adaptive reasoning and productive dispositions or Responsive Teaching (see Robertson, Scherr & Hammer, 2015) which is the process of catering for the individual needs of the learner that arises from any learning activity to support the learners' understanding and growing independence. However, in this study, I want to combine the two practices into one and develop a tentative definition of the approach. Research evinces the benefits of both approaches to the learning of physical sciences. Hence, it is necessary approach them as the two sides of a coin. In order to define learner-centred inquiry-based instruction comprehensively, I need to individually define each of these two approaches.

2.3.1 Learner-centred instruction

There are various conceptions of what learner-centred teaching is in science education literature and no attempt will be made to capture the nuances thereof in this study. In general, the term implies an instructional approach that focuses on the needs of individual learners inclusive of their prior experiences (knowledge, skills, attitudes and beliefs) that they bring to the learning situation combined with an emphasis on effective teaching practices that have been called "culturally responsive", "culturally appropriate", "culturally compatible" and "culturally relevant" (Ladson-Billings,2014:74), "diagnostic teaching" (Bell *et al.*, 1980:142), reform-based or constructivist or reflective teaching (Cobern, Schuster, Adams, Applegate, Skjold, Undreiu, & Gobert, 2010; Van de Grift, 2014). Therefore, learner-centred instruction is responsive pedagogy.

The emphasis on learner-centred instruction is informed by at least three rationales: (1) learners are not passive but active agents in the world where they live (James, Jenks, & Prout, 1998; Corsaro, 1997); b) learners' participation is foundational to their learning according to constructivist theories (Avgitidou, 2014); and c) learners should be proactive in matters that concern them (Lansdown 1994). Any attempt to plan for teaching while ignoring these rationales will be akin to treating learners as thinking machines.

Extant and recent literature is replete with evidence of the benefits of learner-centred instruction. To realise such benefits the South Africa school curriculum advocates the need for transformed instructional practices which are learner-centred (DBE, 2011). The

Curriculum and Assessment Policy Statement (CAPS) mandates teachers to move beyond transmission-based pedagogies characterized by rote learning and drill-and-practice activities toward learner-centric pedagogies that develop higher-order cognitive skills such as identifying and solving problems using critical and creative thinking (1.3. d general aims of CAPS) (DBE, 2011). The physical science curriculum further emphasises the teaching of the subject through inquiry (DBE, 2011). This methodology is consistent with the global focus on science teaching (Capps, Shemwell & Young, 2016; Plummer & Ozcelik, 2015; Srisawasdi & Panjaburee, 2015). Thus, the approach to teaching physical sciences advocated is learner-centred, inquiry-based instruction. Through such an instructional approach, learning becomes:

- **P**ersonal – learners develop a need to know and are driven to figure out what is going on,
- **A**ctive – learners are involved in **exploring, examining,** and **explaining** how and why phenomena occur,
- **S**ocial – learners able to form relationships between themselves and the teacher (There is a corpus of literature suggesting links between strong teacher–learner relationships and engagement (Antrop-González & De Jesús, 2006; Cothran & Ennis, 2000; Hantzopoulos, 2013),
- **H**olistic – the focus is on the development of the whole learner and not only on the cognitive aspect but also the affective and the conative aspects,
- **I**ntegrated- links of concepts in physical sciences with other subjects.

It is thus evident that the preferred epistemology of physical science teaching in South Africa is predominantly constructivism. Through constructivist approaches, learners are thus engaged productively in knowledge constructing processes that does not resemble the linearity of a line of best fit in a correlation graph. I concur with Naiser *et al*., (2004) that good teaching is not about making learning easy (so that as many learners can pass) but about making it active and engaging for all learners to pique their interest.All learners should be proficient in science irrespective of whether they choose to pursue postsecondary studies in science and at the same time develop the 21st century skills (such as critical thinking; problem solving; creativity; collaboration; self-directed learning; scientific, environmental, and technological literacy) (Howard-Brown & Martinez, 2012) which have been identified as necessary for navigating this technology-driven society.

2.3.2 Inquiry-based instruction

To understand what learner-centred, inquiry-based instruction is, I need to define what inquiry is. Smithenry (2010) suggests that the term inquiry has no clear-cut meaning; it is an elastic one which is stretched and twisted to fit diverse paradigms to which different people subscribe. Its use in literature and different curriculum documents is not uniform. It is liable to be populated with different meanings. However, according to the National Research Council (NRC) (1996):

> Inquiry is a multi-faceted activity that involves making observations, posing questions, examining books and other sources of information to see what is already known; planning investigations, reviewing what is already known in light of experimental evidence, using tools to gather, analyse, and interpret data, proposing answers, explanations and predictions, communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking and consideration of alternative explanations (p.23).

Thus, inquiry represents a conglomerate of scientific practices that are largely focused on understanding causal mechanisms that underlie natural phenomena. Here, the term ‘practices’ is used instead of ‘skills’ to stress that engaging in inquiry requires the coordination of both knowledge and skills simultaneously (Ramnarain & Hobden, 2015). Science practices are the multiple ways of knowing and doing that scientists use to study the natural world (Krajcik, 2016). Accordingly, teaching in physical sciences should introduce and engage learners in science practices to encourage them to build knowledge and understanding through inquiry, investigation, problem solving, collaboration, planning, decision making, and connecting science to practical uses in the real world (NRC, 2012, 2013).

In light of this definition of inquiry, I can then define learner-centred inquiry-based instruction as an instructional approach that focuses on the needs of individual learners inclusive of their prior experiences (knowledge, skills, attitudes and beliefs) as they engage in science practices such making observations, posing questions, examining books and other sources of information to see what is already known; planning investigations, reviewing what is already known in light of experimental evidence, using tools to gather, analyse, and interpret data, proposing answers, explanations and predictions, communicating the results.

Learners can engage with one or more of the scientific practices as identified in the definition while studying one or more science concepts (Marshall *et al.,* 2017. However, researchers (Bransford, Brown, & Cocking, 2000; Bybee *et al.*, 2006) posit that at the core of inquiry-based teaching, learners must have the opportunity to explore concepts before formal explanations of the phenomena are provided. Learners must have the chance to make observations (whether real or virtual) of phenomena before the other inquiry activities. According to the National Commission on Mathematics and Science Teaching

(NCMST) (2000), high-quality teaching focuses on the skills of observation, information gathering, sorting, classifying, predicting, and testing and uses technological tools to assist in the learning process, in which learners participate in activities, exercises, and real-life situations to both learn and apply lesson content. However, learners can engage with one or more scientific practices while studying one or more science concepts (Marshall, Smart, & Alston, 2016).

Learner-centred, inquiry-based teaching approaches can be conceptualised to fall along a continuum according to the extent of direction provided by the teacher and the extent of independence given to learners. Bell, Smetana, and Binns (2005) present a four-level model to illustrate how inquiry-based activities can range from “highly teacher directed to “highly student-centred” (p.94). In highly teacher directed learning activities, there is less learner autonomy when compared to highly student-centred learning activities. Tafoya, Sunal, and Knecht (1980) conceptualised four levels of inquiry-based teaching: (a) Confirmation activities require students to verify concepts through a given procedure. (b) Structured-inquiry activities provide students with a guiding question and procedure to follow. (c) Guided-inquiry activities provide students with a guiding question and suggested materials; however, students design and direct the investigation. (d) Open-inquiry activities require students to generate their own research questions and design their own investigations. During inquiry-based teaching, learners typically manipulate materials or observe scientific phenomena or demonstrations, and/or use secondary sources (The Inquiry Synthesis Project, 2004).

In a typical learner-centred, inquiry-based instruction as espoused in the curriculum, “the purpose of Physical Sciences is to make learners aware of their environment and to equip learners with investigating skills relating to physical and chemical phenomena” (Department of Basic Education, 2011, p. 8). Thus the teacher should design learning activities where learners have opportunities to experience (physical and chemical phenomena), make sense and communicate about phenomena making use of science practices/investigating skills (Krajcik,2016) as illustrated in Figure 2.2. Thus according to Rapanta et al., (2020) any engaging and rewarding learning activity should:

- be context-embedded,
- employ tools and resources and
- Involve concrete tasks.

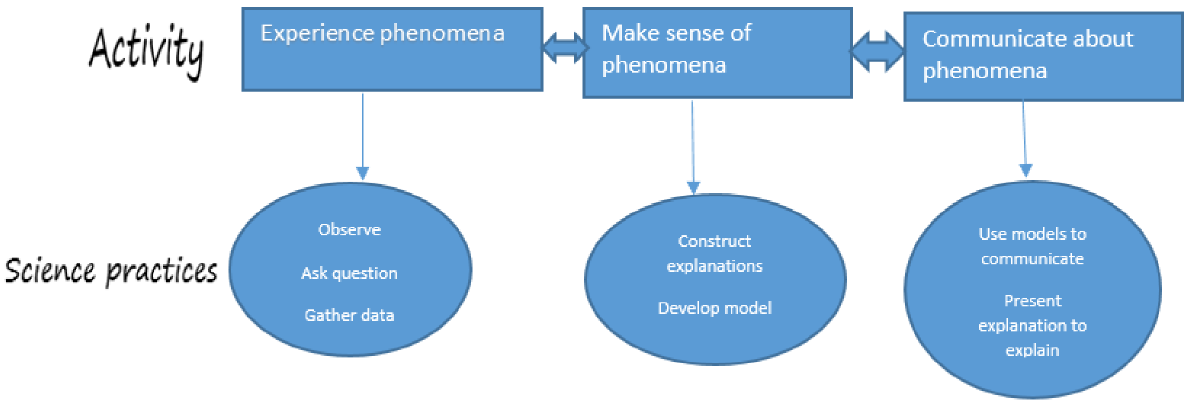

Figure 2.2 Sequence of teaching/learning activities (adapted from Krajcik, 2016)

It is important that teachers design learning environments that may change to various degrees in the order to which new concepts are introduced. Learners need to have opportunities to learn through experiencing, making sense and communicating about phenomena in order to see coherence. Research has shown that learners need learning experiences as interactions with phenomena and ideas to test and revise their own initial or developing ideas so that they can eventually arrive at those goal science ideas themselves (Minstrell, Anderson, & Li, 2011). The national department (DBE) promotes that the learning activities should be organised in such a manner that it is coherent and logical to facilitate both learner comprehension (Department of Basic Education, 2011) and coherent conceptual storyline (Ramsey, 1993). Literature in science education reports that mainstream instruction leaves learners viewing science as an assortment of disconnected fact (Sikorski & Hammer, 2017) because of a lack of conceptual coherence. The argument for conceptual coherence is as follows: For students to construct deep, interconnected understandings of natural phenomena and see a “sense of unity” in science, the curriculum must be carefully sequenced to make those connections clear to students (NRC, 2012: 10). Such a learning space will engage learners by encompassing their ideas and questions into the curriculum, allowing the learners to be part of the problem-solving process, while encouraging collaborative and cooperative learning (Armfield, 2017).

Learners can experience the phenomena either through firsthand or virtual experiences, such as through using computer simulations. Krajcik (2016) advises that the phenomena experienced by learners should (1) address the targeted big idea, (2) be comprehensible and meaningful to learners, (3) be attention-getting and thought-provoking, and require some explanation so that it is likely to engage all learners and motivate them to focus on the big ideas and (4) be efficient in that the benefits justify any financial costs and time devoted to using the phenomenon with learners.

By anchoring learning in compelling phenomena, teachers provide students with a reason and a context in which to communicate (Lee *et al.*, 2018). This focus on explaining phenomena gives a purpose to science learning and departs from a traditional focus on the acquisition of a body of science knowledge (Reiser *et al.*, 2017). Such an approach is a route diametrically opposed to learners' typical roles as passive recipients of information. On the contrary, it will engage learners in scientific practices to construct, question and communicate understandings (Miller *et al.*, 2018). This view is consistent with pedagogical perspectives of instruction advocated by Jerome Bruner (1966), who argued that learning by an individual within a particular discipline:

> is not a matter of getting him to commit results to mind. Rather, it is to teach him to participate in the process that makes possible the establishment of knowledge. We teach a subject not to produce little living libraries on that subject, but rather to get a student to think mathematically for himself, to consider matters as an historian does, to take part in the process of knowledge-getting. Knowing is a process, not a product (p.72).

Decades of research have yielded a corpus of information that can be used by teachers to improve instruction in schools. Still, research on classroom instruction indicates that the instructional methods teachers use often remain at odds with those advocated by research-based reforms designed to increase equity for students (Fullan, 2007). Reform messages often conflict with long-standing and established norms and procedures in schools (Fullan, 2007). As these established norms and procedures inform teachers' work, instructional practices become institutionalized and are, thus, often at odds with the practices advocated by reform efforts.

2.4 Challenges to implementation of learner-centred, inquiry-based instruction

There are perceived challenges to the implementation of learner-centred, inquiry-based instruction. These challenges emanate from the challenges that have been reported in literature concerning learner-centred and inquiry-based instruction.

2.4.1 Challenges with implementing learner-centred instruction

Changing instructional practices and adopting a more learner-centred pedagogy has been cited as problematic in both developing and developed countries (Schweisfurth, 2013). However, in developed countries, such as the United States of America, the challenges are being addressed through tailor-made professional development activities that are being designed to support teachers to changing their instructional practices through the financial and technical support of the federal governments and local universities respectively (DeCoito & Myszkal,2018; Zhang, Parker, Koehler & Eberhardt,2015). In developing countries, the context in which teachers work has various and numerous challenges that hinders teachers from adopting research-based instructional practices into their classrooms. It has been reported that demands are being placed on teachers to focus more on grade attainment especially in critical subjects such as physical sciences and mathematics (Kuboja & Ngussa, 2015). The national government is concerned with the low numbers of learners passing these subjects at the matriculation level. Provincial departments are implementing programmes where learners are being coached to prepare learners for examinations. Macupe (2017) writes that in government schools, grade 12 learners have to attend morning classes from Monday to Friday, which start at about 6am, and afternoon classes, which are from 4pm to either 8pm or 9pm. There are also weekend classes where teachers use classes to cover any work that they might not have concluded during the week. In addition, winter, autumn and spring camps are organised by provincial education departments during holidays. Learners are bussed to a venue where they are taught by teachers from other schools. There are camps for top-performing learners in subjects such as mathematics and physical science, as well as camps for underperforming learners. The learners who do not attend camps go to extra classes at their schools.

It has also been reported that the physical science curriculum is overloaded (Kriek & Basson, 2008), while the time is limited (DeCoito, 2006) and classes are overcrowded (Salavati, 2016). As a result of these challenges, teachers have reported that they are constrained and it is not possible to change their instructional practices to adopt learner-centred instruction (Manqele, 2017; Zenda, 2016).

Scott, Mortimer and Ametller (2011) argue that teachers need to be experts in the subject matter for the successful implementation of learner-centred teaching. This argument concurs with Mtitu (2014) who conceptualises learner-centred teaching as a competence-based instructional approach. In other words, teachers' professional qualifications and their experiences in teaching come into play. Issues of teacher quality come into play. This rationale is the reason why many countries such as South Korea, Singapore and Malaysia have made it mandatory for government teachers to complete continuous professional development (CPD) (Arrifin *et al,* 2018). These CPD programmes equip teachers with knowledge of the current trends in science education which may contribute to school wide improvements. In South Africa, it is not compulsory.

However, CPD given to in-service teachers does not always address their needs, nor do they necessarily result in better realisation of outcomes in science (Pretorius *et al.,* 2014). They consist mainly of disconnected seminars/workshops through which theory is presented independent of practice, which have been proven to be ineffective for improving classroom practice (Anderson & Freebody, 2012; Korthagen & Kessels, 2015).The reason is that most CPD activities are intended to teach teachers about teaching as opposed to engage teachers in learning about teaching so that they can develop knowledge for teaching. Tarling and N'gambi (2016) suggest that once the CPD training sessions conclude, participants return to 'the way things were', like a stretched rubber band returns to its shape after stretching. Gu and Yang (2003) discuss the fate of such an approach to capacitate teachers to implement learner-centred teaching:

> There are many forms of current in-service teacher professional development, which includes short time curriculum training, unit workshops, and teaching observation and deliberation, and so forth. All of these forms are faced with the question of transforming from theory to practice. In fact, most of the teachers in these training programs are not able to apply theory into their daily practice. This has become an insolvable ''chronic disease.'' (p. 1-2)

This has presented a paradox in the teaching space. We propose that professional development opportunities with a focus on specific problems that teachers face can go a long way in transforming practice. Actually self-directed professional development is a viable alternative to other forms of professional development available to teachers. It is established that some teachers lack CK, PCK, and/or TPCK (Mlachila & Moeletsi, 2019; Mavhunga & van der Merwe, 2020) and other problems that are related to these such as the poor utilisation or improvisation of the available resources. Hence it is critical that teachers be given the opportunity to identify those areas that are specific to them that need urgent professional development. However, researchers (Mathias, 2005; Pleschovà & McAlpine, 2016) propose that in order to facilitate more learning-centred approach teachers need to be critically reflective. Cowan (2006) suggests that while critically reflecting on teaching, teachers (1) are accustomed to think of reasons why learners are performing poorly in the subject, (2) identify both strengths and problematic aspects of one's practice, (3) make suggestions or alternatives, (4) test the suggestions and then (5) reflect on whether learning outcomes have improved. In the end teachers are able to suggest changes for future teaching and their expected effects on learner learning (Pleschovà & McAlpine, 2016).

2.4.2 Challenges in implementing inquiry-based instruction.

Research is consistent that inquiry-based teaching is rarely being adopted in schools (Meyer, Pfiffner, & Walter 2007; Prenzel 2008; Ruhrig & Höttecke, 2015). In the South African context, teachers are reportedly struggling to teach Physical sciences through inquiry (Dudu, 2015; Mokiwa, 2014). There is evidence that suggests that more often than not, inquiry-based teaching is confused with hands-on activities and "experiments", sometimes referred to as “cookbook” activities, that focus on finding the “right” answer and are often unconnected to substantive science content (Crawford, 2000:28; Gengarelly & Abrams, 2008:265; National Research Council, 2000:124). There is a greater emphasis on teachers to perform practical work as if it is the only important aspect of inquiry. These activities tend to focus on procedures rather than analysis and understanding and are often not integrated with other classroom activities (Williams, Nguyen, & Mangan, 2017). There is a narrow conception of what inquiry-based teaching is.

Garet, Porter, Desimone, Birman and Yoon (2001) and Marshall, Smart & Alston (2017) have attributed the challenges that teachers face in implementing inquiry-based teaching to insufficient pedagogical content (PCK). As a result, there is a tendency among teachers to conceive and limit inquiry-based teaching to carrying of experiments. Teachers have decried the lack of facilities, materials and apparatus as an impediment to the implementation of inquiry-based teaching (Alhendal *et al*., 2015; Nompula, 2012; Zenda, 2017), hence their relying heavily on the textbook and other traditional methods of teaching.

Because of the challenges that teachers have with both learner-centred and inquiry-based instruction, it is not difficult to conceive that challenges will also be encountered in implementing learner-centred, inquiry-based instruction. However, teachers are expected to continuously learn throughout their career to expand and enhance their practice (Loucks-Horsley, Love, Stiles, Mundry & Hewson, 2003). Therefore, Ariffin *et al.* (2018) have suggested that teachers need to take the role of insider action researchers as a professional development (PD) if ever they are to be responsive to the needs of their classrooms. Classroom action research (CAR) is a form and tool of professional development that addresses the specific challenges that teachers encounters in their practice. In this case, the researcher wanted to learn to integrate technology to implement learner-centred inquiry-based instruction. Specifically, the teacher wants to use technology to:

1. Respond to individual learner’s interests, strengths, experiences and needs as opposed to treat all learners alike and responding to the group as a whole,
2. Select and adapt the curriculum as opposed to rigidly following curriculum,
3. Provide opportunities that promote the acquisition of knowledge, skills, and good learning habits of mind as opposed on focussing on acquisition of information by learners,

4. To assess learner understanding as opposed to testing learners for factual information at the end of unit or chapter,
5. To share responsibility for learning with learners as opposed to maintaining responsibility and authority,
6. To support a classroom community with cooperation, shared responsibility and respect as opposed to supporting competition and
7. To working with other teachers to enhance the science learning in my school as opposed to working alone (NRC, 1996).

Unfortunately, provincial and school districts continue to offer PD that are short term, generic and isolated in respect to time as well as lacking in ongoing support and engagement with facilitators. Pella (2015) asserts that teacher professional development that promotes inquiry cycles is a positive influence for professional growth. Therefore, the researcher desired a professional development programme that was specific to his needs. Ball and Cohen (1999), Kagan (1992), Putnam and Borko (2000) and Smylie (1989) concur that teacher learning and PD are best fostered when connected with the teacher's own instruction. They argue that the classroom is where teachers implement and refine their teaching practices, become more informed about their students, and explore their own teaching styles and methods.

Action research can enable reflection as part of the research process (Cohen, Manion, & Morrison 2011). Through reflection, teachers frame and reframe issues of practice. According to Deaton, Deaton and Koballa (2014), teachers frame issues of practice as they begin to explain them based on their current beliefs and knowledge about teaching. They further assert that as teachers continue to examine issues, they may identify evidence about their teaching that influences their teaching beliefs, and considering this new evidence, reframe their issue of practice. Thus, CAR produces knowledge that can be actionable, at the service of both the academic and practitioner communities (Coghlan, 2007). Additionally, this knowledge describes phenomena as they appear to teachers, in a descriptive and subject-centred context, and not with a focus on general solutions (Coghlan 2010).

2.5 Integration of technology in physical science teaching and learning

The importance of Mathematics, Science and Technology (MST) education in South Africa is evidenced in the drafting of a National Strategy for MST education (DBE, 2001) and many other national strategic planning documents such as the National Development

Plan (NPC, 2011). The National Strategy for Mathematics Science and Technology (MST) Education published in 2001 by the Department of Education (DBE, 2001) seeks

1. To raise participation and performance by historically disadvantaged learners in Senior Certificate mathematics and physical science.
2. To provide high-quality mathematics, science and technology education for all learners; and
3. To increase and enhance the human resource capacity to deliver quality mathematics, science and technology education (p.10).

The policy was drafted in a context where mathematics and science are recognized globally as subjects essential for economic development and prosperity. The Global Competitiveness Report singles out mathematics and science education as a key economic enhancer (Schwab, 2012); unfortunately, South Africa has not fared well in this report. There are challenges that have perennially plagued the teaching and learning of science in South Africa (Graven, Pence, Hakansson & Pausigere, 2013; Makgatho & Mji, 2006; Ndlovu & Mji, 2012). As a result, both national and international assessments continue to communicate the perennial message: the low learner performance and achievement in the physical sciences (Mudadigwa & Msimanga, 2019). To address some of the challenges, educational innovators are advocating while administrators have endorsed the use and integration of technology into the curriculum.Teachers therefore need to act their part - by integrating technology into their instructional practice. There is emerging research that purports the potential of technology to enhance learner achievement and interest in science (Gonczi *et al.*, 2016; Trundle & Bell, 2010) and the perceived instructional benefits to teachers. A technology-supported teaching and learning environment affords new ways of positioning and interacting with learners in learning science. Evidence supporting the benefits of technology to instructional practice is growing exponentially (Hilton & Honey, 2011). To attain these endeavours (1-4), the Department of Basic Education has explicitly entrusted the seamless integration of technology by teachers in their instructional practice. It asserts that:

> Learning through the use of ICTs is arguably one of the most powerful means of supporting students to achieve the nationally stated curriculum goals. It must however be very thoughtfully selected and integrated into educational planning and management. (DBE, 2004:19)

What is inherent in the previous statement is that technology is an ‘artefact’ that can be appropriated by teachers to become an ‘instrument’ to attain the envisaged curriculum goals. The achievement of the curriculum goals is transparent and noticeable. A transition is a learning situation that is found to involve a noticeable change. Thus, technology is envisaged to bring noticeable change in the acquiring new knowledge and skills, analyse and synthesize data, then construct a product that demonstrates their knowledge (NCES, 2003; Partnership for 21st Century Skills, 2002). Thus, the affordances of technology can provide an alternative to using and depending on textbooks when learning content in science. Experts advocate a shifting from "book literacy to screen fluency…" (Kauffman & Mohan, 2009:5). This shift is compatible with the current generation of learners who are turned off when taught through in a passive way; they prefer to be engaged by their learning environment through simulation, using participatory, interactive, sensory-rich, experimental activities (either physical or virtual) (Birt & Cowling, 2018). As a result, McCrindle (2004) states:

> The traditional talk and chalk won't work with this generation. Our communication style is structured, yet they want freedom. We stress learning, they like experiencing. We react, they relate. We focus on the individual, while they are socially driven (p.4).

The differences between the past and present generation of learners are so visible that Prensky (2001) is convinced that the nature of instructional practices must change in order to accommodate the skills and the interests of the new generation who are finding school science irrelevant and insignificant to their lives (Aikenhead 2006; Jenkins 2006; Lyons 2006).Thus, the seamless integration and use of technology by science teachers should become standard practice in this era of technology. Teachers' ways of using technology create not only meaningful learning opportunities for learners but also opportunities for teachers to learn, frame and reframe their teaching practices (Kim, 2017). Technology offers science teachers idiosyncratic ways to redesign curricula with an attempt to make learning more meaningful to learners. However, the challenge is that the curriculum document is less prescriptive on how teachers should integrate and use educational technology when teaching. There are no instructional goals for using technology that have been prescribed for teachers. In developed countries such as the United States of America, the International Society for Technology in Education (ISTE) published the National Educational Technology Standards (NETS) to provide a basic framework for the use of technology in the classroom. Learners using multiple digital technologies, engage as (1) empowered learners, (2) digital citizens, (3) knowledge constructors, (4) innovative designers, (5) computational thinkers, (6) creative communicators and (7) global collaborators. In the absence of national standards, there is fear that technology will be integrated in a cosmetic and superficial way which may not impact learning as intended.

In this study, the term “technology” will refer to all devices that are connected to and with the working of computers such projector, white screen application software, and digital devices, such as digital cameras, digital microscopes, and digital video cameras. In that regard, technology integration will refer to the assimilation of technology resources and technology enabled practices as a routine and seamless element of the day, so that learners are prepared to use technology for learning (National Centre for Education Statistics [NCES], 2002). The integration of technology in the classroom is a process involving changes in the instructional practices and development of a culture that embraces technology as a natural part of the milieu (NCES, 2002). For teachers to successfully integrate technology into their classrooms, they must be competent in the knowledge domains identified by Mishra and Koehler (2006). A teacher in the 21st century is expected to be digitally competent in a range of technologies which have proliferated in today’s digital world (McKnight, O'Malley, Ruzic, Horsley, Franey, & Bassett, 2016). Digital competence, according to IIomäki, Kantosalo and Lakkala (2011) is a recent concept referring to attributes and capabilities related to technology-use. The researchers suggest that the term ‘competence’ is more appropriate than ‘skills’ in that it reflects a wider and more profound content of the concepts. In the South African context, the national policy, *The Framework for Teacher Education* of 2011 (revised 2015) states that computer competency is considered as fundamental learning, and the policy dictates that student teachers should be competent in using ICTs and that they should be able to integrate ICTs in teaching and learning (Department of Higher Education and Training, 2015).

Mishra and Koehler (2009) proposed the Technological, Pedagogical, and Content Knowledge (TPACK) model that describes the different knowledge domains teachers need to acquire for digital competency to be successfully integrating technology in the teaching and learning processes in their various classrooms (Koehler, Mishra, Kereluik, Shin, & Graham, 2014). TPACK addresses teaching and learning complexities that manifest in technology-enhanced classrooms (Angeli, Valanides & Christodoulou, 2016). For science education, much of the work around TPACK focused on science teachers' expertise in TPACK, with less emphasis on how science teachers use specific technologies in their classrooms (Hsu, 2015). However, little is known about how science teachers transform their TPACK in real classroom situations.

The Technological Pedagogical Content Knowledge (TPACK) framework is based on Shulman’s work (Shulman, 1987) and illustrates the interaction between three knowledge domains namely Content Knowledge (CK), Pedagogical Knowledge (PK), and

Technological Knowledge (TK) (see Figure 2.3). The interaction/intersection of the three knowledge domains give rise to additional knowledge domains that teachers need to possess for them to integrate technology into teaching and learning such as Technological Pedagogical Knowledge (TPK) and Technological Content Knowledge (TCK) and Technological Pedagogical Content Knowledge (TPCK). These are the knowledge required by teachers who are interested and wants to integrate technology successfully in the practice. Proponents assert that each of these components is equally necessary for effective instruction, though some inconsistencies occur in the literature in operationally defining technology within the model (Graham, 2011).

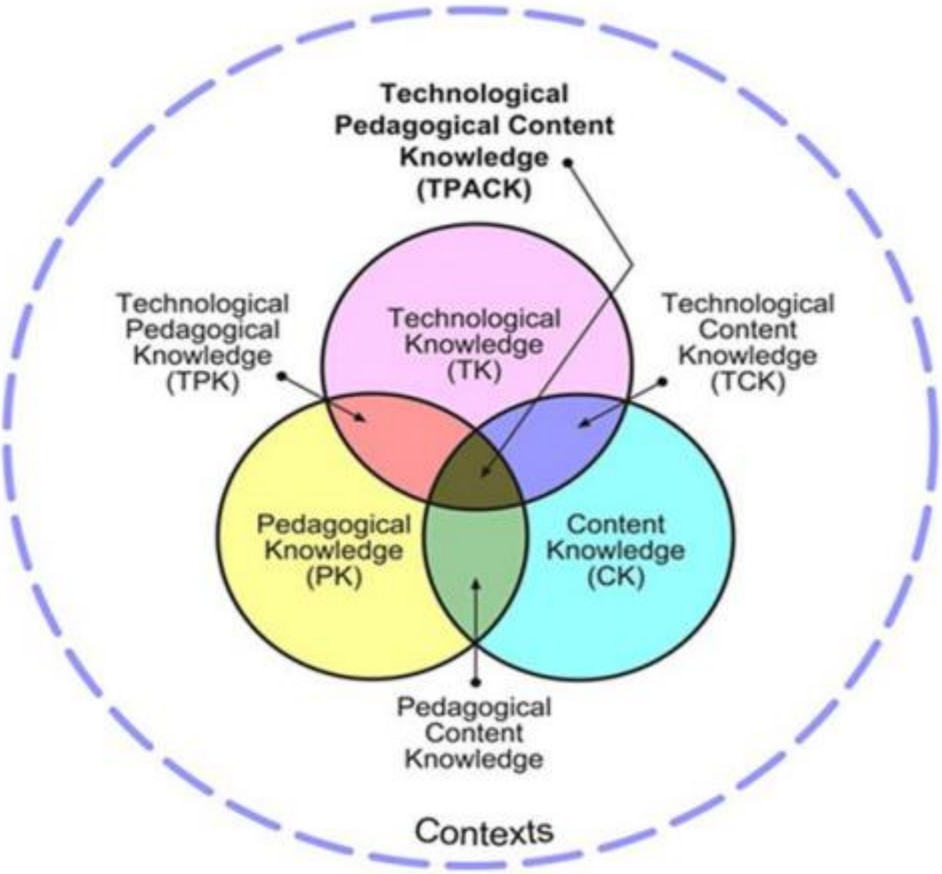

Figure 2.3 TPACK Framework according to Koehler and Mishra, 2009, p.48

2.5.1 Technology Knowledge (TK) (knowledge of the tools we use to teach)

Technology knowledge refers to the knowledge about various technologies including how to select, master, and utilize various technologies for information processing, communication, and problem solving (Sickel, 2019). New technologies are entering the classroom today, and TK is always in a state of flux. Acquiring TK is on-going and a lifelong developmental process. Even the definition of technology is evolving and dynamic as is the technology itself. In this study, the technology includes the computer, computer simulations, projector, and white screen. The teacher needs to know how to:

1. Utilize the digital device/applications,
2. Create an interactive, multimedia presentation and can embed it (e.g., PowerPoint presentations)
3. Make decisions regarding how to interact with learners using different technologies,
4. Assess using technology,
5. Use multiple technologies concurrently in a way that is unobtrusive to learning.

2.5.2 Content Knowledge (CK)

Content knowledge is the "knowledge about the actual subject matter that is to be learned or taught" (Mishra & Koehler, 2006:1026). In this study, the content knowledge was on electromagnetism (see Appendix 3). It included the facts, concepts and theories that comprised the topic. Content knowledge, however, extends beyond an understanding of the facts and concepts to an understanding of the variety of ways in which the basic concepts and principles of the discipline are organized to incorporate the facts (Nyamupangedengu, 2016). In addition, it requires an understanding of the rules by which "truth or falsehood, validity or invalidity" are established (Shulman, 1986, p.9).

2.5.3 Pedagogical Knowledge (PK)

Shulman (1986) defined general pedagogical knowledge as "broad principles and strategies of classroom management and organization that appear to transcend subject matter" (p.10). PK entails the knowledge of all the aspects of teaching such as teaching procedures and teaching activities, in addition to what is in Shulman's definition and what was described by the students in the studies by Entwistle (1990) and Marris (1964). This study seeks to implement learner-centred, inquiry-based instruction in a resource constrained secondary school. Therefore, the teacher needs to know how to:

1. Formulate achievable learning objectives.
2. Design age-appropriate learning activities and assessment
3. Maintain discipline.
4. Employ learner-centred, inquiry-based instruction.
5. Apply content to the "real world" outside the classroom to increase relevance.
6. Motivate learners.

2.5.4 Pedagogical Content Knowledge (PCK)

PCK includes an understanding of what makes the learning of specific topic easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons (Shulman, 2004, p. 203). Gudmundsdottir and Shulman (1987) argue that PCK is the most important source of knowledge for teaching, the "knowledge to make subject matter accessible to students" (Kleickmann *et al*., 2013:241). The teacher needs to know:

1. How to elicit learners' prior knowledge
2. How to link what the learners know with new knowledge
3. The benefits of visual presentation of this content.
4. How to achieve affective objectives
5. How to implement the learner-centred, inquiry- based instruction

2.5.5 Technological Content Knowledge (TCK)

Technological content knowledge refers to the knowledge of how technology can create new representations for specific content. There is a variety of technologies that are available to teachers, some of the technologies have been specifically designed for while others are being adapted for teaching and learning processes. According to Mishra and Koehler (2008), teachers need to understand which specific technologies are best suited for addressing subject matter learning in their domain and how the content dictates or perhaps even changes the technology-or vice versa. As stated in Chapter 1, this study seeks to explore the use of computer simulations as TPR tool in the teaching and learning of electromagnetism. Therefore, the teacher needs to know:

1. How computer simulation affordances can enhance the learning of abstract scientific phenomena that are otherwise difficult or impossible to experience.

2.5.6 Technological Pedagogical Knowledge (TPK)

Technological pedagogical knowledge refers to the knowledge of how various technologies (in this case, computer simulations) can be used in teaching and understanding that using technology may change the way teachers teach. This knowledge includes knowing the pedagogical affordances and constraints of a range of technological tools as they relate to disciplinarily and developmentally appropriate pedagogical designs and strategies (Mishra & Koehler, 2008). In this case, the teacher also needs to know how to:

1. Scaffold interactive simulations effectively for engaging, mind-on learning.
2. Leverage pedagogical affordances of computer simulations.
3. Recognize pedagogical constraints of computer simulations.

2.5.7 Technological Pedagogical Content Knowledge (TPCK)

TPCK is the knowledge that emerges from the intersections of content, pedagogy and technology knowledge. It involves an understanding of the representation of concepts using various technologies, instructional strategies that integrates technologies to teach content in constructive ways, knowledge of gate-keeping elements within a concept which makes the learning difficult and how technology can help ease learning (Mishra & Koehler, 2008).

Mishra and Koehler (2006) have singled out TPCK as the knowledge required by teachers for integrating and using technology in teaching and learning. TPCK is the knowledge necessary to effectively adapt and align available technology with developmentally and contextually appropriate methods and content (Sickel, 2019). To effectively integrate technology, teachers require TPCK that is subject-specific and relevant to the learning area content such as science (Hindle, 2007). TPCK is developed through repeated planning and teaching of regular topics using technology informed by the context. It is personal and topic specific. This tacit knowledge is developed in practice in a particular context. The context of the teaching event, where the learning was situated was added in 2008 to the seven components as "an indispensable part of the TPACK framework" (Voogt *et al.,* 2012:57). According to McAdam, Mason and McCrory (2007), tacit knowledge is "knowledge-in-practice developed from direct experience and action; highly pragmatic and situation specific; sub-consciously understood and applied; difficult to articulate; usually shared through interactive conversation and shared experience" (p.46). It has been reported that the various government and non-government initiatives to train in-service teachers to use ICT seems not to contribute to the competence in teaching with ICT tools in the classroom (Jita, 2016), because the trainings are done theoretically outside the context and practice of teachers.

The construct TPACK has generated much interest from researchers globally resulting in approximately 1,200 publications that utilise the construct as a foundation (Harris, Philips, Koehler & Rosenberg, 2017). The research on TPACK have been done from two epistemological perspective: the integrative and transformative approach. In the integrative approach, studies measured (pre-/in-) teachers' self- reported TPACK by its components mainly through survey instruments and interviews (Kafyulilo, Fisser, &Voogt, 2016). In the study by Mouza, Karchmer-Klein, Nandakumar, Yilmaz Ozden, and Hu (2014), the Survey of Pre-service Teachers' Knowledge of Teaching and Technology aimed to measure pre-service teachers' knowledge under the components of TPACK. In another study by Kotoka (2019), the aim was to assess the teachers' TPACK in the topic of electricity, while the study by Jang and Tsai (2013) aimed at exploring Taiwanese science teachers' TPACK in the domains of a contextualised TPACK model. Even though the integrative approaches were helpful in measuring preservice and in-service science teachers' self-assessed TPACK, researchers noted the challenges of separating and classifying TPACK subcomponents in teachers' actual teaching performances (Jang & Tsai, 2013). The boundaries between the knowledge domains within the TPACK model are blurred and difficult to isolate.

On the other hand, a growing corpus of research is conceptualizing TPACK as a transformative type of knowledge (Angeli, Valanides & Christodoulou, 2016). TPACK transforms when it is applied in classrooms. Transformative approaches toward science teachers' TPACK included assessing knowledge components of TPACK model in practices in knowledge domains such (a) assessment, (b) planning and designing, and (c) practical teaching (d) curriculum (Canbazoglu Bilici *et al.*, 2016; Yeh *et al.*, 2015) using main data collection tools such as performance assessments, interviews and video recorded lessons. Other studies have been carried to observe teachers with different years of teaching experiences, and they reveal a diverse range of TPACK practices with the reasons guiding their actions (Ocak & Baran, 2019).

Comparing the two approaches, the TPACK assessed through the integrative approach is more theoretical than the one assessed through transformative approach. It is the view of this study that the transformative approach assesses TPACK-in-action. Hence, several authors have begun to consider the ways in which teachers' TPACK connects to specific educational practices through explorations of pedagogical reasoning and action (Harris *et al.*, 2017). More research on TPACK is needed considering the fact that both preservice and in-service teachers need to integrate and use technology in their practice. With the myriad technologies available today teachers need to develop their TPACK to determine how best to utilize technology to support teaching and learning. Such knowledge informs their decisions on what technology and how technological affordances can enhance all the cycles of teaching. Researchers affirm that future TPACK research should focus more upon cycles of teachers' doing and focusing TPACK scholarship particularly upon representations of teachers' knowledge in action, and the reasoning processes that led to specific technological pedagogical, and curriculum-based decisions and teaching acts within particular teaching and learning contexts (Harris *et al.*, 2017).

As outlined in Chapter 1, the focus of this study is on an individual teacher who sought to integrate technology into teaching and learning in a particular secondary school. This study is in response to calls/encouragement for school teachers to adopt different technological tools and develop their literacy of technology, content, and pedagogy for the enhancement of professional development and teaching effectiveness by using technological devices (Harris *et al.*, 2017). In line with other researches, this study will adopt a transformative approach to reveal how the teacher integrated the technologies to support his teaching. Yeh, Hsu, Wu, and Chien (2017) emphasized that research should be focusing more on what happens in teachers' classrooms, rather than on what they know about effective technology integration. Teachers' ways of using curricular materials create not only meaningful learning opportunities for students but also opportunities for teachers to learn and change their teaching practices. The TPACK model outlined the knowledge required by the teacher to successfully integrate technology into teaching and learning. The focus of this study is not on the TPACK model but on how the knowledge components in the TPACK model as a whole influence the teaching of the topic of electromagnetism. Examining teaching in practice has significant implications for understanding teachers' TPACK when the focus is on teachers' instructional decision-making processes that are built around classroom management and assessment (Ocak & Baran, 2019). As previously stated TPACK has an influence on the technological pedagogical reasoning of the teacher.

2.6 Pedagogical reasoning and action

Pedagogical reasoning (PR) is a construct coined by Shulman in 1986 and has grown into area of inquiry by researchers in education. Pedagogical reasoning and action describe what teachers have to engage in in order to successfully carry out their teaching role within particular contexts (Nyamupangedengu, 2016). Pedagogical reasoning and action can therefore be said to be a set of processes that are important to the development of a teacher's technological/pedagogical content knowledge (PCK/TPCK). Research shows that pedagogical reasoning that is informed by Topic Specific Pedagogical Content Knowledge (TSPCK) can result in the effective transformation of content knowledge to developing learning or concept understanding (Zimmerman, 2015).

Research on pedagogical reasoning has been completed with novice and experienced teachers to understand the complex and robust ways in which they plan to teach a particular topic, then teach that topic to particular group of learners in a particular classroom within a particular school. What has emerged is that though there are some general aspects common to PR, the process is not only idiosyncratic, but context related. The process is guided by the nature of the subject matter, the learning context and the characteristics of the learners (Pella, 2015). Thus, it involves teachers making informed and appropriate decisions specific to the dynamics of the topic and class they are teaching. Decisions are incubated by teachers and manifested in less visible and socially recognised activities. Activities include aspects of planning and assessment, and these are the activities to be considered during the preparation and analysis of knowledge of teachers (Fernandez, 2014). Decision-making is therefore done at three levels via pre-instructional, instructional and post-instructional stages.

2.6.1 Pre-instructional pedagogical reasoning

Pre-instructional pedagogical reasoning largely involves lesson planning. The planning of a lesson is a complex problem-solving process involving a conversation between the teacher and the intended/ prescribed curriculum. It encompasses thinking about recasting, transforming and tailoring the intended curriculum into teachable forms that fit the unique circumstances of the class. It also involves teachers considering alternative plans when given a different set of teaching circumstances and projecting their pedagogical ideas and content into an imagined future practice (Stroupe, 2014). The outcome of planning is a cognitive representation of typical lesson sequences, which are classroom scripts that guide both the teacher and learners in their understanding and help them to act in specific classroom situations (Mäkitalo-Siegl *et al*., 2011). Research focusing on how classroom scripts can support the teachers' role in inquiry-based science learning is thus needed (Edelson, Gordin, & Pea, 1999).

Pre-instructional pedagogical reasoning is a core activity that should be prioritised by teachers in schools. Spencer (2003) regards planning as a basic principle of effective teaching. However, from my experiences as a teacher in South Africa, planning is overlooked and left to the discretion of individual teachers in most schools. However, Navy *et al.* (2018) reports that science teachers in the United States collaborate in lesson planning as a result of school policies that required common planning. This preparative task involves considering subject matter in relation to the learners' backgrounds, the relationship of the subject matter to other subjects, and the context in which the subject matter is delivered. In other words, pre-instructional pedagogical reasoning involves contextualisation of the intended curriculum, the need to communicate the curriculum in such a way that it speaks to the local context of the teachers and learners. Teachers may encounter challenges in interpreting the intended curriculum and transforming it to the level and context of learners. Most curricular designs place more emphasis on performance outcomes for mastering content and skills while at the same time leaving the "how" up to the teachers. Others place more emphasis on suggested teaching methods, leaving the particulars of content and performance up to the teachers (Wallace & Priestley, 2017). Hence, there is need for teachers to translate the intended curriculum into teachable forms to suit the local context. However, there are limits to how far teachers should go in contextualising the intended curriculum.

Global trends stress the value of planning instructional practices that include learning activities that are interesting, challenging and relevant to one's future (NRC, 2012; Next Generation of Science Standards, 2013). This goal is against a background of research documenting the decline in interest in learning science because of the manner it is presented in the classroom (Lin *et al.*, 2012; Osborne & Dillion, 2008; Zeyer *et al.*, 2013). Important questions are being raised such as to how this process occurs and what kinds of thinking are involved (Richards, 2014). Most importantly, how does technology enhance the process? It is important to shed light on the importance of technology in lesson planning and the result in teacher development.

2.6.2 Instructional pedagogical reasoning

Instructional pedagogical reasoning involves the playing of the mental scripted lesson resulting in visible and socially recognised actions in the classroom. This process involves the implementation of the planned curriculum. During the process of teaching, the teachers' planned decisions may be substantially revised according to how the learners respond to the lesson. Shavelson and Stern (1981) introduced the metaphor of 'routines' to describe how teachers manage many of the moment-to-moment processes of teaching. Richards (2014) posits that teachers teach using well established routines. According to Berliner (1987), "…these routines are the shared, scripted, virtually automated pieces of actions that constitute so much of our daily lives [as teacher]. In classrooms, routines often allow students and teachers to devote their attention to other, perhaps more important matters inherent in the lesson" (p.72).

The relevance to this study is to understand what role technology plays in enhancing instructional pedagogical reasoning. Most importantly, how technology changes the established routines and position learners as legitimate participants in learning. Is technology an amplifier[7] or a reorganiser[8] (Dörfler, 1993) of classroom practice? How does technology position the teacher to facilitate the shift from traditional teacher-centred classroom scripts to learner-centred classroom scripts? The answers to these questions reveal how the teacher is responding to the challenge of implementing a prescriptive curriculum such as CAPS with professional autonomy when making decisions about technology, pedagogy and content. Teachers tend to be conservative in their approaches to curriculum development and they tend to teach from a narrow range of curricular materials typified by lectures, workbooks and verification laboratory exercises (Wallace & Priestley, 2017).

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[7] Amplifier implies doing the same as before more efficiently but without changing the basic structure, methods and approaches. In this way we will not be utilising the potential of the tools.

[8] Re-organising occurs when learners' interaction with technology as a new semiotic system qualitatively transforms their thinking,

2.6.3 Post-instructional pedagogical reasoning

Whilst pre-instructional pedagogical reasoning involves the comprehension and transformation of the 'intended curriculum', instructional pedagogical reasoning results in the 'enacted or implemented curriculum'. Post instructional pedagogical reasoning determines the 'achieved or attained curriculum'. It involves an assessment of the teaching to determine the successes and failures of the lesson and the improvements that can be made to future lessons. Teachers should devote time to this activity in order to maintain their effectiveness. Teachers can develop new perspectives, new ways of looking at their own actions and a new awareness or understanding of their own behaviours (Osterman, 1990). By engaging in post-instructional pedagogical reasoning, teachers are freed from a circle of routine behaviour as they reflect upon their practice and use what they learned in order to inform their future cycle of actions or instruction.

2.7 Evolution of the pedagogical reasoning process

Teaching is evolving from where PCK is the knowledge required for teaching (Barendsen & Henze, 2017; Shulman, 1987) to TPCK is the knowledge required for teaching in the 21st century (Mishra & Koehler, 2009). There is an evolution of the pedagogical reasoning process in terms of sophistication and robustness. Pedagogical reasoning (PR), as coined by Shulman in 1986, describes actions engaged by teachers in order to successfully carry out their teaching roles within particular contexts (Nyamupangedengu, 2016). Shulman (1987) developed the initial rudimentary model for PR. Over time, this model has evolved because of the changes that are occurring in schools with the introduction and emphasis on the use of technology in teaching and learning. In carrying out their roles in modern classrooms, teachers are using technology as a curriculum resource while at the same time to implement the curriculum. Technology is becoming increasingly an integral part of instruction and continues to become more intertwined with other facets of teaching (Sickel, 2019). It can be a mediator of the teaching process. When technology is incorporated into teachers' practice, it becomes an instrument which is a mixed entity that include both the technology and the ways it is used (Rabardel, 1999). It is therefore not a merely auxiliary component in teaching, but it shapes the teachers' actions thus making it an important component of teaching. The use of technology is affecting all aspects of the pedagogical reasoning process (Smart, 2016). Harris *et al.* (2017) suggest that teachers use their TPACK to make pedagogical decisions which underlie their (technological) pedagogical reasoning. A discussion on the development of models of pedagogical reasoning is made in the following sections. This discussion centres on the models developed by Webb (2002); Starkey (2010) and Smart (2016). A discussion on each of the model is explained to identify the changes that have occurred since the initial model was developed.

2.7.1 Shulman's model of pedagogical reasoning

In his model, Shulman (1987) depicts six aspects that are importantly involved in the process of PR. He suggested that pedagogical reasoning is a cyclical process, which consists of aspects of teaching such as comprehension, transformation, instruction, evaluation, reflection and new comprehension of the pedagogical content knowledge (see Figure 2.4). These aspects reflect Shulman's (1987) conceptualisation of teachers' pedagogical reasoning more than an empirically derived categorisation of the reasoning processes. The process starts with comprehension and ends with new comprehension. A pedagogical shift occurs, resulting in new or improved understanding of the phenomenon of teaching. The aspects are compartmentalised and represented as separate for clarity purposes, but in reality, they merge and the boundaries between them are often blurred (Smart, Sim, & Finger, 2015). Furthermore, pedagogical reasoning is a complex, dynamic, iterative and recursive process that is idiosyncratic. The processes are dynamic as they undergo continual development, transformation and integration. It is the interaction of these processes with each other that leads to the development and generation of a teacher's PCK (Shulman, 1987).

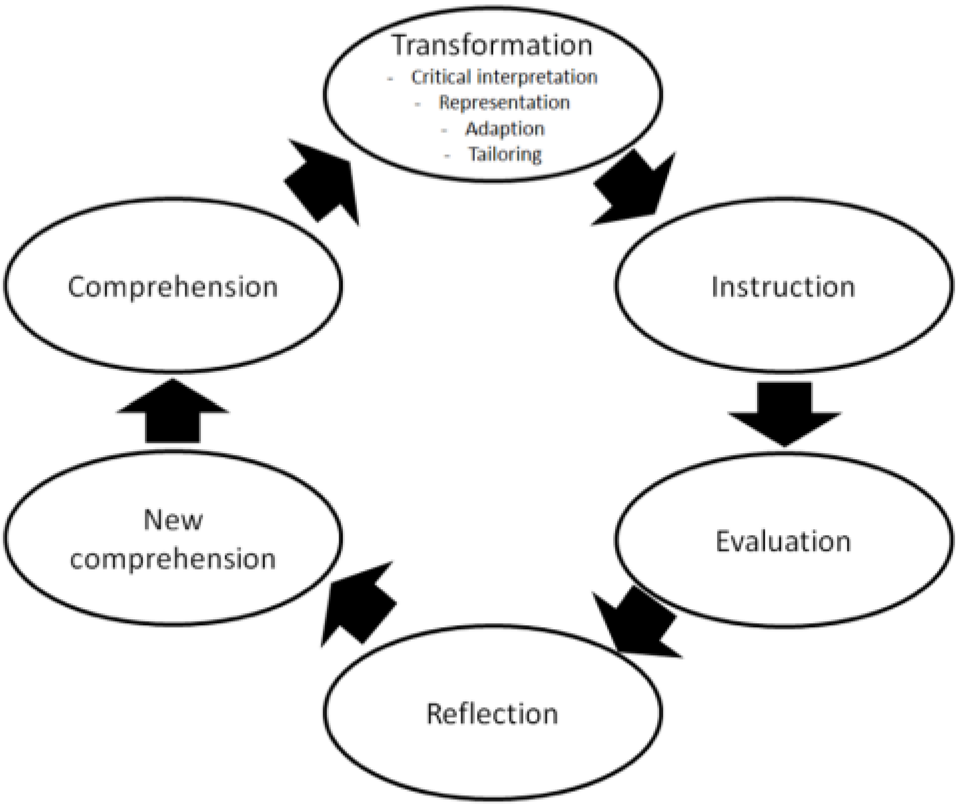


Figure 2.4 Model of pedagogical reasoning and action (Wilson et al., 1987:119)

Comprehension and transformation are processes undertaken during the pre-instructional phase. These are pre-instructional pedagogical reasoning processes. The instructional pedagogical reasoning processes include instruction and evaluation. Reflection and new comprehension are post-instructional pedagogical reasoning processes. In the sections that follow are detailed accounts of the processes of pedagogical reasoning as conceptualised by Shulman.

Comprehension is the first stage for pedagogical reasoning. It involves the teacher analyzing and understanding the content to be taught from many angles to choose the most appropriate one as dictated by the context. Perkins and Blythe (1994) indicated that understanding something is a matter of being able to carry out a variety of "performances" that show one understands of a topic and, at the same time, advance it. These performances are called "understanding performances" or "performances of understanding" (p.5-6).

It seems intuitively obvious that "Teachers cannot help children learn things they themselves do not understand" (Ball, 1991:5). Teachers must need to understand the content and purpose that needs to be taught. The content to be taught is usually outlined in the curriculum documents. Comprehension is a prerequisite if teachers are to be able to transform the content into a form that is more accessible to learners (Nyamupangedengu, 2015).

Transformation is about "unpacking" and "repacking" the comprehended ideas and shapes them into acts of teaching that are accessible to the learner. The reorganization of the grasped ideas is very important, so that it can become teachable content to be understood by learners (Mudau, 2014:5). Shulman considers transformation as a highly complex process and hence further divided it into four sub-processes namely preparation, representation, selection and adaptation and tailoring.

Preparation: Prior to instruction, teachers need to examine and analyse the teaching materials according to their understanding of the subject matter. This process entails simplifying and structuring the content into forms that are more suitable for teaching. Therefore, contextual factors are considered during preparation as teachers have to consider learners in terms of their prior knowledge, their level of competence and cognitive abilities before they can make decisions on what content to teach and how to teach it (Bishop & Denley, 2007). A teacher's past experiences and stored professional knowledge play an important role at this stage of transformation (Nyamupangedengu, 2016).

Representation refers to the explanatory frameworks that a teacher uses to make the subject matter comprehensible to learners. Teachers use explanatory frameworks such as analogies, metaphors, explanations, demonstrations in order to transform their knowledge of subject into a form that learners can understand. According to Nyamupangedengu (2016), to be able to choose and use appropriate representations requires sound knowledge of the subject matter.

Instructional selection refers to the choices that a teacher has to make regarding the activities, models, analogies and others that the teacher will use in the classroom. Teachers select teaching strategies and teaching models to fit their instructional goals.

Adaptation and Tailoring is the last stage of transformation. The teacher has to customize the representations according to the characteristics of the learners to enhance learning. Some considerations that a teacher has to make during adaptation and tailoring include learners' prior conceptions, social class, gender, ability and motivation (Geddis & Wood, 1997).

While Shulman presented the four stages of preparation, representation, selection and adaptation and tailoring as separate entities of the process of transformation, they influence and affect each other (Nyamupangedengu, 2016). In practice, the boundaries between the four stages are blurred making the process of transformation an integrated one.

Instruction: This is the observable acts or performances involving a variety of teaching and class management activities. It is an enactment of the plan drawn from the preceding processes. Here, attention is given to the responses by learners to the series of actions of the teacher and/or the activities designed to guide the learners through the learning process designed. As instruction occurs, pedagogical shifts arise due to new understandings of the activities in the classroom. Therefore, teaching is an act of learning.

Evaluation: This reasoning process includes monitoring of learning during the instructional phase as well as post-instructional phase to check for the quality of learning and appropriateness of instruction given. Checking for quality of learning can be both formal and informal. Informal evaluation is employed during the interactive phase of teaching through some form of questioning. Formal assessment is when questions are prepared in advance and compiled for the learners to answer and for teachers to provide feedback. Information from evaluation offers feedback about the appropriateness and effectiveness of the instructional pedagogical reasoning based on the pre-instructional pedagogical reasoning.

Reflection is what teachers do when they "look back at the teaching and learning that has occurred, and reconstructs, re-enacts, and/or captures the events, the emotions, and the accomplishments or failures to derive new understanding in relation to the choices made in planning and instruction phases of teaching" (Shulman, 1987:17). The teacher can apply the knowledge gained in future pedagogical reasoning cycles. Reflection can be done through journaling or with the help of recording devices. Reflection provides opportunities for teachers to learn from their practice.

New comprehension: Through the acts of preparation, instruction, evaluating and reflecting, the teacher gains new insights into his/her teaching. This insight can lead to a new understanding of content to be taught, of learners, of purposes, of self and of the process of teaching itself (Geddis & Wood, 1997). This pedagogical reasoning processforms the basis of pedagogical shifts that teachers make in subsequent lessons when all previous processes have been completed.

Borko and Livingston (1989), Chang (1996), Lee (2001), and Lin (1994) have applied Shulman's model to explore pedagogical reasoning and action of teachers from various subject areas and Mercier (2012) concluded that the model was an adequate depiction in real-life teaching environments. However, criticisms have been made on Shulmans' model. The model has been criticized as teacher-centred (Smart, 2016). The model focuses only on teacher's actions, yet learners and the environment contribute to the context of teaching.

2.7.2 Webb's model of Pedagogical reasoning

Webb (2002) initially proposed a model of PR with ICT (see Figure 2.5). The model is similar to Shulman's, though it shows linear relationships between the processes as first suggested by Wilson *et al.,* (1987). It consists of five sub-processes, which are comprehension, transformation, instruction, evaluation and reflection.

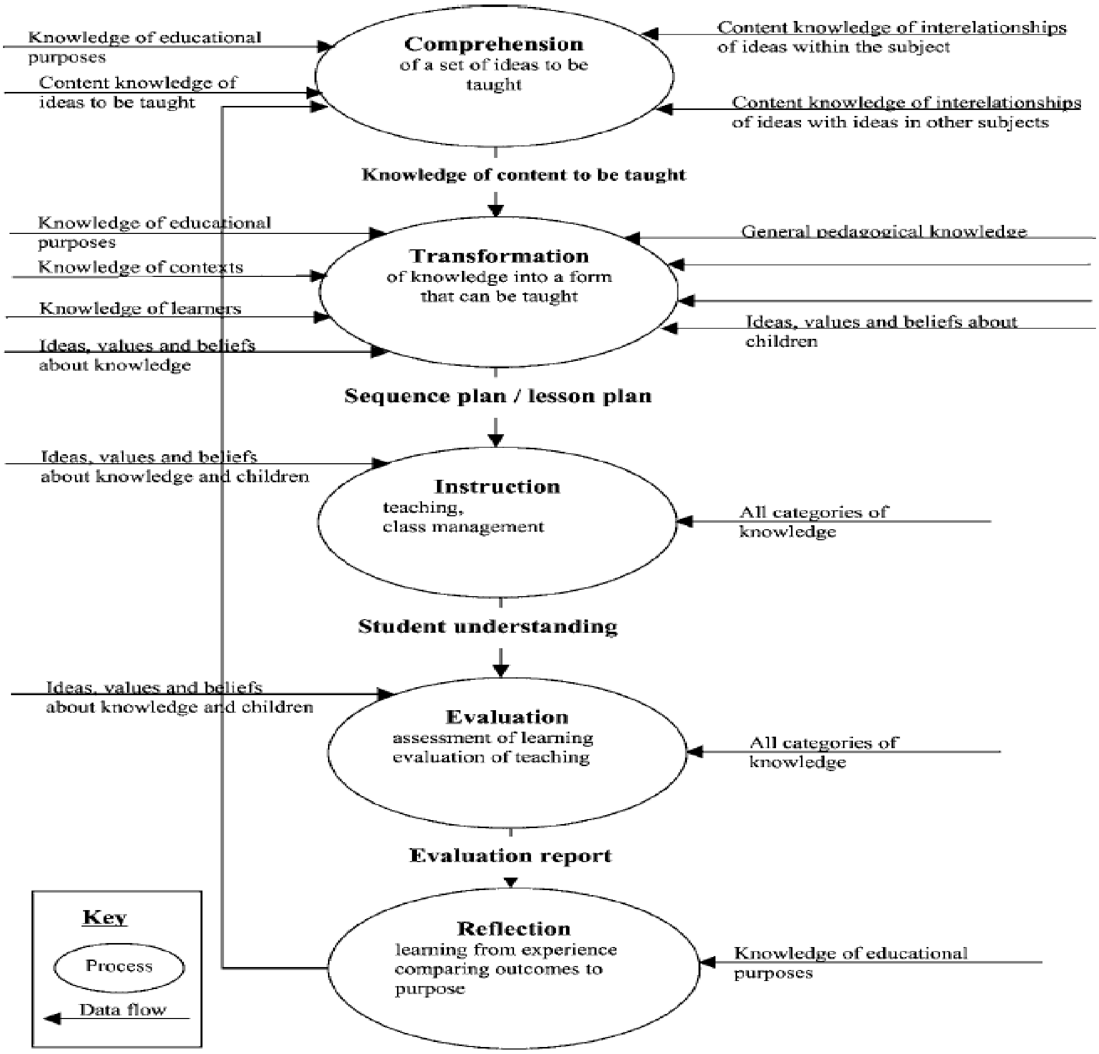
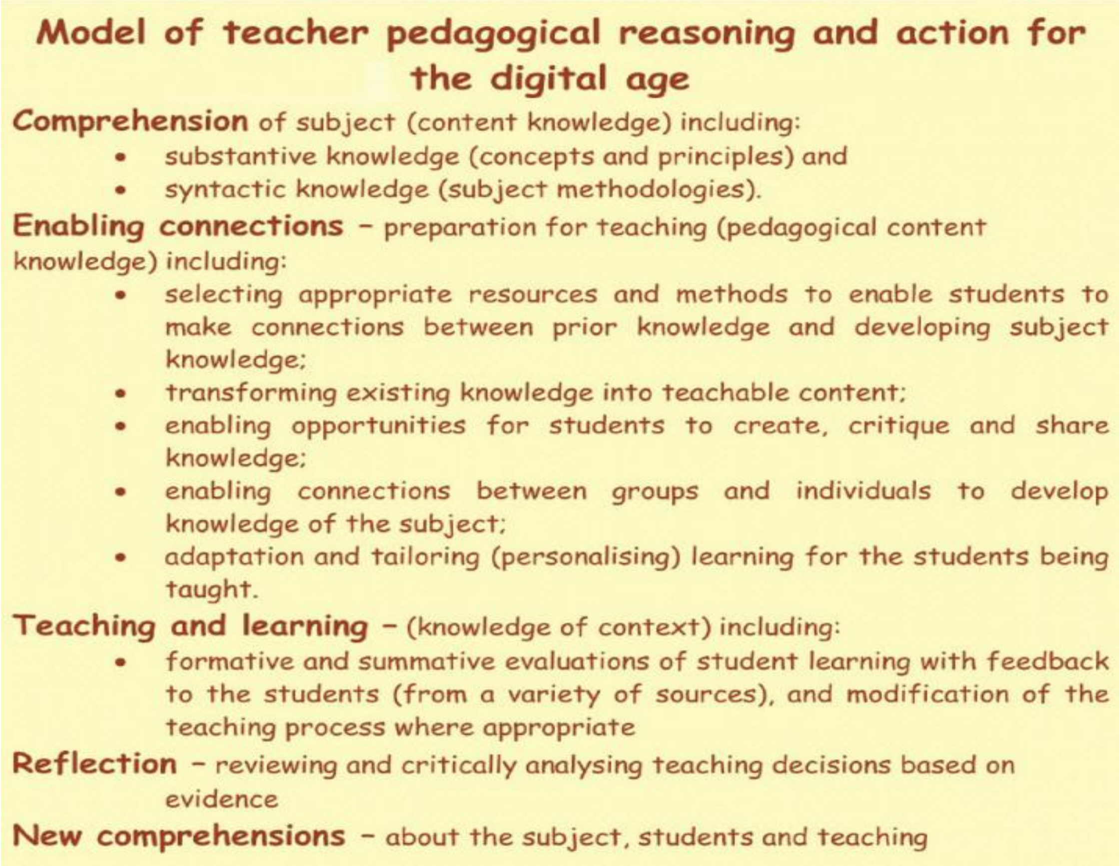


Figure 2.5 Webb's model of pedagogical reasoning (Webb, 2002:312)

Webb (2002) identifies the process of transformation as the crucial feature of this model. The model which was conceptualised in the context of teaching Information and Communications Technology (ICT) in physical sciences is valid. This fact is critical, considering the paucity of research on effective teaching with ICT (Webb, 2002). However, conspicuously absent in Webb’s model is new comprehension as a process and no explanation has been given. The model also does not address the issue of the context of teaching.

2.7.3 Starkey’s model of pedagogical reasoning

To show the influences of ICT, Starkey (2010) proposed a model of pedagogical reasoning and action for the digital age (see Figure2.6). This model has five processes similar to Shulman’s though it has been modified for the digital age. The five processes are comprehension, enabling connections, teaching and learning, reflection and new comprehensions. Thus, the model has three processes similar with the one for Shulman. A description of the processes is made in the diagram below (Figure 2.6).



Model of teacher pedagogical reasoning and action for the digital age

Comprehension of subject (content knowledge) including:

- substantive knowledge (concepts and principles) and
- syntactic knowledge (subject methodologies).

Enabling connections – preparation for teaching (pedagogical content knowledge) including:

- selecting appropriate resources and methods to enable students to make connections between prior knowledge and developing subject knowledge;
- transforming existing knowledge into teachable content;
- enabling opportunities for students to create, critique and share knowledge;
- enabling connections between groups and individuals to develop knowledge of the subject;
- adaptation and tailoring (personalising) learning for the students being taught.

Teaching and learning – (knowledge of context) including:

- formative and summative evaluations of student learning with feedback to the students (from a variety of sources), and modification of the teaching process where appropriate

Reflection – reviewing and critically analysing teaching decisions based on evidence

New comprehensions – about the subject, students and teaching

Figure 2.6 Starkey's model of pedagogical reasoning (Starkey, 2010:.220)

Unlike other models that have indicated the data flows between processes, Starkey's model has not presented this relationship. It is therefore difficult to understand the relationship between the processes and the categories of knowledge needed for each process. Furthermore, the model does not explicitly inform how and where technology plays a role in the PR of teachers. This haziness makes the model difficult to articulate when integrating technology into teaching. The model only identifies PCK as the knowledge required for teaching and does not articulate how PCK and technology interact.

2.7.4 Smart's model of technological pedagogical reasoning

Smart (2016) proposed a new model of technological pedagogical reasoning (see Figure 2.7). The model is a culmination of a study involving the use of digital technologies by teachers across three career stages (beginning, middle, and experienced) in Australia. The model is not cyclical as originally proposed by Shulman but linear. Other researchers (see Nilsson, 2009; Starkey, 2010; Webb, 2002) have suggested the linearity of the process of pedagogical reasoning. In the model, new comprehension is not a process. Smart (2016) argues that a process is defined by an action and a result, for example, transformation, involves a series of actions with a result that include teacher plans, resources and assessment. As for new comprehension it is a change in knowledge where "it is a new understanding that has been enhanced with increased awareness of the purpose of instruction, the subject matter of instruction and the participating teachers-teachers and student…this enriched understanding may grow slowly by accretion…or a single experience may promote a quantum leap" (Wilson, Shulman, & Richert, 1987:120). New comprehension is thus represented as data flow, which influences the process of comprehension, transformation, instruction and evaluation.

Smart's model is different from other models in that it identifies the knowledge base that informs the pedagogical reasoning process. However, it should be clear that there is a repetition of knowledge domains, such as content and pedagogy, as these are included in either PCK/TPACK.

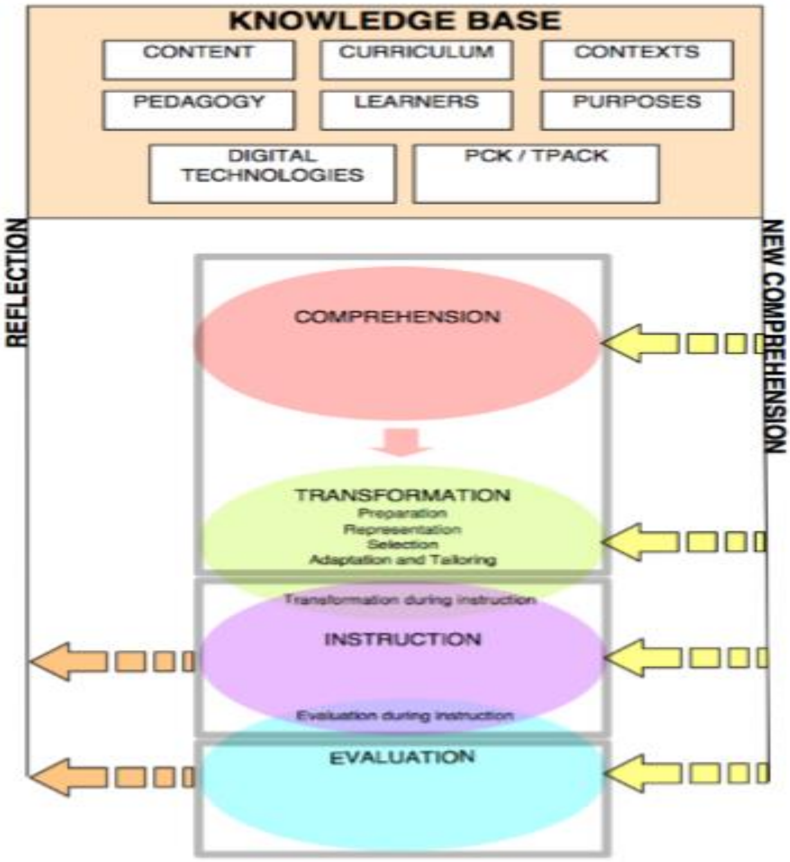


Figure 2.7 Smart's model of technological pedagogical reasoning and action (Smart, 2016:302)

The model also highlights the crossover of processes between transformation, instruction and evaluation. This characteristic of pedagogical reasoning has been hinted though not clearly articulated in Shulman's model. However, Smart (2016) identifies two cross over processes: transformation-during-instruction and evaluation-during-instruction.

Transformation-during-instruction occurs when teachers have to adopt contingency plans and change learning activities temporarily or permanently due to digital technologies not working. Evaluation-during-instruction subsumes class, group and individual verbal questioning, physically checking computer screens for functionality and using digital tools to share progress.

While Smart (2016) views reflection as a process, the model presents it as a data flow from the processes of instruction and evaluation. There is no explanation for this presentation. Furthermore, because of the crossover of processes such as between transformation and instruction, reflection is also bound to occur. Hence, the view of this study is that there should be an arrow linking transformation and reflection and even between comprehension and reflection. In each cycle of teaching, there is room for further improvement. Smart adds another knowledge component of digital technologies but does not articulate the difference between this knowledge component and TPACK proposed by Mishra and Koehler. It is rather obfuscating considering that digital technologies used by teachers in Smart's study can all fall under the label of technology as defined by Mishra and Koehler.

2.8 Theoretical Framework

The theoretical framework is the lens or lenses that the researcher used to analyse the data generated. LeCompte and Preissle (1993) define a theoretical framework as a collection of interrelated concepts that can be used to direct research with the purpose of predicting and explaining the results of the research. In literature several roles that a theoretical framework plays in scholarly work which improve the quality of research have been suggested.

1. Connect the researcher to existing literature (Herek, 1995; Smyth, 2004).
2. Convince the reader of the relevance of the research question (LeCompte & Preissle, 1993; Mishra & Koehler, 2006)
3. Guide the researcher toward appropriate data collection methods (Miller, 2007).
4. Assist the researcher to make predictions of the outcomes and to interpret and analyse the results of research based on the existing literature. The results can be used "to test and critically appraise a theory" (Abd-El Khalick & Akerson, 2007:189).

In light of the roles that a theoretical framework plays in a scholarly work, the theoretical framework that underpins this study is discussed. It addresses how technology was used during the entire teaching cycle from planning, through teaching to evaluating, and as such, a process-based model is deemed the most helpful (Ekanayake & Wishart, 2014).

To be able to collect, analyse and interpret the data, this study used the theoretical framework proposed by Smart (2016) as a lens to unpack the teachers' technological pedagogical reasoning. The framework is an outline of the processes that the teacher was engaged in when planning, teaching and evaluating his lessons. Thus, it is a theoretical/diagrammatic representation of a teacher's practice as represented in Figure 2.7. The model illustrates how the knowledge base of teaching influences the technological pedagogical reasoning. Pedagogical reasoning is a term coined by Shulman (1987). According to Nyamupangedengu (2016), pedagogical reasoning and action describes what teachers have to do in in order to successfully carry out their teaching role within particular contexts. Pedagogical reasoning and action can therefore be said to be a set of processes that are important to the development of a teacher's technological/pedagogical content knowledge (PCK/TPCK).

The knowledge base includes the following knowledge domains which are applicable to this study:

Content: Electromagnetism

Curriculum: CAPS grade 11

Context: Rural secondary school with limited resources

Pedagogy: Learner-centred, inquiry-based instruction

Purpose: To construct the models of magnetic field and electromagnetic induction

Digital technologies: Sets of computer simulations

PCK/TPACK: Technological Pedagogical Content Knowledge

Learners

This study was carried using grade 11 learners at a rural secondary school. The knowledge of learners has also been identified as important in influencing the teachers' technological pedagogical reasoning. In Smart's study, the participating teachers began with understanding the learners' level of understanding and their experience of using digital technologies to determine what will engage them. Nyamupangedengu (2016) also suggests that the knowledge of learners include the alternative conceptions held by learners in that particular topic.

All the knowledge domains identified with the knowledge base for teaching can be viewed as the core of a teacher's professionalism and as a filter for interpreting new experiences, thus guiding a teacher's activities in concrete and specific situations (Brown & McIntyre,1993; Pajares 1992; Putnam & Borko, 1997). They have an influence on the teachers' technological pedagogical reasoning. However, in this study, the researcher seeks to focus on one aspect that of the emerging technology, i.e., computer simulations. This study seeks to understand how the use of computer simulations can create opportunities for the teacher to learn, frame and reframe his teaching practices. The technology serves as a display, instruction, communication, and an interactive medium (Peters, 2003). Emerging technologies possess multifunctional capabilities (Molenda & Bichelmeyer, 2005). They generate open space for action, and at the same time, it poses onto the user certain restrictions which makes possible the emergence of new kinds of actions (Mariotti, 2001). To that end, Laurillard's (2002), classifies media into following categories: Narrative, Interactive, Communicative, Adaptive and Productive.

Narrative media forms are non-interactive and are usually used to present subject content structure.

Interactive media form is engaged when the learner interacts with technology or the teacher. The media referred to in this form is digital where the user can 'navigate and select content at will' by using media such as hypertext, hypermedia, multimedia resources and web-based resources (Laurillard, 2002:107).

Communicative media can support discursive media, in the sense that participants can have space to discuss or debate an aspect of a concept.

The adaptive media is different from the interactive media. The users can change "their state in response to the user's actions" by using "the modelling capability of computer programs to accept input from the user, transform the state of the model, and display the resulting output" (Laurillard, 2002:126).

Productive media are technologies that can be used by learners to articulate their conceptions.

Today's technology affords teachers and learners with the ability to synthesize their own media far more easily and with a greater array of options than previous generations (Sickel, 2019). Kozma (1991) proposes that a medium enables and constrains the instructional approach, and the instructional approach draws on the affordances of the media. The decisions made by teachers involve an understanding of the potential affordances of technology (medium)and a consideration of how they could be used in relation to different aspects of their practice (Holmberg, 2014; Norman, 2013). According to Kennewell (2001), "the role of the teacher is to orchestrate affordances and constraints in the setting in order to maintain a gap between existing abilities and those needed to achieve the task outcome, a learning gap which is appropriate to the development" (p.234).

The term “affordance” according to Gibson (1977) refers to particular property of the environment that is relevant-for good or ill-to an active, perceiving organism in that environment. In this study pedagogical affordances of computer simulations can be regarded as the opportunities provided to the teacher to enhance their pedagogical reasoning process, i.e., the opportunities to enhance the processes of comprehension, transformation, instruction and evaluation. According to Gibson (1986), perceptions play a big role in what the technology is used for. What becomes an affordance is latent and it depends on what the organism perceives to satisfy a need. Different teachers can for instance use the same technology differently because they perceive its affordances differently (Ndlovu, 2015). Therefore, the same affordances of computer simulations may support different decisions and actions in different science teachers. For example, how a grade 11 teacher may use computer simulations is different to how a university lecturer may use the same simulations. The perception one has of an affordance therefore “depends on the information available as well as the person’s disposition” (Webb, 2005:707). However, it is critical to mention that the capability to orchestrate the affordances of computer simulations is dependent on TPACK.

Since affordances of any tool shape its possibilities (Wertsch, 1998), I briefly discuss the affordances of computer simulations as a medium. I present a transformed view of the process using CS, where computer simulations play a mediating role in all the actions of the subsumed aspects. In this transformed view, the focus is on how the pedagogical affordances of computer simulations as an emerging teaching tool (medium) can assist the teacher to understand the content; transform the content for teaching purposes; deliver the content using various instructional strategies; evaluate the teaching and learning of the content and finally reflect on the teaching and learning process. In this manner, the computer simulations influence the teachers’ pedagogical reasoning and influence how CS are used as tools.

I suggest that there is a wide range of actions, which can be shaped or influenced by computer simulations, in each aspect of pedagogical reasoning. As identified by Ottesen (2006), mediated action changes how teachers think, how they control their actions and who they are. Therefore, as teachers become attuned to the use of computer simulations, they gradually acquire a capacity for diverse responses to the potentialities for action. Subsumed in this view is the thought that teachers who have experience in the use of computer simulations display a wide range of actions in their pedagogical reasoning as compared to novices.

2.8.1 Comprehension

As argued by Shulman (1987), to teach is to understand the content as outlined in the curriculum statement (syllabus). Previously, this preparation involved searching for content in the textbooks since these were the major teaching tool to access scientific material (Moreno, Spires & Lester, 2001). In the South African context, science teachers tend to rely solely on textbooks as the curriculum material to teach content (Navy, Luft, Toerien & Hewson, 2018). However, what is clear is that the content on electromagnetism is organised differently in different textbooks. Sometimes the depth to which the topic is covered is different. The non-uniform presentation of content by different authors presents challenges to educators. There is a possibility that physical science teachers are bound to have varied levels of content knowledge. In fact, science teachers have been identified to lack content knowledge (Kriek & Grayson, 2009). In cases where teachers do not have adequate content knowledge, this variation poses a problem for teaching, as teachers might not know where to start teaching and how to approach the topic (Molefe, 2012).

Web-based resources are increasingly becoming popular for accessing information useful for teaching purposes. The search for content is no longer restricted to only textbooks but it involves the search for relevant and appropriate virtual simulations on the internet to address the content as prescribed in the curriculum document. According to Smart (2016), the search for content has taken on a whole new meaning. It is no longer a simple linear process but a never-ending iterative and interactive process. Time and again, new designs of computer simulations are being created as informed by research and new developments in content. According to Correia *et al.* (2019), computer simulations have been extensively tested and evaluated to ensure educational effectiveness. Computer simulations present teachers with the opportunity to understand new developments in content more regularly as compared to the way it is presented in textbooks. I believe computer simulations present teachers with an opportunity to interact with content/ideas in an active way. Nevertheless, the critical aspect of comprehension lies in having an understanding of how the technology is going to be used for teaching and learning. As reported by Smart (2016), teachers need to comprehend how technology works and how it can be used for teaching and learning. Mishra and Koehler (2009) also refer to this aspect as Technology knowledge (TK) and Technological pedagogical knowledge (TPK) respectively.

2.8.2 Transformation

The transformation process is the process during which the disciplinary content is to be "educationally reconstructed" (Kattmann, Duit, Gropengießer, & Komorek, 1996:36) or what I call contextual reconstruction. According to the Model of Educational Reconstruction (MER) (Duit, Gropengießer, Kattmann, Komorek & Parchmann, 2012) science subject matter as well as student learning needs and capabilities have to be given equal attention during the reconstruction process to improve the quality of teaching and learning. The process of contextual reconstruction is concerned with ‘contextualisation’: transforming the content as prescribed in the curriculum statement into a format suitable for teaching and learning within the borders of that context. Duit *et al*., (2012) affirm that contextualisation is critical since science content structure for a certain topic may not be directly transferred into content structure for instruction. It needs to be *elementarized* for it to make sense and be accessible to learners. Teachers must transform the content to suit the context and enable it to constitute a challenging, but accessible problem for learners (Nilsson, 2009). A number of reasons have been suggested for the need to contextualise the content being taught. Contextualisation (1) develops an appetite to know, (2) shows the importance of what they are learning, (3) assists learners in becoming driven to figure out what is going on and (4) emotionally involves learners in the learning (Krajcik, 2016). Shulman (1987) conceptualised the stage of transformation as comprised of four sub-processes namely, critical interpretation (preparation), representation, selection and adaptation and tailoring. Today, some of the sub-processes have been eliminated using technology. The selection of suitable computer simulations is one way to transform the content as well as adapting and tailoring it to the needs of the learners (TK). The selection of computer simulation refers to the action of the teacher in purposefully choosing and adopting computer simulations from diverse websites in order to accomplish the lesson objectives. The process of selecting computer simulations is an attempt to ‘scrutinise’ the teaching material in order to decide whether it is fit to be taught and if it is not, to decide how it could be “made more suitable for teaching” (Shulman, 1987:16). The multimedia nature of computer simulations enables the dynamic representation of knowledge in different modes to cater for the diverse needs of the learner population (TPK). The multimedia nature of computer simulation is a powerful application of ICT that has transformed teaching practices that promote learning activities that are learner-centred and collaborative. The appropriateness of the selected computer simulations has the potential to impact and resource the learners’ comprehension of the targeted science ideas.

After selecting the CS that I intended to use in my lessons, I had to test it by first playing them before I could show them to learners. This aspect of testing is not found in Shulman’s (1987) initial model, and it is important to any teacher that would integrate any educational technology in their lessons. By testing them, I wanted to become familiar with them by identifying the salient components of the visual tools and the ability to understand the concepts they intend to communicate. Consistent with any new technology in a classroom, the more educators use it, the more they become less techno phobic. Familiarity with a technology gives the educator a sense of control like "what to expect when using the tool in a classroom, which reduces their anxieties during implementations" (Bell & Gresalfi, 2017:514). In the process of familiarising myself with the simulation, I formulated possible questions to ask my learners during the lesson. On thinking reflexively about this process, I felt that I was developing authentic and context-based tasks that have not been imposed from a foreign milieu (Webb, 2015). By exercising such authority over content, educators can no longer depend solely on textbooks or workbooks for their lesson plans. Webb (2015) posits that when educators actively take ownership of the content of their lessons, they will not follow the textbook in a rote manner. I also wanted to prepare myself for the questions that learners might ask during the lesson about the computer simulations. Hence, according to Feng and Hew (2005), the selection of technology (computer simulations) is an essential pedagogical reasoning process engaged by educators when they plan to integrate technology into their lessons.

In selecting the simulations, great care was taken to ensure that the simulations were not too complex, to overwhelm the learners which would distract the learning process. The learners had no prior learning experiences with computer simulations. Therefore, in selecting the computer simulations to develop my content knowledge, I did not only consider the learners' backgrounds but also their prior learning experiences. I designed the warm-up activities that complemented the computer simulations. Thus, learners were afforded an opportunity to learn the same content from two different perspectives, both a macroscopic and the microscopic perspective (simulation and real experiment). The design principle used here was that of multi-perspectiveness and multidimensionality. These choices of multi-perspectiveness and multidimensionality were motivated primarily by a broader goal of challenging an image of science, in which a single point of view of the teacher or textbook is privileged (Levrini, Levin, Fantini, & Tasquier, 2019). Learner ideas will not only be welcomed, but they also become topics of discussion or reflection.

2.8.3 Instruction

In this context, the term 'instruction' will simply be defined as all activities (both cognitive and physical) undertaken by teachers and learners which have the intent of bringing about learning (Beauchamps, 2011). Technology could play a transformative role by enabling teachers to exploit a wide range of interactive opportunities with learners during instruction. It could transform the way the teacher organises and manages the classroom (PK). It could enhance classroom communication and the interaction with learners. During instruction, there are varying levels to which computer simulations can be used by teachers depending on the experience and skills.

As presented in Figure 2.7, the use of technology has resulted in the overlap of the processes of transformation and instruction. Smart (2016) terms this process transformation-during-instruction. Initially, Smart (2016) refers to transformation-during-instruction (T-d-I) as occurring when teachers have to adopt contingency plans and change learning activities temporarily or permanently due to failure of working of digital technologies. However, I want to extend the idea and consider T-d-I as occurring even when there is no failure in working of technology. For example, learners can ask questions with ideas which are or are not directly related to the content under consideration. Teachers need to respond to such questions and clarify the ideas that learners would have stated. In other instances, teachers need to link the ideas of the current lesson with ideas from previous or future lessons. These cases are considered as T-d-I. Smart (2016) also identified the overlapping of evaluation and instruction which she terms evaluation-during-instruction (E-d-I). E-d-I occurs when the teacher either probes for prior knowledge or when the teacher moves around the classroom checking for understanding.

2.8.4 Evaluation

The boundary between evaluation and instruction is usually fuzzy and difficult to delineate. An assessment of learning and how the teaching is progressing is usually on-going and not left until the end of teaching. However, the use of ICT enables teachers to execute several approaches to evaluate learners' learning. These include asking direct questions to individuals, groups and/or whole class, peer evaluation, moving around the room and watching over learners (Smart, 2016). These approaches are examples of evaluation-during-instruction. In contexts where schools have adequate ICT infrastructure, teachers use ICT to check learners' assignments and provide feedback, and learners can use digital technologies to prepare and submit assignments. However, in poor schools, this affordance is not feasible.

2.8.5 Reflection

Reflective reasoning is equivalent to what Schön (1983) called reflection-on-action. In this phase, the teacher looks back at the teaching and learning that has occurred, reconstruct, re-enact and/or recaptures the critical events, emotions and accomplishments or failures to derive pedagogical shifts in relation to the choices made in the planning and instruction phases. Based on the pedagogical shifts gained, the teacher may reconstruct and/or re-enact part of the practice in future cycles (Shulman, 1987). Smart (2016) reports that many experienced teachers' reflections focused on their successes in using new digital technologies or using new digital technologies in the classroom for the first time. Though teachers have no regular formal processes for recording reflection, reflections can enlighten all aspects of pedagogical reasoning. As illustrated in Figure 2.7, reflection feeds (informs) the knowledge base of teaching. The insights gained from reflection are added to the prior knowledge base of the teacher as new comprehension.

2.8.6 New comprehension

New comprehension is the new insights gained after a successful pedagogical reasoning cycle. The new comprehension now informs the next cycle of pedagogical reasoning. Teacher gains new insights (pedagogical shift) into his teaching through reflecting on the acts of comprehension, transformation, instruction and evaluation, which usher in a new understanding of content to be taught, of students, of purposes, of self and of the process of teaching itself (Geddis & Wood, 1997). Hence teachers need to be encouraged to have confidence in their own experiences as a basis for their learning and their understanding of their own practice and not rely solely on the dictates of those establishing the parameters of their reflection (Beauchamps, 2015). New comprehensions consist of all that was learned from the cycle of pedagogical reasoning processes and how things might be done differently in a particular context. Obtaining new comprehension also takes into account the selected approach, environmental situations, emotions experienced by students and by the teacher, and other such internal and external factors (Nyamupangedengu, 2016). New comprehension usually does not come immediately or after the reflection stage; it normally takes longer (Shulman, 1987).

This framework or model presented above permits data capture to occur at each process of pedagogical reasoning. The participants and data sources at each stage will be presented in Chapter Three.

2.9 Learning experiences

The anticipated outcomes of any cycle of technological pedagogical reasoning is the development of the teachers' PCK/TPACK (Shulman, 1987; Mishra & Koehler, 2008) and student learning (Nyamupangedengu, 2016). The research by Nyamupangedengu (2016) has revealed different meanings ascribed to their learning experiences by pre-service students in a university setting. The term 'experiences' here refers to the manner in which events, situations, and phenomena are perceived and interpreted by individuals, as they describe their personal thoughts, emotions, and feelings in the context of their involvement in a particular activity (van Manen, 2014). The practice of soliciting learner feedback on their experiences is well established at university level with the learner feedback used to give information to teachers on their instructional practices (Denson, Loveday & Johnson, 2010). Learner feedback on their learning experiences provides valuable information about learners' perceptions of assessment and teaching processes, in addition to increasing rapport between learners and teachers through the process (Stockham & Armann, 1994). Elsewhere, Flutter (2007) posits that learners are able to communicate their vulnerabilities in the classroom, and other learning challenges presented to them when given the opportunity. Levin (2000) opines that feedback on learning experiences is crucial as learners are active participants in their own learning, and the producers of the school performance outcomes.

The current study deals with learners' learning experiences in three categories: the cognitive, affective, and conative domain (Alsop & Watts, 1997; Lelliot, 2007; Nyamupangedengu, 2017). An examination of the learners' descriptions enables teachers to identify categories of experience and the valence of such experience. According to Marton and Booth (1997), "we have to ask learners what their experiences are like, watch what they do, observe what they learn, analyse what learning is for them" (p.16). Assessment should not be limited to what learners know and can do; it also includes how they learn, how they feel about themselves, how motivated they are, and what they do and do not like (O'Donnell, Reeve, & Smith, 2009). There is a dearth of research on the categories of experience afforded when computer simulations are used in low-quintile schools. In our context, learning experiences contain narratives of the learners' thoughts, feelings, and emotions regarding the use of computer simulations in their learning process. Therefore, these three categories can be viewed as lenses that can be used to assess the learners total experience of the learning situation, in order to know the valence of the experiences and the foci of the experiences.

The **cognitive** dimension contains declarative, procedural, schematic, and strategic knowledge. Declarative knowledge refers to the way concepts are linked together while procedural knowledge refers to the abilities to apply this knowledge. According to Shavelson, Ruiz-Primo and Wiley (2005) schematic knowledge includes knowing why (e.g. knowing why the magnetic field changes when the number of turns is increased) and strategic knowledge includes knowing when, where and how our knowledge applies (e.g. knowing where the electromagnetic induction principle is applied). There are assessment methods that have been developed to measure the extent (how much) and structure (how it is organised) of each knowledge domain (see Table 2.2). However, Shavelson *et al.*, (2005) concede that strategic knowledge is rarely ever directly measured but it can be implied whenever other types of knowledge are assessed.

	Declarative knowledge	**Procedural knowledge**	**Schematic knowledge**
Extent	Multiple choice Fill in Science notebooks	Performance assessments Science notebooks	Performance assessments Predict, Observe, Explain Multiple choice

Structure	Concept Maps Cognitive Maps	Procedure Maps	Models/mental maps

Table 2.2 Links between types and characteristics of science knowledge and assessment method (White & Gunstone,1992)

In this study no formal assessment of the different types of knowledge was done for the following reasons: firstly, I wanted learners to be free to participate in this research and secondly to remove the anxiety that is associated with tests/examinations. Instead of pre-setting the types of knowledge, I wanted these to emerge from the learners' statements. Learners' descriptions of what they have learnt during the teaching process and how they can apply that knowledge can be taken as evidence of cognition.

The **affective** dimension refers to expressions of emotions, feelings, beliefs, and values. Evidence emerging from research in science education suggests that learning is influenced by feelings and emotions and that, in turn, learning can influence feelings and emotions (Alsop & Watts, 2000). In South Africa, Kyu, Frempong and Winnaar (2015) report that educational policy is silent on the crucial role of and the integration of the affective domain in learning and as a result educator practice has put less emphasis on them. Sowell (2005) adds, "as important as affective learning may be, it is included infrequently in curricular" (p.74). Koballa and Glynn (2007) posit that the development of complex understanding of science content is facilitated by the affective dimensions, hence, it is important for educators to consider that during instruction.

Anecdotal evidence shows that the humanness of science education is an affective dimension that is being neglected by educators. For example, learners expressed the sentiments that school was boring because of what Alsop and Watts (2000) term a "sanitized antiseptic science" devoid of "informed excitement and animated understanding" (p.138). Researchers have reported a decline in interest and motivation in science learning with physics being singled as the least interesting subject (Osborne & Dillon, 2008; Osborne, Simon & Collins, 2003; Zeyer *et al*., 2013). Therefore, Campbell (1999) laments that

> Conventional science education does us all a disservice, misrepresenting the nature of science and at the same time alienating learners. There is a great need to re-establish the humanness of science. (p.4)

The **conative** dimension describes the way the attitudes influence one's disposition towards ideas, people, thing, and so forth. It is defined as the mental processes that predispose individuals to certain actions (Huitt, 1999; Huitt & Cain, 2005). Conation has a bifurcated disposition. It is composed of two aspects: motivation and volition. The motivational aspect includes among other things goal-orientation, fear of failure, need for achievement, belief in one's own abilities and prospects (Kyrö, Seikkula-Leino, & Mylläri, 2008). The volition aspect entails among others, persistence, the will to learn, endeavour or effort, mindfulness in learning, intrinsic regulation and evaluation processes as well as different control strategies (Ruohotic & Koiranen, 2000). It has been therefore suggested that the desire to perform an action (conation) affects the learning of science (Irwin & Wynne, 1996).

2.10 Summary

The problems encountered by learners in physical sciences could be attributed to the instructional practices adopted by teachers when teaching the subject is taught (see section 2.2.1). Two major approaches are being used by teachers when teaching physical sciences-teacher-centred and learner-centred (see section 2.3). However, in physical sciences, teachers are further encouraged to use the inquiry-based teaching which is learner-centred. Thus, the instructional approach being advocated for meaningful learning in physical sciences is learner-centred, inquiry-based instruction. There are challenges that have been reported as hampering the employ of learner-centred, inquiry-based teaching by teachers. The challenges are cause by both exogenous and endogenous factors. The exogenous factors include the teachers' lack of robust TPACK, and the pressures exerted on teachers to prepare learners for national examinations while endogenous factors include lack of teaching and learning materials and overcrowded classrooms. Technology is emerging as an instructional tool which teachers can adopt and adapt to perform learner-centred, inquiry-based instruction.

In order to integrate technology into teaching and learning, teachers should develop/possess the knowledge domains identified by Mishra and Koehler in their TPACK model. It has been established in the TPACK model the various domain of knowledge required by teachers to successfully integrate technology in teaching and learning and this knowledge is developed through practice. The knowledge domain arises from the intersection of three knowledge domains namely Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK). These knowledge domains inform the teacher's decision on how to use technology in their practice. This knowledge is tacit and developed in practice. The thinking and the decisions taken by teachers when they execute their practice is termed pedagogical reasoning (PR). The PR carried by teachers when using technology has been referred to technological pedagogical reasoning (TPR).

Pedagogical reasoning is a process that teachers do during planning, instruction and after instruction. According to Shulman pedagogical reasoning involves the sub-processes of comprehension, transformation, instruction, evaluation, reflection, and new comprehension. PR has evolved from a period where textbooks were the only source of content for teaching to a period where technological developments is changing the landscape of learning. Different technologies are now entering and becoming *de facto* curriculum materials. Technology, as argued, has potential affordances which teachers can appropriate for use within all the processes of pedagogical reasoning. However, it has been reported that the harnessing of the potential of technological affordances is still a challenge for many teachers. Studies on technological pedagogical reasoning have been carried in developed countries where the classrooms have adequate ICT infrastructure. There is need to investigate TPR in a developing country perspective to understand how teachers integrate technology in teaching and learning. Research suggests that teachers’ ways of using new curriculum materials create meaningful learning opportunities for both learners and teachers. These learning opportunities are breeding grounds for teachers to frame and reframe their instructional practices.

Chapter 3

Research Methodology

3.0 Introduction

In this chapter, I revisit the purpose of this study and then describe the methodology used in this study. Methodology refers to a range of approaches used in educational research to gather data which are to be used as a basis for inference and interpretation for explanation and prediction (Cohen, Manion & Morrison, 2000). The research design (see section 3.2), data collection strategies (see section 3.6), the rationale for using such strategies and data analysis (see section 3.7) are all considered to be part of the research methodology and are outlined in the sections indicated. The ethical issues are also addressed (see section 3.8).

3.1 Purpose of the study

Chapter 1 presented the challenges I encountered when I began teaching at my school. Using technology was self- initiated and aimed at mitigating the encountered challenges and improving my professional efficacy in teaching in an educational context that is not using computers. Already immersed in the organization, I built knowledge of the organization as an actor in the processes being studied (Coghlan, 2007). I have "a personal stake and substantial emotional investment" (Grant & Fine, 1992:433) in this study. Since there were no professional development programmes to capacitate teachers in teaching with technology, I decided to learn-while-teaching on how I can integrate technology into my practice. Mishra and Koehler (2008) proposed that the wisdom of teaching with technology is developed in actual practice. This study is on classroom teaching with technology, and on the interactive relationship between teachers and learners in the dynamic process of classroom teaching (Ye & Cheng, 2018). Thus, the study seeks to explore how does the teacher carry out technological pedagogical reasoning with computer simulations? The purpose is to explore whether Smart's model of TPR can be applied to describe the teacher's instructional practice using computer simulations in a resource-constrained context. Teaching in a resource-constrained environment especially in rural areas is notoriously difficult and trammelled. It is through TPR that teacher's knowledge, skills, judgements, analyses, decision-making processes are manifested and can be studied (Holmberg, Fransson & Fors, 2017). The purpose of exploring TPR to understand the teachers' actions and how these mediated actions not only to create meaningful learning opportunities for disadvantaged learners but also create opportunities for the teacher to learn and change his instructional practices. Without the effort of learning-while-teaching, teachers will miss opportunities to develop TPACK and to effectively integrate technology so that it becomes routine instruction. For long-term success of physical science teaching, teachers should make the use of technology in high school “which marks the final stage of high school science” (Sadler & Tai, 2000:11) a standard practice.

3.2 Research Design

In order to ensure that the evidence collected addresses the research questions, there is need to employ an appropriate research design. A research design is a plan or blueprint of how the research is conducted (Babbie et al, 2001). Research designs can be classified as either exploratory or conclusive. The exploratory research design seeks to provide insights and understanding of the problem confronting the researcher, while the conclusive research design seeks to test specific hypotheses and examine relationships. According to Babbie *et al.* (2001), the reasons for carrying exploratory studies are to: (1) satisfy the researcher’s curiosity and desire for better understanding; (2) test the feasibility of undertaking a more extensive study; (3) develop the methods to be employed in any subsequent study; (4) explicate the central concepts and constructs of a study; (5) determine priorities for future research and (6) develop new hypotheses about an existing phenomenon.

For the teacher/researcher, the use of computer simulations as a teaching tool/resource was a new phenomenon. He wanted a better understanding of the tool and how learning might can be enhanced with the support of the tool. Eventually, he wanted to able to create contextual learning situations. This study is taking a large view (Hamilton & Pinnegar, 2014). A large view is in contrast with a small view. A small view is seeing schooling as a place where test scores, time on task, management procedures, ethnic and racial percentages and accountability measures are important. Also, it ignores the faces and gestures of individuals, of actual living persons (Greene, 1995:11). Seeing large is to see individual events, persons, or contexts more clearly and develop practical responses to the difficulties of the time and place (Schwab, 1970).

Action research is the most appropriate design because of the central position of the teacher in addressing issues that are practical and relevant to the working and learning environments. The teacher investigated what is problematic and relevant to them in his work. Through this small act he started to question and go against the long-accepted educational hierarchy (Chadwick, 2017). Action research can be a form of staff development and professional development that can improve teachers’ instructional practices, thereby enhancing classroom learning.

3.2.1 Action Research

There are various terms synonymous with action research, such as classroom research (Hopkins, 1985), self-reflective enquiry (Kemmis, 1982), exploratory teaching and learning (Allwright & Bailey, 1991), educational action research (Carr & Kemmis, 1986), diagnostic teaching (Bell et al, 1980), practitioner research (Zeichner & Noffke, 2001), teaching experiment (Meng, 2013) and teacher research (Arif, 2002). Some define action research rather generally while others are specific. What is common among all the definitions is that action research is intended to give solutions to challenges/problems affecting teachers in their practice. For example, Corey (1953) defined action research as the process through which practitioners study their own practice to solve their personal practical problems, while Mills (2003) define action research as a practical approach to professional enquiry in which the research aims to understand professional action from the inside, carried out by practitioners in their own practice. Thus, action research addresses issues that are practical and relevant to the context of teachers which Babione (2015) argue are multifaceted and unpredictable real-world environments. She further suggests that the social and cultural factors that surround and permeate schooling need to be incorporated in educational action research.

3.2.2 Types of Action Research

At the classroom level, three types of action research is conceptualised based on the role teachers play, especially with regard to exactly who maintains control (Carr & Kemmis, 1986; Grundy, 1982; Kemmis, 1993). The three modes are: technical, practical (also called interactive) and emancipatory (see Figure 3.1). Each mode has a distinct goal.

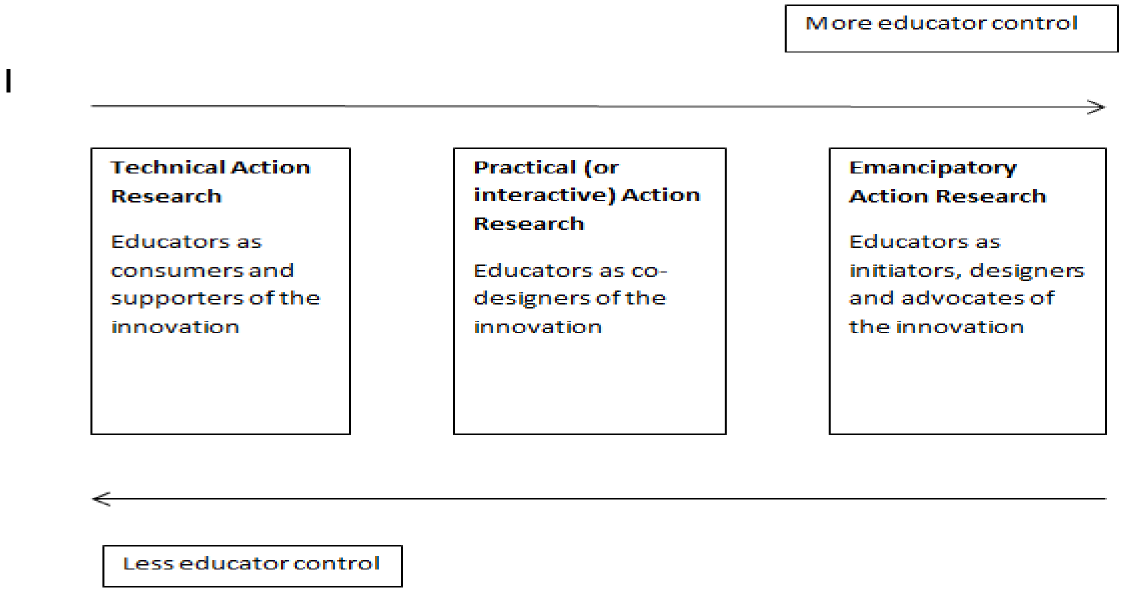


Figure 3.1 Types of action research adapted from Grundy (1982:243)

In technical action research, the researcher is the initiator of an intervention to address a specific problem that s/he has identified. The researcher identifies teacher/s to facilitate with the implementation of the intervention. In practical action research, the researcher and the teacher work together to identify potential problems, their causes and potential interventions. The problem is defined after the researcher and the teacher dialogue and a mutual understanding is reached. In emancipatory action research, the teacher identifies a problem that is specific to his or her own classroom. The teacher then designs the intervention and implements the innovation. For example, the problem of poor performance by learners in physical sciences in South Africa is well documented (Mnqele, 2017; Zenda, 2017); it is a national problem, which has even caught the attention of university academics (Sethusha, 2015; Stephens, 2018). In technical action research, the agenda is driven by university academics while teachers play secondary roles of being research subjects/participants. They are the object of research. The advantage of technical action research is the expertise of university academics in research. However, for technical action to be successful it must promote and respond to the teachers (Llorens, 1994). Academic research has been seen as disconnected from the daily lives of teachers, it is rarely promoted among teachers as critical to their practice. Even the articles published in journals are not accessible to teachers, they do not resonate the daily issues affecting teachers and their practice. Teachers are involved in research as participants in initiatives or agendas driven by academics (Kinskey, 2018; Sibomana, 2016). Hence the audience of such research articles in journals remain in the academia. Teachers are not passive consumers of knowledge; they are producers and users of their own knowledge as well (Han & Feng, 2015). In practical action research, mutual cooperation is possible if the skills and expertise of the teacher and university academic can blend and complement each other. In most cases, the teacher may not possess advanced research skills to complement that of the university academic. Emancipatory action research is both empowering and transforming to teacher practices. This perspective of teacher empowerment refers to the teachers' small measures of authority and their ability to act on them (Dierking & Fox, 2016). The small nuggets of teacher authority seized energizes them to go beyond questioning the status quo and to problematize current educational practice. Then, they proactively and collaboratively develop solutions besetting their practice (Bennett, Athanases & Wahleithner, 2016; Razfar, 2011). By taking greater responsibility of what happens in the classroom, teachers do not need to be told what to do from the outside. Instead, they trust themselves enough to take the risks in order to facilitate changes in classroom practice and learner achievement. Inherently, a problematizing orientation fundamentally leads to a transformative consciousness whereby one sees themselves as a subject who can transform the world rather than be passive recipients of the actions of more dominant groups (Freire, 1970).

The study posits that emancipatory action research is the basis for effective teaching in physical sciences especially in rural schools beset with a myriad of problems such as lack of resources/materials, learners with weak conceptual knowledge, disciplinary problems, and teachers with low PCK and CK. These circumstances can promote research-oriented teachers to think differently and seek for the solutions to these problems. Therefore, any improvement in the quality of science teaching is dependent on the involvement and co-operation of the science teachers themselves. Any suggestions in the improvement of teaching must be obtained by research, with teacher participation. When teachers engage in reflective inquiry like emancipatory action research, they are more intrinsically inclined to investigate questions situated in their particular context. Therefore, instead of lamenting over the poor performance of learners and attributing these issues on outside forces, teachers become architects of authentic educational reforms that address their particular concerns of their context. Thus, emancipatory action research became the most suitable research style for this study because it is driven by personal reflection.

3.2.3 Models of Action Research

Three principal models of action research in literature incorporate a process of five steps. The models have a variety of differences but common to the models are the steps of data collection and analysis and acting on an identified problem. The models are summarised in Table 3.1:

	Kemmis & McTaggert (1990)	**Sagor (1992)**	**Calhourn (1994)**
Step 1	Planning	Problem formulation	Selecting the area of focus
Step 2	Acting	Data collection	Collecting data
Step 3	Observing	Data analysis	Organising data
Step 4	Reflecting	Reporting of results	Analysing and interpreting data
Step 5	Re-planning	Action planning	Taking action

Table 3.0.1 Process steps of the models of action research

While in theory the 5-steps have been represented as separate, in practice these steps overlap. For example, in this study the teacher was involved in all the steps of action research, therefore teacher was also making observation when he was acting.

3.2.4 Application of action research

In this study, the emancipatory action study using the Kemmis and McTaggert model was adopted. The Kemmis and McTaggert (1990) model was chosen because it aligns closely with the processes of pedagogical reasoning and action (as described in section 2.6). The process of planning corresponds to the process of comprehension and transformation, while the steps of acting and observing corresponds to instruction, the step of reflecting corresponds to the processes of evaluation and reflection while the step of re-planning correspond to the process of new comprehension. Furthermore, another reason is the opportunity given to the teacher-researcher to explicitly observe and reflect on the process. The research process is described as:

Cyclical and composed of five sequential phases: plan, act, observe, reflect and re-plan (Figure 3.2). The curriculum policy document, computer simulation suites in addition to science textbooks were used as artefacts to **plan** for the teaching of electromagnetism. The planning involved the sub-processes of **comprehension** and **transformation** which entailed an understanding of how the computer simulation suites would be used, to teach the content (electromagnetism) that is accessible to the learners. The transformation process involved the selection of the computer simulations which were deemed relevant to teach the content. The planning process resulted in the design of a lesson plan or the curriculum-as-planned. Two lesson plans were designed for the topic (see Appendix 4). The **action** stage involved the sub-process of **instruction** which were lessons lasting 35 minutes each. The computer simulations were projected on a screen and used in a guided inquiry mode in a whole-class setting. It was during **evaluation-during-instruction** that the researcher began data analysis. Concurrently with the **action** stage, an observer, a senior university science education lecturer was present **observing** the process of instruction. The lessons were also video recorded (see section 3.12) to assist the teacher in the reflection process. Lastly, after the lesson, the researcher and the observer **reflected** on the lesson (curriculum-as-implemented): the observer reporting on his/her observation and the researcher reflecting-on-action (evaluation-after-instruction). The process is not straightforward and simple as the diagram suggests. Rather it is more spiral in nature. The later iterations were used to challenge and refine the results of the first iteration. If the desired outcome would not be reached, the researcher is then prompted to employ the pedagogical reasoning process as depicted in the Smart (2016) model.

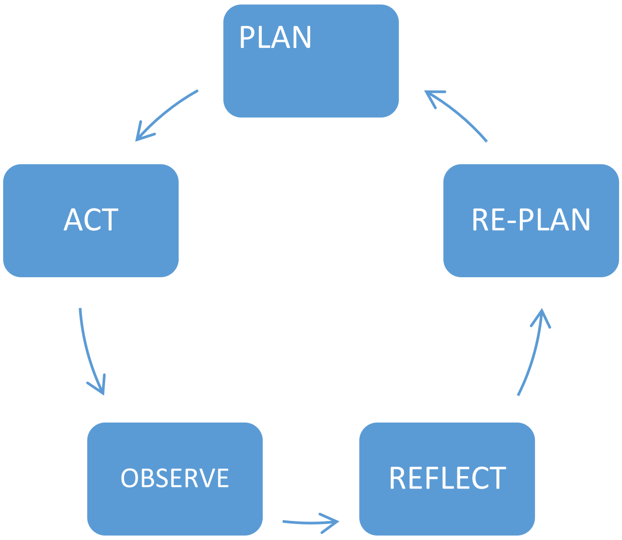


Figure 3.2 The action research cycle

Collaboration with colleagues and/or critical friends.

Action research is not a solitary activity (May, 1993). Price (2001) who asserts that action research should be “intentional, collaborative and democratic in intent and process” (p.43) shares the same view. While this study is a personal-initiated inquiry that is motivated by the desire to improve the way l teach physical sciences using technology in a particular context; it entails collaboration with other. Perhaps the greatest argument for cooperation is suggested by Elliot (1993). He argues that:

> Individual teachers cannot significantly improve their practices in isolation without opportunities for discussion with professional peers and others operating in a significant role relationship to them. (p.176)

This thought is also advanced by Fullan (2007:297) who writes that (teachers) need access to other colleagues in order to learn from them.

Japanese and Chinese teachers work collaboratively on research as they continuously seek to improve their teaching (Darling-Hammond *et al.*, 2010). Collaboration involves enlisting a colleague or colleagues to engage in conversations to improve practice (Nyamupangedengu, 2015). It serves to validate individual analyses, thereby addressing potential biases. I have shared my work and sought feedback from colleagues at various platforms such as research schools and international conferences. Hargreaves and Fullan (2012) claim that without feedback and support teachers will be short of professional capital. In addition to colleagues, l shared my work with a *critical friend*. The term coined by Kemmis and McTaggart (1988) refers to a “person who will listen to a researcher’s account of practice and critique the thinking behind the account” (p. 256). According to

Samaras (2011), critical friends are trusted colleagues who serve to mediate, provoke and support new understandings. The element of being critical does not mean being judgemental or evaluative, but to provide optimal feedback, enhance self-reflection, help articulate and make explicit one's thinking, and ease anxiety (Beslin *et al.*, 2008). Costa and Kallick (1993) also echoed this thought in the following statement when they describe the essential work of a critical friend:

> A critical friend, as the name suggests, is a trusted person who asks provocative questions, provides data to be examined through another lens, and offers critique of a person's work as a friend. A critical friend takes the time to fully understand the context of the work presented and the outcomes that the person or group is working toward. The friend is an advocate for the success of that work. (p.50)

A university lecturer and a head of a science department at another school were the critical friends in this study. The lecturer is an established academic in the field of science education. The critical friends served to extend the teachers' analyses beyond his personal views thereby addressing potential biases. The critical friends were able to examine and validate the researcher's interpretation of pieces of data to check the interpretations (McNiff & Whitehead 2006). In my discussions with the critical friend, we did not use any conversation protocol during our interactions. The discussions were centred on the observations made by the critical friends and informed by the RTOP. However, conversation protocols have been used in professional learning communities which is a network of 5-12 teachers involved in action research (Blake & Gibson, 2020).

3.3 Participants

The participants in this study were the teacher, who was also the researcher and conductor of the study, learners from grade 11 physical sciences classes who were taught by the teacher/researcher, and critical friends. The first critical friend who observed the lessons for the first two iterations was a University senior lecturer with a background in science education. Due to commitments, this university lecturer was not available for the third iteration. Therefore, a second critical friend was selected who was the head of the science department (HOD) at a different school. The HOD was unknown to the researcher and had not interacted with him previously.

Furthermore, both critical friends used the same instrument to critique the researcher. It was difficult to ensure that they were on the same level as the first critical friend were a university lecturer and the second was the head of the department (HOD). The university lecturer observed my classes using the RTOP observation schedule (see section 3.6.2.1), while the HOD was given the video recorded lessons to observe and make comments (see Appendix 11) using the RTOP observation schedule. Both critical friends provided different perspectives/insights into my lessons. The university lecturer suggested that it was also important to involve the learners in the manipulation of the computer simulations. The HOD suggested that the learners' desks were supposed to be arranged in such a way that the learners were facing each other in a group.

There were two classes of Grade 11 learners who opted for physical sciences during 2016. For the first iteration (third quarter of 2016) of the Action Research cycle, 67 learners of a Grade 11 class were selected[9], where the class was comprised of 14 boys (29,3%) and 53 girls (70.7%). Their average age was 17.5 years old.

For the second iteration (third quarter of 2016), 58 learners in the second physical science class were selected[10]. This class contained 17 boys (20.9%) and 41 girls (79.1%). The average age was 17.2 years old.

The third iteration (third quarter of 2017) involved only one class with 65 learners, comprising 19 boys and 46 girls since there was only one class. All the classes were of mixed ability since they were not streamed (or tracked). Streaming learners in schools involves separating learners into classes based on their intellectual or academic ability.

3.4 Instruments

3.4.1 Curriculum documents

Curriculum documents are materials that teachers use when planning for teaching and learning (Schwartz, Gunckel, Smith, Covitt & Bae, 2008). The way teachers use curriculum documents involve them making decisions based on their own beliefs, goals, pedagogical content knowledge, and subject matter knowledge as well as knowledge of their learners (Bismarck *et al*., 2014). Curriculum documents have the potential to support teachers' capacity to make pedagogical decisions that allow them to enact with the curriculum (Schwarz *et al*., 2008). While novel in educational technology research, there is a precedent for using classroom artifacts and lesson plans as proxies for teacher practices (Darling-Hammond, 2010; Silk, Silver, Amerian, Nishimura & Boscardin, 2009). In this study, curriculum documents such as the national curriculum policy (CAPS) (DBE 2011) and grade 11 textbooks (Study & Master Physical Sciences) were used as sources of data collection to compile the lesson plans (artefacts). These sources were

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[9] This class was selected because it was the one which the critical friend was able to come and observe.

[10] This class was selected because it was the one that I managed to get a colleague to come and video-record.

consulted for planning purposes, which according to the theoretical framework (see section 2.9) involves the comprehension and transformation of the content knowledge.

3.4.2 Classroom Observations

In order to observe the classroom, it is essential to capture the events of the classroom as accurately and objectively as possible, as observation makes a record of impressions (Allright, 1988; Wajnryb, 1992). Accordingly, Williams (1989), opines that classroom observations should be “developmental rather than judgemental” (p. 85) in the sense that they offer opportunities for teachers to improve their awareness, abilities to interact and evaluate their own teaching behaviours (Maingay, 1988). Hence, classroom observations together with other techniques could give a more reliable and fuller estimate of the teacher’s pedagogical reasoning and the learners’ reflection on the teaching.

Classroom observations afford the collection of more detailed, holistic and contextual data not permissible by interviews or other methods (Cohen, Manion & Morrison, 2000). Such data has the potential of providing greater insights into complex issues that have to do more with actual practice. It allows the researcher to observe what is happening rather than relying on perceptions of what is happening (Opie, 2000).

Gaining a portrait of the pedagogical reasoning of teachers requires observing them as they carry out instructional duties in their classrooms. Classroom observations were conducted to understand teacher’s behaviours bounded within an activity such as a specific lesson. Thus, observations were made looking for insights principally on the instruction stage of the pedagogical reasoning process, such as the enactment of the comprehended and transformed content. According to the theoretical framework, this third stage is where experienced teachers reveal their expertise when delivering engaging experiences with their learners and their ability to facilitate, in a meaningful manner, a learning environment for addressing learners’ issues (Youngs & Bird, 2010). By systematically observing a teacher across a cycle of instructional tasks, one may be able to understand his/her reasoning (Wilson, 1988) as well as to develop a partial inventory of the understandings and assumptions that underlie his/her actions (McDiarmid & Ball, 1988). A variety of strategies exists for conducting classroom observation in secondary settings include observation protocols and video-recordings of classroom instruction.

3.4.2.1 Classroom Observation Protocols

Classroom observation instruments have been used in science education. Two examples of such instruments are the Teacher Behaviour Inventory (TBI), Danielson observation protocol and the Reformed Teaching Observation Protocol (RTOP).

Teacher Behaviour Inventory (TBI)

The TBI was designed by Murray (1983) and requires observers to rate teachers on 124 items after the conclusion of an observed class. These items are categorised according to six categories, namely (1) Enthusiasm, (2) Clarity, (3) Interaction, (4) Task orientation, (5) Rapport and (6) Organisation. However, the TBI is designed for lecture-oriented teaching. Teachers are being dissuaded from lecture-oriented instructional practices to hands-on active learning methods (Hora & Ferrare, 2013). Another weakness of the TBI is that it rarely refers to digital technologies such as computers. Therefore, this tool was excluded.

Reformed Teaching Observation Protocol (RTOP)

In order to ascertain whether the pedagogy is aligned with the reform principles, the Reformed Teaching Observation Protocol (RTOP) (Sawada *et al.*, 2002) was adopted to capture those characteristics that define "reformed teaching" in this study. The Evaluation Facilitation Group of the Arizona Collaborative designed the RTOP for Excellence in the preparation of Teachers (ACEPT). It is a 25-item classroom observation protocol where items are grouped according to the five dimensions of reformed teaching: (1) a pedagogy of inquiry teaching, (2) content or subject matter knowledge, (3) pedagogical content knowledge, (4) community of learners and (5) reformed teaching which represented how teachers encouraged divergence of thinking and capitalised on learners' input. The use of technology is not explicitly mentioned in the RTOP instrument. Therefore, both the university lecturer and HOD were requested to write field notes. These notes helped to provide more feedback on teacher's practices that could not be observed in the RTOP instrument. It also provided an opportunity for the teacher to reflect on his lessons.

3.4.3 Videorecording of lessons

Video recording is the filming of an event, which captures the physical happenings of that event that is both the audio and the visual (Nyamupangedengu, 2016). Video is increasingly the data collection tool of choice for researchers interested in the multimodal character of social interaction (Jewitt, 2012). Furthermore, video recording is necessary "whenever any set of human actions is complex and difficult to be comprehensively described by one observer as it unfolds" (Loizos, 2008:149). One hour of teaching is a complex activity that cannot be reduced to a decontextualized, single behaviour of an individual teacher (Spillane, 2006). It is a multifaceted activity that involves the interaction of individuals (teacher and learners) with artifacts within different tasks in an integrated whole. Thus, according to Hora and Ferrare (2013), classroom instruction is viewed as a system which encompass the use of specific teaching methods, the types of cognitive engagements that learners experience, and the use of instructional technology.

The matrix of interaction between the teaching methods, cognitive engagements and instructional technologies represent repertoires of practice for individual teachers (Gutierrez & Rogoff, 2003). Therefore, the use of video enables the teacher to notice both apparent and less apparent aspects of his repertoire, essential components of successful instruction. An awareness of such aspects develops and deepens the understanding of the complex nature of teaching.

Coffey (2014) and Star and Strickland (2008) opine that videos can potentially assist the teacher develop the ability to *notice* what is occurring in the classroom from a “self-as-observer perspective” (Quigley & Nyquist, 1992:326). According to Sherin and Van Es (2005), noticing encompasses three different components. The first dimension is the capacity to determine what is important in a teaching situation. In a typical classroom, there are numerous patterns of interaction and events occurring concurrently as a result of the use of teaching methods, cognitive engagements and instructional technologies. Therefore, the need to focus attention to the most salient of these events is important. The second dimension is to ground what has been observed to broader principles of teaching and learning. Lastly, observations entail teachers making judgements about specific teaching situations based on the personal knowledge and experiences.

Accordingly, it helps teachers to divert their attention from general perceptions of lessons and focus on complex analyses of classroom interactions, prioritise learner thinking, and identify areas for self-improvement (Laparo, Maynard, Thomason, & Scott-Little, 2012; Rosaen *et al.,* 2010; Santagata & Guarino, 2011). With deeper insights, teachers are empowered to make meaningful changes in the classroom.

Cochran-Smith *et al.*, (2016) noted that reflection is a vital component of teaching. However, I concur with Palliotet (1995) that reflection is a complex task that needs to be aided. In teacher education, reflecting on videos of teaching has become a common practice (e.g., Hawkins & Park Rogers, 2016; Rosaen, Lundeberg, Cooper, & Fritzen, 2010). For teachers, Calandra, Brantley-Dias, Lee and Fox (2009) advise the use of video recording of their teaching as a basis for focused reflection. Rich and Hannafin (2009) proffer that specific, ubiquitous, and easy to use tools, such as video-recording and reflective analysis could encourage deliberative reflective behaviour. Video recording oneself teaching is a way to catalyse and enable self-reflection, “an action necessary for better practice and an innovative consideration of addressing teaching challenges and student learning” (Pellegrino & Gerber, 2015:67). I concur with Goodlad (1984) that with the availability of resources for videotaping lessons for purposes of self-examination, teachers can engage successfully in a considerable amount of self-improvement.

According to the World Bank (2010), policymakers and teachers seeking to improve teaching using ICT could use low cost video recording (World Bank, 2010). The method has been used in countries such as the United States, Namibia, Macedonia and Liberia as a tool for teachers to improve their own teaching practices (ibid).

There were two main reasons for making the videos. Firstly, video recording the researcher's lessons afforded him the opportunity to reflect critically on the teaching situation to identify evidence to unpack and reflect on his technological pedagogical methods. It afforded him the opportunity to look at what he had planned (the espoused curriculum) (Kim, 2017) and what actually transpired (the enacted curriculum) (Kim, 2017) in the class and discover the dissonance between the two. He was able to pause, annotate, rewind and replay the video (Calandra, *et al.*, 2009) which enabled him to move from a superficial reflection on vague recollections of classroom events to more critical and evidence-based analysis of how the lesson unfolded (Rosaen, *et al.*, 2010). Structured self-reflection plays an important role in teacher's professional growth (Centre for Education Policy Research, nd).

Secondly, the video recordings were used for feedback from the critical friend. The critical friend that was previously used was unable to come to the school again as he had other commitments and could not observe his lessons in real time and provide him with the critical feedback after the lessons. The solution to this problem was to have the critical friend to evaluate the teacher's lesson via the video recordings and use the RTOP instrument.

3.4.4 Focus group discussion (FGD)

The FGD was a method to elicit from learners their cognitive, affective and conative experiences on the phenomenon under study. It was not used to obtain in-depth information of their understanding of the particular concepts of magnetic field or electromagnetic induction. FGDs were used to generate information on the collective experiences of the learners. The essence of using FGDs with the learners is that they create the possibility of co-constructing ideas, drawing out a variety of responses and enabling participants to hear and respond to the ideas of others (Smithson, 2000). Table 3.3 presents the advantages and disadvantages of the Focus Group in relation to other research methods.

Advantages	**Disadvantages**
• It is comparatively easier to drive or conduct.	• The researcher has less control over the data that are generated.

It allows to explore topics and to generate hypotheses. It generates opportunity to collect data from the group interaction, which concentrates on the topic of the researcher's interest. It has high "face validity" (data). It has low cost in relation to other methods. It gives speed in the supply of the results (in terms of evidence of the meeting of the group). It allows the researcher to increase the size of the sample of the qualitative studies.	The data analysis is more difficult to be completed. The interaction of the group forms a social atmosphere, and the comments should be interpreted inside of this context. It demands interviewers carefully trained. It takes effort to assemble the groups. The discussion should be conducted in an atmosphere that facilitates the dialogue.

Table 3.0.2 Advantages and disadvantages of focus group discussions based on Kruger (1994) and Morgan (1988)

Group size is an important consideration in focus group research. The optimum size for a focus group is six to eight participants (excluding researchers) but focus groups can work successfully with as few as three and as many as 14 participants. Small groups risk limited discussion occurring, while large groups can be chaotic, hard to manage for the moderator and frustrating for participants who feel they get insufficient opportunities to speak (Bloor, Frankland, Thomas, & Robson, 2001). Three groups with six learners each were involved in the FGDs.

Piloting of the interview questions

In 2015, I requested six of my learners for permission to interview them about their views of my teaching. The reason why I interviewed them was to experience how to conduct an interview and possibly assist the person who would be doing it in my study. It would be likely that I would not find a trained person to conduct the interview.

The initial interview guide had only five questions (see Box 1).

Box 1 : Interview Guide

1.Have you used computer simulations in your learning before in any subject/grade?

2.Can you describe your experiences with learning with computer simulations?

3. If you were to make a suggestion, how can we use computer simulations in learning to enhance your learning?

4. What have you learnt ‘new’ about magnetic fields and electromagnetic induction?

5. In what ways (if any) do computer simulations assist you in learning of the topics?

My first interview did not yield as much information as I would have wanted. Learners did not clearly understand the word “experiences”, so they could not clearly articulate their ideas. I reflected on this situation with my critical friend who then suggested that l should break the word experience into terms or words that learners would understand. From these interviews, I learnt an important attribute that an interviewer should have, and that is the ability to elicit ideas from an interviewee (Trumbull, 2012). Otherwise, I am likely to miss important data. From my pilot study, I discovered that learners do not provide complete details or information that I needed. It is only after probing further that learners are able to articulate themselves. The process of getting the information is not linear and straight forward. The process is iterative and creative.

In the final study, the questions were altered to six questions (see Box 2)

Box 2: The Interview Guide

1. Have you ever used computer simulations before in your learning in any grade/subject?
2. Can you tell me about what you like about learning with computer simulations? Why?
3. What don’t you like about computer simulations? Why?
4. If you were to make a suggestion, how can we use computer simulations in learning to enhance your learning
5. What have you learnt ‘new’ about magnetic fields and electromagnetic induction?
6. In what ways (if any) do computer simulations assist you in learning of the topics?

Questions 2 and 3 were used to elicit affective experiences, while question 5 was to elicit cognitive experiences. Conative experiences are also intertwined with both cognitive and affective experiences. Hence, conative experiences can be elicited when considering cognitive and affective experiences (Huitt & Cain, 2005).

3.4.5 Teacher's Portfolio

In South Africa, teachers should possess a file referred to as a teachers' portfolio. This portfolio is an important document with records of their teaching practice. Portfolios include but are not limited to lesson plans, official records, learners' continuous assessment information, performance statistics, schemes of work, diaries, evaluation reports, work schedules, pace setters, curriculum policy. A teacher's portfolio is a record of his or her pedagogical decision-making and instructional practice at a given time (Seldin, Peter & Associates, 1993). For this study, two documents from the portfolio were used: lesson plans and the reflective journal.

3.4.5.1 Lesson plans

Lesson plans can be used to assemble evidence of teacher practice (Darling-Hammond, 2010). They have been used to identify instructional practices of teachers seeking National Board Certification in the United States of America (Silver *et al.*, 2009). Used as a proxy of the teachers' pedagogical reasoning, lesson plans are teaching aids that outline the course of instruction for one class by specifying what learners are expected to learn (learning objectives, subject matter), how the teaching and learning process will be organized (learning activities, teaching approach), and which resources are needed (study materials, technology) (Janssen & Lazonder, 2015). Two lessons plans were designed for the purpose of facilitating the teaching of electromagnetism content knowledge. These lesson plans (see Appendix 4a & 4b) had a common structure with four sections:

1. Introduction: Macro representation of the phenomenon to arouse interest in the lesson
2. Demonstration: Micro representation of the phenomenon
3. Group/Class discussion: Making links between macro and micro representations
4. Conclusion

When planning for my lessons, I first consulted the curriculum policy document (see Appendix 2) to understand the content that was to be taught. As I was planning, I made use of the following driving questions:

1. What are the objectives[11] for this lesson?
2. What are the challenges that learners might have in understanding this topic?
3. What are the misconceptions that learners have on this topic?

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[11] The curriculum document does not plainly state the objectives but the content to be taught hence it is up to the individual teacher to frame the objectives of their lessons.

4. What can the appropriate computer simulations be used to achieve these objectives?
5. What opportunities are presented to learners by using these computer simulations?
6. What is required of learners when using computer simulations?
7. What support might be required of learners to learn using computer simulations?
8. What will I need to do as an educator as I use computer simulations?
9. Are there any links to prior or future learning?
10. What other materials are required?
11. What are the limitations of computer simulations?
12. How will the learners be assessed?

These questions implicitly reveal the teacher’s pedagogical reasoning in terms of how he planned to teach the content knowledge and revealed how computer simulations were used. I added the last two questions after the second and third iterations respectively.

These questions were instrumental in designing learning activities, which involved interactions between the teacher and the learners with computer simulations. These learning activities were designed to engage learners in (a) constructing their knowledge of electromagnetism, (b) developing science skills for example, observation, cooperation, communicating evidence, constructing explanations, and visual thinking and (c) creating positive attitudes and interest in physical sciences (DBE, 2011).

3.4.5.2 Reflective journal

An important component of classroom instruction/inquiry is reflection as a mental action that distances the person from events in order that they may be viewed in an objective manner (Shulman, 1987 as stated in van Manen, 1991). Reflection involves thinking about past or on-going experiences or events, situations, or actions to make sense of them as then to inform future choices or actions (Duquette & Dabrowski, 2016). Critically, the intention of reflection is not to deny or reject unpleasant thoughts, feelings, or sensations. Rather, it is to cultivate a clear and open receptiveness of our lived experience (Bishop *et al.*, 2004; Cullen & Brito, 2014). Reflection can occur individually or collaboratively. At an individual level, reflection occurs through engaging in journal writing. Collaboratively, it occurs in discussion with critical friends or more knowledgeable individual like university professor (Hatton & Smith, 1995). Educationally speaking, reflective practice is the starting point for improving quality teaching, as this process transform teacher from blaming the situations on external forces, to one which takes responsibility of improving teaching. Reflection challenges the ideas that teachers hold in relation to new experiences.

3.5 Validity and reliability of the study

3.5.1 Validity of the study

Qualitative research has its defenders, but also some detractors who question the validity of a research based on stories that may or may not be plausible (Phillips 1994). Therefore, concerns with action research have been raised on issues to do with objectivity and validity. On the issue of objectivity, researchers need to understand that a classroom is not a laboratory. Educational contexts cannot be controlled like physical phenomena (Taber, 2000). They are complex dynamic and social systems with many moving parts, all of which may need to interact with one another at any given instance (Megowan-Romanowicz, 2010). Stenhouse (1981) asserts:

> The problem of objectivity seems to me as a false one. Any research into classroom must aim to improve teaching. Thus, any research must be applied by teachers, so that the most clinically objective research can only feed into practice through an interested actor in the situation. There is no escaping the fact that it is the teacher's subjective perception, which is crucial for practice since he is in a position to control the classroom (p. 157).

The challenges with validity in action research stem from at least three reasons: (1) it is carried out by teachers or teachers in collaboration with more 'formally' educated researchers, (2) it is perceived as qualitative research and (3) it focuses on local concerns instead of representative samples (Lederman & Lederman, 2015). Hence, proponents of action research insist on their own validity criteria that are different from positivistic and naturalistic research (Anderson & Herr, 1999; Newton & Burgess, 2008). Research is not, in the words of Conle (2001), "strategizing in order to win others to my own position' but promoting 'mutual understanding" (p.23) with a view to facilitate a process of change among the participants involved in the research. Action research may therefore be considered as a process for co-generating legitimate knowledge with the participants who are one of the objects of the study, with the aim of generating a democratic and participative process (Greenwood & Levin, 1998).

In action research, Moghaddam (2007) suggested that "validity refers to the reasons we have for believing truth claims" (p.236). In that regard, Anderson and Herr (1999) suggested that action research must address validities related to *outcome, process, democratic*, *catalytic* and *dialogic*.

Outcome validity refers to the extent to which actions of the intervention lead to the success of the intended purposes. This validity asks the question: Did the research unpack the influence of a teachers' technological pedagogical reasoning when using computer simulations in the teaching and learning of electromagnetism in a whole class rural setting?

Process validity focuses on the extent to which problems are framed and resolved in a manner that permits on-going learning of the individual or system. According to Mundalamo (2015), process validity asks the question: Was the activity or intervention *educative* and *informative*? The word 'educative" has been defined as "of educational value to the persons doing a systematic study of their work methods with the intention of getting better results" (Maddox, nd: online). The term "informative" generally refers to providing useful or interesting information. In this case, it is the researcher's TPR when using CS in the teaching and learning of electromagnetism.

Democratic validity is concerned with the extent to which research was undertaken in collaboration with all partners involved with the problem under investigation. In many action-research studies, the researchers themselves are the object of study, which attempts to solve issues pertinent to them in their contexts. Teachers have to include learners who are supposed to be the recipients of improved teaching. The learners are not viewed as "outsiders" by practitioner researcher's "insiders". Democratic validity is what Cunningham (1983) refers as "local" validity; the problems arise from a particular context and the solutions are relevant to that problem in that context. Watkins (1991) calls this "relevancy" or "applicability" criteria for validity (p.34).

Catalytic validity refers to the ability of the research process to transform the participants, deepen the understanding of the participants, and motivate participants to further social action. According to Mundalamo *et al.* (2015), catalytic validity seeks to determine how the study transformed the realities of those involved. All involved in the study should deepen their understanding of the social reality and should be moved to some action to support or change it (Anderson & Herr, 1999). How my TPR of using computer simulations transformed my thinking and mind-set this new learning milieu created by technology is to be reported in Chapter 5.

Dialogic validity is concerned with the extent to which the research has been reviewed and critiqued by peers. Anderson and Herr (1999) have referred to dialogic validity as key to ensuring the goodness of educational action research. Newton and Burgess (2008) consider it as a central validity type for all three action research modes. In order to promote both democratic and dialogic validity, researchers have insisted that action research should be collaborative inquiry involving critical friend(s) familiar with the context (Carr & Kemmis, 1986). Anderson and Herr (1999) suggest that "practitioner researchers participate in critical and reflective dialogue with other practitioner researchers" (p.16). As has been reported (see section 3.2), this study involved critical and reflective dialogue with a critical friend who is an established university lecturer in science and the HOD. Furthermore, I shared my work with friends at research schools (Southern Africa Association of Research in Maths, Science & Technology Education-SAARMSTE) and conference (Institute of Science & Technology Education International Conference, 2017). I used their feedback to further reflect and gain insights of my practice from a research perspective.

Using multiple sources of information assists in triangulation of the data gathered in the study thereby increasing the credibility of the obtained data (McMillan & Schumacher, 2001). Jick (1979) suggests the following advantages and reasons why triangulation is important: a) it allows researchers to be more confident of their outcomes; b) it motivates the development of creative ways of gathering data; c) it can lead to deeper, rich data; d) it can lead to the synthesis or integration of theories and e) it can uncover contradictions. Patton (1990) opines that the use of different data sources also helps the researcher to validate and cross check findings. For this study, the data is triangulated through learner data (reflecting on the products of learner activity in the classroom and focus group discussions), self-reflection captured in reflection journals, classroom observation by myself and critical friends, and artefact collection.

3.5.2 Reliability of the study

To establish reliability, a detailed protocol for data collection and analysis were made while rich detailed descriptions of the data and results were provided. This information provides a framework for comparison for other researchers who may be interested in conducting a similar study (Creswell, 1994).

3.6 Data Collection and data analysis

Action research was used as research methodology to explore the influence of a teachers' technological pedagogical reasoning when using computer simulations in the teaching and learning of electromagnetism in a whole-class rural setting. Data were obtained through FGDs and learner in-class activities, self-reflection, observation, and conversations with critical friends.

Qualitative data were collected using reflective journals (as the focus was on the reasoning process of the teacher), focus group discussions (not conducted by the researcher as he was the teacher) and observation using RTOP and videos. During the data collection, the researcher remained open to the possible emergence of new patterns and insights while still keeping in view the initial ideas (Patton, 2002). The emerging data is not quantifiable in the traditional sense of the word, as the data is interpreted considering the unique particulars of a classroom rather than generalizations. Therefore, the process is more relevant than the outcomes.

The different forms of data include narrative texts, audio and video transcripts. Mulholland and Wallace (2003) suggest that the primary research text is "reconstruction from the field text that represents experiences of the field" (p.6). Narrative data come in many forms and from a variety of sources. In this study, narrative data came from reflective journals, audio and video transcripts and focus group discussions. The narrative data contained descriptions and explanations of my planning, my observations during lessons and my experiences. Thus, the narrative data involve "telling or retelling of the events related to the personal or social experiences of an individual" (Ollerenshaw & Creswell, 2002:332).

3.6.1 Data collection from reflective journals

Schon (1983) distinguishes between reflection-in-action and reflection-on-action. The former suggests a simultaneous monitoring when performing or practicing a task; the latter suggests a retrospective evaluation after the task is accomplished. In this study, the researcher preferred evaluation-during-instruction. To reduce the danger of forgetting what actually happened during the activity the researcher compiled notes and comments as soon as the lessons ended. To consolidate the researcher's reflections, I used the Gibbs (1998) Model for Reflection. Reflection was conducted on all the sub-processes (i.e., comprehension, transformation, instruction and evaluation) of Smart's (2016) model of technological pedagogical reasoning. The model involves the use of several steps to achieve successful reflection on practice:

Step 1: Event description

This stage involves the researcher detailing the event on which he is reflecting. The description seeks to answer the questions, such as where the practitioner was, who else was present at the event, why the practitioner was at the event, what the practitioner was doing, what other people were doing, what the context of the event, what then happened, and what the final result was (Fook, 2000).

Step 2: Feelings and thoughts

This step involves answering questions such as how the practitioner was feeling at the start of the event, how it made him feel, how other people made the practitioner feel, how he felt about the outcome of the event and finally what the practitioner thinks of the event.

Step 3: Evaluation

This step involves the practitioner making value judgements about what happened. He is also expected to consider and distinguish between that what did or did not work.

Step 4: Analysis

The practitioner may need to analyse data of what the practitioner did well, what others did well, what did not turn out as had been expected and finally the manner in the practitioner together with other participants contributed to the happenings.

Step 5: Conclusion

This stage presents the practitioner with an opportunity to ask himself that which he would have done better

Step 6: Action plan

The practitioner questions himself what he would have done differently if the event was encountered again in this self-evaluation.

Thus, the reflective journal, reflections from the videos, discussions with the critical friends and FGDs were the main source of information to review and consolidate learning, to evaluate performance, to plan future learning based on past learning experience. The reflective journal was kept to provide credibility for the research (Smetana, 2013) (See Appendix 12 for an example of the reflective journal after lessons).

3.6.2 Data collection from focus group discussion

FGDs were held in the afternoons after the learners attended the lessons. I asked for a volunteer at schools and a colleague; an English teacher indicated that she would conduct the discussions so that the learners were free to express their views. I did not want my authority as their teacher to intimidate and influence what learners might say. My presence was likely to induce some reactivity which was likely to compromise the objectiveness of their feelings. I wanted learners to be objective in their assessment of their learning experiences and minimise the inclination of them telling me what they thought might please me. So, the approach of using another teacher was meant to circumvent the Hawthorne effect. Three sessions were held with learners from the three classes, and the discussions were held with learners who volunteered. However, the challenge was that the teacher was new and did not have interviewing skills. Therefore, I taught what I wanted her to do and suggested how she could conduct the interviews. I emphasised that the discussion should be natural with interactions between the learners themselves. She was not supposed to re-phrase learners' ideas; she was supposed to take them as they are and where she did not understand she was to seek for clarity. Her duty was to facilitate the discussion and where necessary probe learners to articulate their views. For example, if a learner said the lesson was "interesting", she must probe as what the learner meant by the term interesting. In the trial session, the interviews sounded unnatural as most of the learners' answers were very brief. However, in the next sessions, the interviewer tried to make the discussion more natural seeking to involve all the learners. Six questions were asked during the interviews:

Box 1: The Interview Guide

1. Can you tell me about what you like about learning with computer simulations? Why?
2. What don't you like about computer simulations? Why?
3. If you were to make a suggestion, how can we use computer simulations in learning to enhance your learning.
4. What have you learnt 'new' about magnetic fields and electromagnetic induction?
5. In what ways (if any) do computer simulations assist you in learning of these topics?
6. What is 'different' with learning with computer simulations in physical sciences?

3.6.3 Data collection from RTOP

The process to conduct classroom observations followed three stages: the discussion with the observer before the class, the observation and recording in class, and analysis and feedback after the class. The pre-observation discussion between the teacher and the observer helped to alleviate anxiety and provided the observer with information about the classroom settings and the objectives the teacher wanted to accomplish on the day of the visit. It also enabled the teacher to identify areas where he wanted feedback. The post-observation discussion was a reflection of what transpired during the lesson with the critical friend. The observations though specifically designed for this study occurred under routine instruction. During the discussions, I noted the areas of concern raised by the critical friends. These notes are also an instrument/data source.

3.6.4 Data collection through videos

A colleague in the school was asked to make video recordings of my lessons, during the third iteration. The colleague used a video camera to record both lessons. Stationed at a strategic position, he captured most of the action that was occurring in the class. The recording of the video was done with the consent of the learners. Those who did not want to be recorded were told that they were free to do so. However, the learners were informed that the videos were not going to be publicized and only the researcher and the teachers (critical friends) who had access to them. Videos provides ease with the analysis of classroom events for the situations that teachers cannot remember (Hiebert *et al*., 2003). Video data is also beneficial for enabling repeated analysis by the teacher (Derry *et al.*, 2010). The recorded lessons lasted 30 minutes. In total, 120 minutes of video recordings were collected.

3.7 Data Analysis

Data analysis occurs throughout the research process rather than being a separate activity after data collection. The process of data analysis is where the findings of the study are used to answer the research questions. Accordingly, data analysis is the process of making sense from the data to communicate an understanding (Merriam & Tisdell, 2016). In action research with multiple cycles of action, the process of data collection and data analysis are not linear processes. Rather, preliminary data analysis occurs concurrent with data collection. Data analysis is an on-going and iterative process. In this study, three cycles of action research were conducted where the findings from one cycle were used to improve the subsequent cycle.

Data was embedded in these descriptions and explanations of my experiences (Nyamupangedengu, 2016). To analyse the narrative texts, the theoretical framework (see section 2.9) was used. The theoretical framework used was that of Smarts' (2016) model of pedagogical reasoning and action (MPRA). The sub-processes were used as initial codes. However, salient themes subordinate to the initial codes were added to illustrate the relationship between them.

Smarts' stage	**Description**	**Phase**	**Data collection method**
Comprehension	An understanding of the content/investigating skills to be taught	Planning	Curriculum documents

Transformation	A reconstruction of the comprehended content into activities or actions that made content to be accessible to learners in varied and creative ways	Planning	lesson plans
Preparation Representation Selection Adaptation and tailoring	A search of the internet for the various computer simulations (see section 4.1.2.3 for criteria) and design of demonstration activity	Planning	Curriculum documents Lesson plans
Instruction	The interaction between the teacher and learners during classroom activities. Observed within the process of instruction are other sub-processes such as transformation-during-instruction and evaluation-during-instruction.	Teaching	Reflective journals RTOP Focus group discussions
Transformation during instruction	Instances where the teacher has to respond to learner questions, or the teacher has to change the technology being used due to malfunction or other challenges.	Teaching	Reflective journals
Evaluation	Instances when the teacher checked for learners' understanding during the teaching process.	Exploring and analysing learner feedback	Reflective journals Focus group discussions Discussion instrument with critical friend
Evaluation during instruction	The teacher moving around the room to check for student understanding and asking questions to create discussions	Teaching and Learner feedback in class	Reflective journals

Reflection	Checking for what worked, what did not, what l would consider changing, and why		Reflective journals
New comprehension	What did I learn from each lesson		Reflective journals

Table 3.3 Summary of data analysis process

3.7.1 The analysis of video lesson transcripts

The purpose of videorecording was to present “naturally occurring data” (Jewitt, 2012:24) of what happened in my lessons. Video captured *in situ* can contain a great richness of information, often revealing subtle yet important incidents relating to the interactions between people and technology (FitzGerald, 2012). Video-recording my lectures also served to triangulate my data sources. The analysis of the video-recordings happened in three stages. I describe these stages next.

Stage one: Familiarisation with the data (Rabiee, 2004). After copying the videos onto my laptop computer, l viewed the videos using the software My Movie (see Figure 3.3). The software divides the video into ten seconds long segments. The advantage of using this software is that displays all the segments of the video, and I can choose which segment I wanted to examine. Therefore, I do not need to view the whole video. The videos were 120 minutes long. I took time to watch them many times which would provide an opportunity to identify elements of my teaching that I may have missed on previous viewings. On two occasions, I watched the two videos in the third iterations with a critical friend. Even though the critical friend could not watch all the videos, he was still able? to make comments on those sections of that he was able to watch. Watching the videos allowed me to see if I followed through on my thinking and planning as outlined in the lesson plans. I was able to record these notes in my reflective journal.

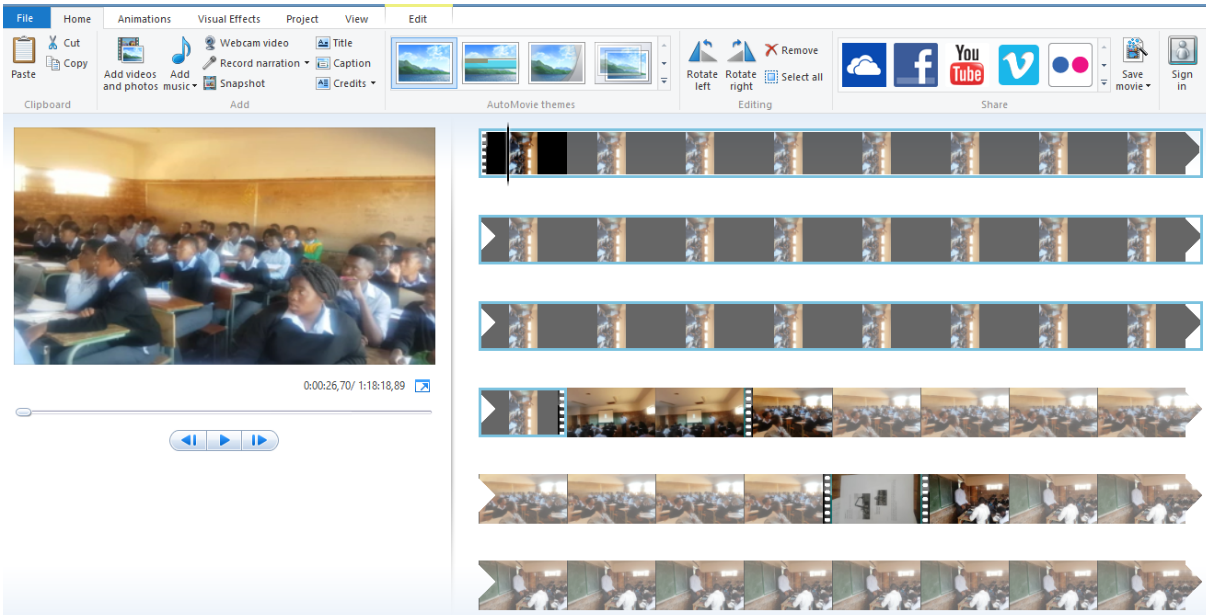

Figure 3.3 Screenshot of My Movie

In addition, watching my own teaching helped me to gain a deeper appreciation of my teaching behaviours, which in turn, was more receptive to the feedback I received about my teaching (Wang & Hartley, 2003). This feedback was instrumental in assisting me to make informed decisions on how to proceed in the following lessons in a way that would improve my teaching.

Stage two: As I watched the videos, l noted aspects which l may have missed by reflecting only on the RTOP only. Since video data can "preserve the temporal and sequential structure which is so characteristic of interaction" (Knoblauch, Schnettler, & Raab, 2006:233), l was able to reflect on such aspects as body, facial and verbal language, reactions of learners in face of the activities, and social interaction alongside speech. I used Smart's MPRA during the analysis process and checked for instances where pedagogical reasoning occurred. I looked for episodes or evidences where technological pedagogical reasoning had occurred. In addition, I checked for teacher and learner actions supported using computer simulations and how these simulations could contribute to the learning of the topic. Lessons on the following topics were recorded: magnetic fields of current-carrying conductors and electromagnetic induction.

3.7.2 Analysis of FGD transcripts

The first step was familiarisation with the data. This entailed repeatedly reading all the transcripts to develop what Ely (1991:150) called "intimate knowledge" about the data. The first impression had me reflect whether these views were a microcosm reflection of the experiences of all the learners of my teaching practices. The second was to categorize the data into meaningful chunks. There are two ways to categorize narrative data: using pre-set or emergent categories. For pre-set categories, categories are identified in advance, and data is search for what matches with the identified categories. In the emergent categories, the text is read and the themes or issues that recur in the data are found. In this study, pre-set categories were chosen and a search in the data for text that matches the themes was taken. A description of the categories is made in Chapter 2.

The three dimensions of learning experiences (cognitive, affective, and conative dimension) described in Chapter 2 were used as a lens for both analysing the interview transcripts of the FGDs and describing the learning interactions with computer simulations as experienced by learners. The units of the analysis were learners' expressions, defined as a clause or clause complexes (a number of clauses) (Tysbulsky, 2019). According to Halliday and Matthiessen (2004), a clause is a unit of language that contains at least one predicate and one subject. The approach to analysing the interview transcripts was deductive as opposed to inductive. The following example illustrates how the process of coding was completed using this lens.

> *Lesson yo vha ya vhudi ngamaanda eh! Ndo vhona zwi khwine ngauri muthu u thoma u vha interested uri like kharali hu khou pfi i experiment, like hezwila zwa galvanometer, I tshi deflecta ...magnet uri I vha I khou dzheniswa hani, ri vha ri sa khou sokou fuziwa nga maipfi fhedzi ri vha ri khou vhona. Zwi ita uri na rine ri pfe ri tshi zwi funa. (The* ***lesson was very good (affective-enjoyment),*** *eh what l think is that it is better because it makes someone to* ***become interested in the lesson (affective-enjoyment)****,* ***like the experiment with the galvanometer when deflecting (cognitive)****, we could not understand the movement of the magnet when we are just taught using words without seeing what exactly is going on. It makes one* ***become interested (affective-enjoyment)).***

The bold statements served as units that enabled identification of experiential categories. These units are not considered the common denominator of certain phenomena but serve as classifications that help reveal meaning in the text (Tysbulsky, 2019). In the final stage of the analysis, quotes selected from the data were linked with the identified domains of learning experiences (i.e., cognitive, affective and conative). Finally, the number of the learners' expressions in each category of learning experiences were determined. The transcribed interviews were also given to two researchers who were not involved with the study to code the FGD according to the three categories described. There was an initial agreement on 90% of the coding decisions, and this agreement increased to 100% following discussion of the disagreements.

3.7.3 Analysis of RTOP

Both the university lecturer and the HOD wrote notes when they observed my lessons. I also recorded the suggestions made by the two critical friends during the discussions. Using Smart's (2016) model of technological pedagogical reasoning (fig 2.7), I analysed the RTOP and checked instances where any of the sub-processes of pedagogical reasoning occurred or been suggested. For example, after the first iteration I had a discussion with the university lecturer and wrote the following:

> *The discussion with the critical friend was very fruitful. He was excited by the attitude of the learners towards the lesson. The learners were active and were responding to the questions being posed by the teacher in a positive way. However, he suggested that l needed to also* ***involve the learners in manipulating the computer simulations so*** *that they can have a feel of using the technology (August 2015).*
>
> *Involving learners in manipulating the computer simulations* is an instructional practice that could be used by the teacher during instructional pedagogical reasoning.

3.8 Ethical considerations

There are standard ethical guidelines regarding the treatment of participants that should be followed in any educational research. Ethical considerations ensure that the identity and dignity of those involved in the study is protected and respected, and no risk or harm is done to the participants as a result of the activities of the study. Also referred to as non-malfeasance, the study must be ensured not to cause any injuries, harm, or any emotional offences (Christiansen *et al.*, 2010; Cohen *et al.*, 2013). In this study, the participants were informed that they have a right not to participate in the activities of the research and can withdraw anytime without any consequences to their schooling. Furthermore, if they decided to participate, their identity would be withheld or kept confidential in the manuscript of the research. Direct quotations from individuals were anonymised by using pseudonyms.

Ethical standards were followed when reporting the research, regarding misrepresentation, plagiarism and assistance from others (Robson, 2005).

Ethical clearances were obtained from the Department of Education through the district office (see Appendix 1C) and from the school through the principal (see Appendix 1B). Ethical clearance was also sought through the Unisa College of Education Research Ethics Review Committee and was granted (see Appendix 1A).

3.9 Summary

Table 3.5 summarises the data collection process in this study.

Research question	**Theoretical framework**	**Instrument**	**Data collection**	**Data analysis**
Can the sub-processes suggested by model of technological pedagogical reasoning (TPR) be used to describe a teachers' technological pedagogical reasoning when using computer simulations (CS) in the teaching of electromagnetism to students in grade 11?	Smarts' model of pedagogical reasoning and action (MPRA) in the context of technology (Chapter 2 section 2.8)	Lesson plans, reflective journals and observations (see sections 3.4.5.1; 3.4.5.2; 3.4.3)	section 3.6	section 3.7
What are the cognitive, affective and conation experiences of learners when computer simulations were used in the teaching of electromagnetism?		Focus group discussion (section 3.4.4)	Section 3.6	Section 3.7

Table 3.4 Summary of research questions and instruments

Chapter 4

Results

4.0 Introduction

The findings of this study are presented according to the sub-processes in Smart's model of pedagogical reasoning. These sub-processes are used as pre-set codes to label or organise the collected data. Since the researcher is exploring new territory of teaching with computer simulations as reasoning tool, it may not be best to start out looking for something (Hesse-Biber, nd). These sub-processes have been identified as characterising teaching, and I explored how computer simulations enhanced and transformed them. According to Salavati (2016) the reality of technology use in everyday practices is not only complex and challenging but also messy. This situation is against a background of fear of technology being used extensively in recommendations, curricula and reports of experimental teaching. However, the characterisation of this integration is left unelaborated (Laborde 2002). Smart (2016) includes processes suggested by Shulman, namely: Comprehension, Transformation, Instruction, Evaluation, Reflection and New Comprehension. Also included are Transformation-during-instruction and Evaluation-during-instruction. As the theoretical framework, I used these lenses in my data analysis. Description of these processes is provided in Chapter 2 (see section 2.8). The data collected answered the following research questions:

1. Can the sub-processes suggested by model of technological pedagogical reasoning (TPR) be used to describe a teachers' technological pedagogical reasoning when using computer simulations (CS) in the teaching of electromagnetism to students in grade 11?
2. What are the cognitive, affective and conation experiences of learners when computer simulations were used in the teaching of electromagnetism?

In the sections that follow I present the experiences from the three iterations. Each iteration consists of two lessons: (1) Magnetic fields around current-carrying conductors and (2) electromagnetic induction. The first iteration was carried during the third quarter of 2015, the second iteration during the third quarter of 2016 and the third iteration during the third quarter of 2017.

4.1.1 Iteration 1

Lesson 1: Magnetic fields around current-carrying conductors

Comprehension

After getting an understanding of the content to be taught, l was now prepared for the second stage which was the transformation of the content into formats that would be accessible to learners. The comprehension process involved thinking about the links I needed to make with the previous content taught in grade 10 and the work they would do in grade 12. I needed to assess the learners' prior knowledge, informing me how I was going to teach the topic. However, I was disturbed and confused by the significance of the six hours allocated to the teaching of the topic. Many questions came to my mind that needed answers: *What did the curriculum planners consider allocating the topic 6 hours? Are learners constrained to understand the topic in 6 hours? Do learners have the same capacity to understand the topic in 6 hours? If the learners didn't understand the content in 6 hours, what's next? Is the 6 hours also catering for the time of preparation?* Whilst I was the one asking these questions, at the same time I felt challenged because I was unable to answer them. If the six hours were the time to cover the described content, doesn't that assume that I was going to be teaching a homogenous class of learners? Furthermore, by stipulating the time, the focus is now on the content and not on the learners. Teaching is now teacher-centred. This time allocation may be used as a basis to design the pace setter (see Appendix 3) which stipulates the time period which the topic should be taught. Work schedules are used by the district curriculum advisors to monitor curriculum implementation, and at the same time used to set quarterly tests. In order to prepare your learners for the quarterly tests, teachers need to cover the content as outlined on the work schedule. I also inquired from a colleague about his interpretation of the six hours; I did not get a satisfactory response.

4.1.2 Transformation

4.1.2.1 Preparation

Lesson One: Magnetic fields of current-carrying conductors

The first lesson focused on assisting learners to construct appropriate mental models (conceptual models) of magnetic fields due to current-carrying conductors which allows them to explain how electromagnets works. In lesson 1, the warm-up activity (see Appendix 7) was a guided inquiry task, designed to demonstrate the phenomenon of (magnetic) fields. The phenomenon was demonstrated using insulated wires, which were wound on an iron nail and connected to a cell. The iron nail was now brought close to the iron filings (Warm-up activity 1). This phenomenon was not described to learners, because they had the opportunity to observe through firsthand experiences. The phenomenon was attention-getting and thought-provoking, and required some explanation. Thus, it engaged cognitively all learners and motivated them to focus on the lesson. The warm up activity was designed to cognitively engage learners in:

1. **Creating ideas,**

2. **Integrating ideas** and

3. Connecting to the real world.

These elements (intending to develop conceptual connections) are lacking in many science lessons and therefore learners are not adequately supported in building a more coherent scientific understanding of core ideas. For example, I have seen that learners do not understand how an iron nail attract the iron fillings when there is no physical connection between the cell and the iron nail. Learners need to be engaged in brainstorming as to what is the cause. This brainstorming requires them to actively reflect on their prior knowledge and how it can be linked to new information. At the same time, learners need to relate what they would have learnt to common experiences or aspects of their daily lives. The instructional goal is for conceptual understanding.

Lesson Two: Electromagnetic induction[12]

The focus of the next lesson was on facilitating learners to integrate the magnetic field model in order to explain electromagnetic induction and concepts related to it like magnetic flux. The warm-up activity (see Appendix 8) is a situation, which they could relate to in real-life experiences. The activity is an open-inquiry task that requires learners to develop a design in which they could light a bulb when supplied with a magnet, bulb, and a solenoid. The warm-up activity was meant to provide learners with a reason and context in which to communicate about science (Lee *et al.*, 2018). The activity was designed to introduce the concept/phenomenon of electromagnetic induction to learners thereby relating science to their lives. As in the first lesson, the warm up activity was designed to cognitively engage learners in creating ideas, integrating ideas and connecting to the real world.

(Examples of the two lesson plans are given in Appendices 4A & 4B).

4.1.2.2 Representation of the lesson

All the lessons for this study had a particular sequence of activities that became the *modus operandi*. The lessons had two sections that were purposely designed to engage learners in a series of science practices to enhance the learning of content on magnetic fields and electromagnetic induction. The lessons were designed for learners to carry out ***O**bservations, **R**eflections, **D**iscussions, **E**xplanations and **R**easoning* hereafter referred as **ORDER**. These activities/tasks were supported by the pedagogical affordances of computer simulations. The ORDER pattern was complex epistemological scaffolding that the teacher enacted across the lessons (Levrini *et al.,* 2019). The **O**bservation and

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[12] Lesson number two preparation

Reflection phases were enacted to allow the learners to **experience (become acquainted with) the** phenomenon (see Figure 2.2) with the purpose of allowing learners to **a**cquire the necessary information about the anchoring phenomenon which would help them to generate a model. This model is anchored in emerging research which provides evidence that learners of all ages learn better when seeing an object before hearing its description (Ma & Komarova, 2019). The **D**iscussion and **E**xplaining phases were enacted to help learners to **make sense of the phenomenon** to **g**enerate the models (magnetic field and electromagnetic induction) while the **R**easoning phase was enacted to allow the learners to **e**valuate the generated model thereby **communicating about the phenomenon**.

Figure 4.1 summaries the representation of the lesson. As can be seen in the following diagram the arrow pointing down shows the progression of the lesson while the arrow pointing to the right shows the purpose (learning experiences) to be achieved during each stage.

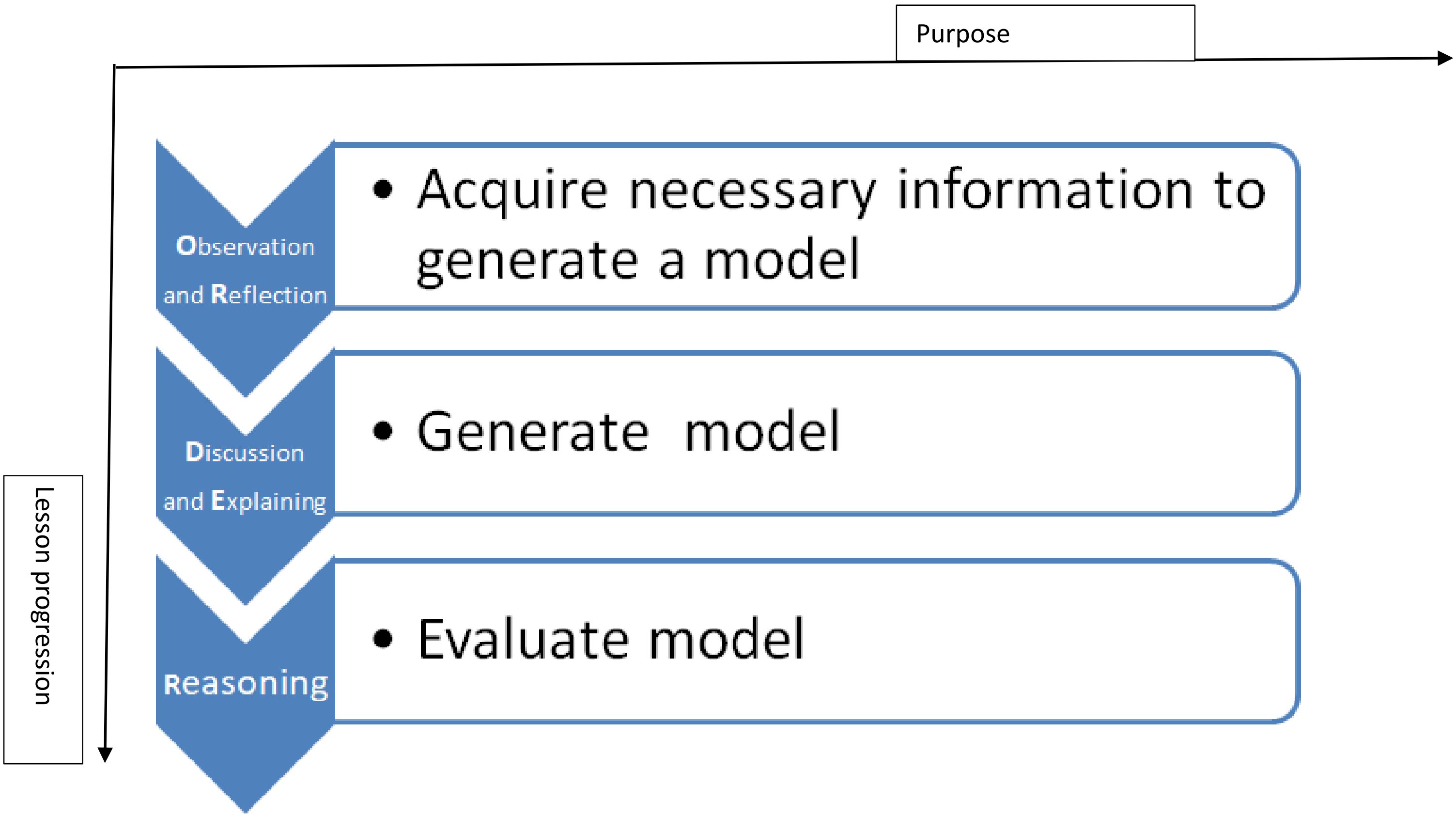


Figure 4.1 Representation of the lesson

It was purposed in the planning stage that the learning experiences should results in the learners developing correct models of magnetic field and electromagnetic induction. As shown in Figure 4.1 the process has three stages which are shown below:

A-Acquire the information necessary to generate the model (Stage 1)

G-Generate the model (stage 2)

E-Evaluate the model (stage 3)

Referred to as **AGE,** for meaningful learning to occur learners must go through the three stages of model development. This learning cycle helped the teacher to organise the lesson and 'package' learning experiences into a conceptual 'storyline' (Ramsey, 1993, p. 1) or "science content storyline", which Roth et al. (2011) define as the flow and sequencing of learning activities such that concepts align and progress in ways that are instructionally meaningful to student learning of the concepts. The study by Zhang *et al*., (2015) reported that teachers needed PD in how they could improve the organisation of a lesson, the sequencing and flow of lessons.

4.1.2.3 Selection

The computer simulations chosen for this study were purposely chosen, as certain criteria were used in selecting them. It has been documented that teachers tend to rely heavily and uncritically on curriculum materials to determine what and how to teach (Grossman & Thompson, 2004; Mulholland & Wallace, 2005). However, teachers need to analyse, adapt and enact curriculum materials in a principled, reform-based manner for effective science teaching (Schwarz *et al.*, 2008). Introducing these criteria would support the teacher in selecting those simulations where the linkage between science principles and visual representations were discernible (Stephens, 2012). The simulations need to:

1. Relate to the electromagnetism concepts prescribed in the CAPS document. This consideration is important for the achievement of the objectives of the lesson and the integration between the animations and the curriculum for the success of the animations (Barak and Dori 2011).

2. Present 3D representations, which promote learners' spatial visualization ability thereby enhancing learners' understanding by "providing a degree of reality unattainable in a traditional two-dimensional interface" (Kim, Park, Lee, Yun, & Lee, 2001:38). Interactive 3D simulations have the potential to enhance learners' conceptual development of the basic science phenomena (Huang *et al.*, 2015)

3. Depict the dynamic, transient and interactive nature of scientific phenomena (Wu & Shah 2004)

4. Link the macro-processes with the micro-processes.

5. Provide affordances that enables someone to interact with the animation and manipulate variables and entities (Akpınar 2014; Velazquez-Marcano *et al.,* 2004; Wilkerson-Jerde *et al.,* 2015)
6. Link abstract concepts to real-world examples (Kozhevnikov & Thornton 2006; Wang *et al.,* 2014)
7. Be appropriate for the learners and support the learning experience.

The computer simulations were meant to transform the content knowledge to ameliorate functional understanding of such content by learners. One of the aspects of transformation in Smart's model is adaptation and tailoring of instructional materials. In this context, adaptation and tailoring is about the selection of various computer simulations to suit or tailor to the needs of teaching electromagnetism concepts to grade 11 learners. The computer simulations were congenial and allowed learners to become acquainted with a new phenomenon to build a perceptive background. Studies have indicated that learning with virtual labs or computer simulations enables learners to have a sense of the mechanism behind the phenomenon to build a mental model (Shubha & Meera, 2015). The suites of computer simulations used in this study were downloaded from various locations and were not specially designed for this study.

Interactive physics

The first suite came from a collection of simulations from Interactive physics. The simulations are primarily developed for learners in grades 10-12 for a variety of topics in physics, chemistry and biology in developed countries. Users can access the computer simulations free of charge from www.interactivephysics.com. Each simulation focuses on a single or a small number of physical concepts and omits all the unnecessary and complex details to channel the attention of the user to the targeted science ideas. It tends to give the user a simple, manageable task (Ceberio, Almudi, & Franco, 2016). The simulations are designed to be interactive, allowing users to manipulate its components. The website provides the theory behind the simulations and direct instructions for using the simulations. The computer simulations run on Java, a computer language.

The selected computer simulation (see Figure 4.2) selected from this suite, was to familiarise and illustrate the spatial configuration of the magnetic field around a current-carrying conductor to learners. The use of the computer simulation in this manner was a deliberate attempt to remove the authority of the textbook as the only source of content, thereby eliminating or ignoring learners' perspectives and present ready-made notes. By changing the direction of the flow of current, learners were asked to describe the corresponding changes to the magnetic field. Therefore, learners were able to engage with the information by describing what they were observing. Peters (2010) observed that when learners saw the source of information entirely from an authority figure, they failed to see how it related to them and why they should engage with the materials other than to be successful on a test.

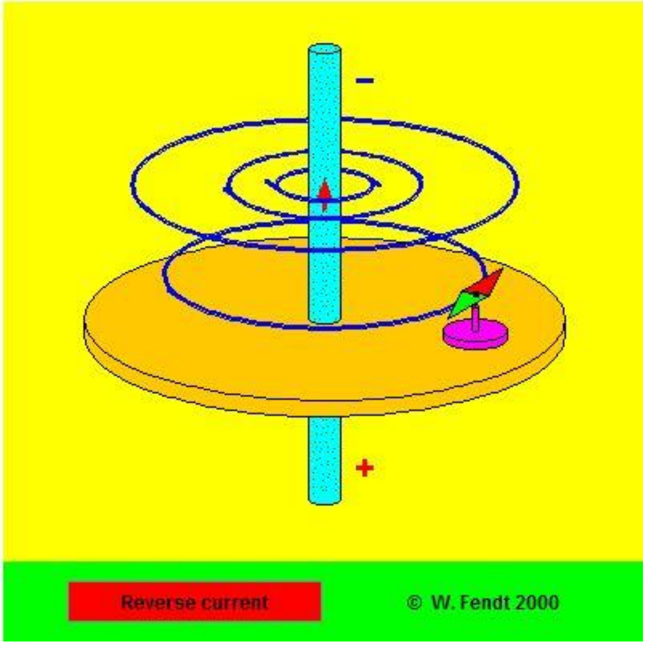


Figure 4.2 Screenshot from the interactive physics simulation showing the magnetic field around a current-carrying conductor

Technology Enabled Active Learning (TEAL) Simulations

The second suite of computer simulations was downloaded free from TEAL website (http://web.mit.edu/viz/soft/visualisattions/visphysics/visphysics.htm) to illustrate the magnetic field around two conductors carrying currents in opposite directions (see Figure 4.3). Using this simulation, learners could observe and build an understanding of the spatial configurations of the magnetic field around the two conductors carrying current in opposite directions. Learners were requested to describe the field patterns on the two conductors when carrying current in opposite directions. They were also asked to predict what will happen when the current increased. In this manner, the computer simulation was used to assist learners to generate knowledge beyond what was presented in the instructional material (Chi *et al.*, 2017). This activity was an attempt by the teacher to allow learners to participate as epistemic agents in knowledge construction processes, thereby lessening the teachers hold on authority in determining what ideas are valued in the lesson. When learners are positioned by teachers as epistemic agents, they not only have a hand in shaping the knowledge production and practices of their community, but they also play a key role, with support from their teacher, in making key decisions about their learning (Ko & Krist, 2019).

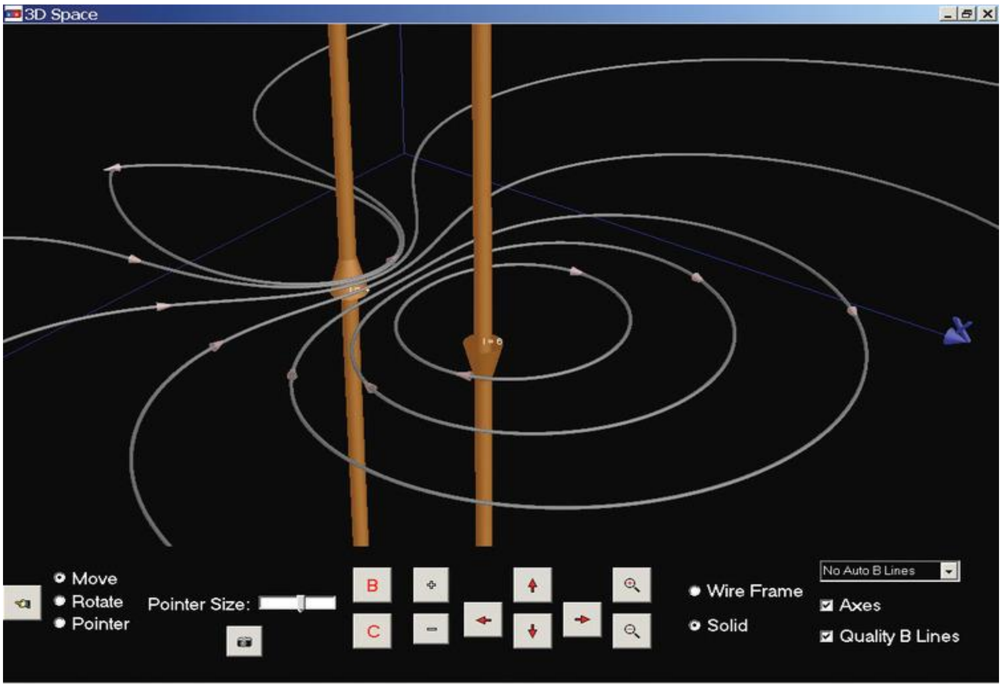
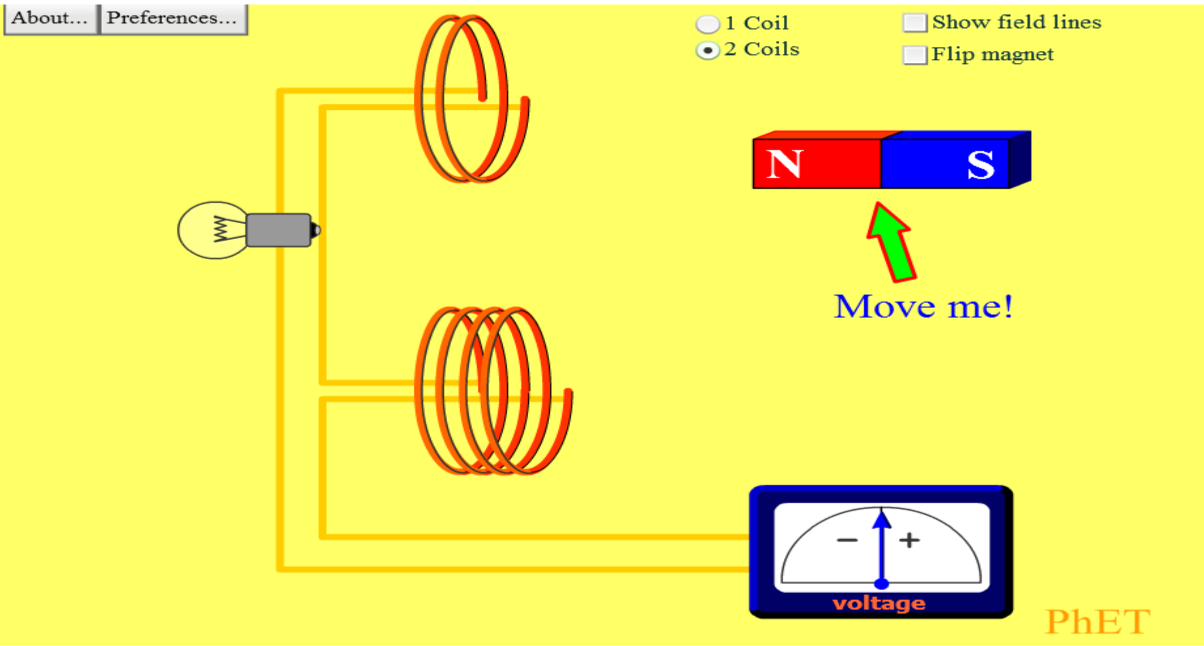


Figure 4.3 Screenshot from TEAL showing the magnetic fields around two straight conductors carrying current in opposite directions.

Physics Education Technology (PhET) Simulations

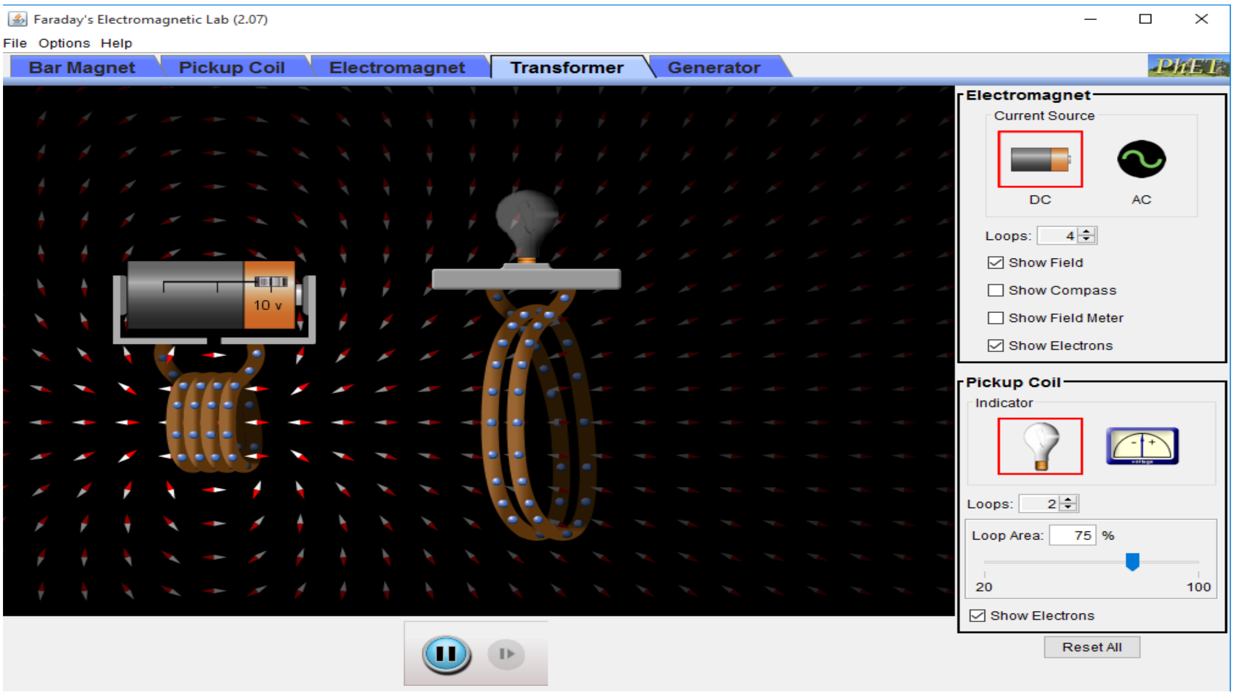
The third suite used was the PHET interactive simulations downloaded from web page of University of Colorado (http://phet.colorado.edu/en/simulations /category/physics). Two sets (see figure 4.4 and figure 4.5) were downloaded from this site. These computer simulations were used to familiarise and illustrate magnetic flux and electromagnetic induction. As with magnetic field, the concepts of electromagnetic induction and magnetic flux are abstract and non-intuitive for high school learners. Learners were required to predict what would happen when the magnet was moved relative to the solenoid. They were also asked to suggest possible changes that could be made to the set-up to increase the intensity of the light produced by the bulb (see Figure 4.4).



○ 1 Coil
● 2 Coils
☐ Show field lines
☐ Flip magnet

Figure 4.4 Screenshot from PHET interactive physics simulation

The fourth suite of computer simulations used was downloaded from web page of University of Colorado (http:// phet.colorado.edu/en/simulations/category/physics). The computer simulations were used to illustrate Faradays' Law. From experience, learners have difficulties with the concept as it is counter-intuitive (see Figure 4.5).

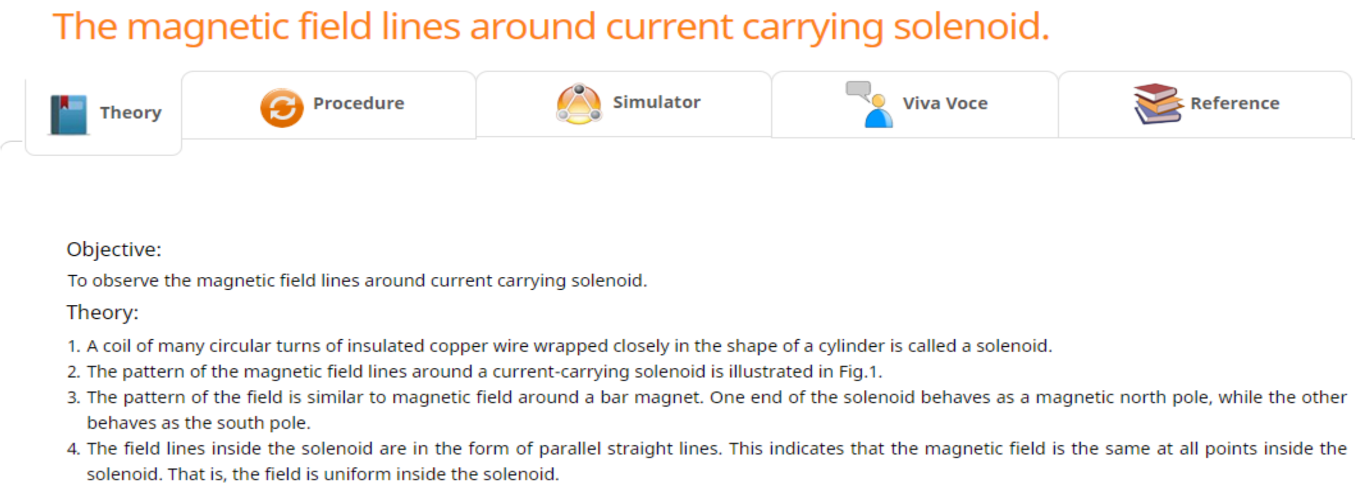


Loops: 4
☑ Show Field
☐ Show Compass
☐ Show Field Meter
☑ Show Electrons

Loops: 2
Loop Area: 75 %
☑ Show Electrons

Figure 4.5 Screenshot from PHET Faraday's Electromagnetic Lab Simulation

The fifth suite of computer simulations (*ONLINELabs*) were developed by Amrita University and found on www.olabs.edu.in. These suites of simulations benefit learners in grades 10, 11 and 12 because they provide the theory, the procedure, and practice questions) (see Figure 4.6). Two suites of computer simulations were used (see Figure 4.7, 4.8). In these computer simulations, learners are able to change the variables and observe the outcome.



The magnetic field lines around current carrying solenoid.

Objective:

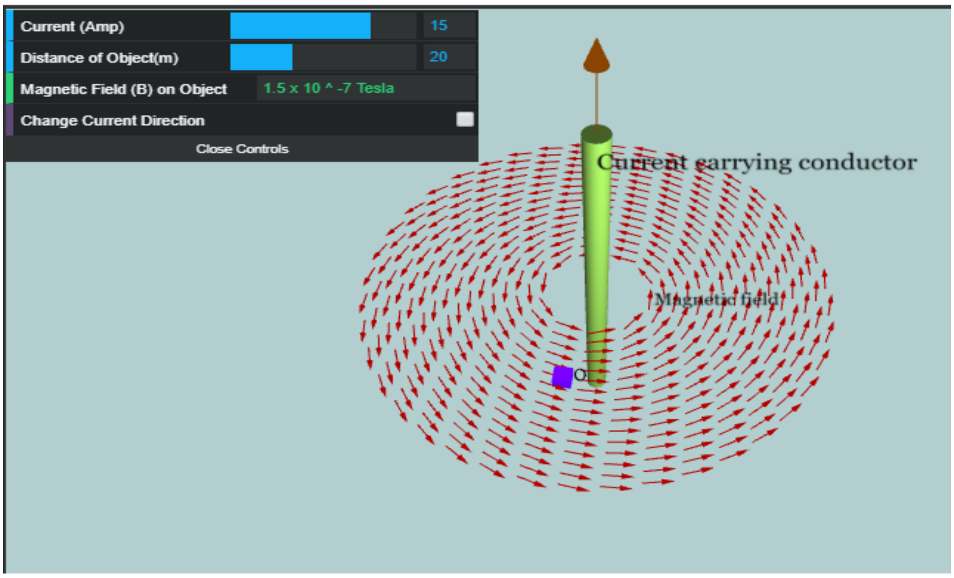
To observe the magnetic field lines around current carrying solenoid.

Theory:

1. A coil of many circular turns of insulated copper wire wrapped closely in the shape of a cylinder is called a solenoid.
2. The pattern of the magnetic field lines around a current-carrying solenoid is illustrated in Fig.1.
3. The pattern of the field is similar to magnetic field around a bar magnet. One end of the solenoid behaves as a magnetic north pole, while the other behaves as the south pole.
4. The field lines inside the solenoid are in the form of parallel straight lines. This indicates that the magnetic field is the same at all points inside the solenoid. That is, the field is uniform inside the solenoid.

Figure 4.6 Screenshot from ONLINE Lab simulations

The challenge with this suite of computer simulations is that they are online and cannot be downloaded. They require the use of the internet all the time.



Current (Amp) 15

Distance of Object(m) 20

Magnetic Field (B) on Object 1.5 x 10 ^ -7 Tesla

Change Current Direction ☐

Figure 4.7 Screenshot of the magnetic field around a straight conductor from ONLINE Lab

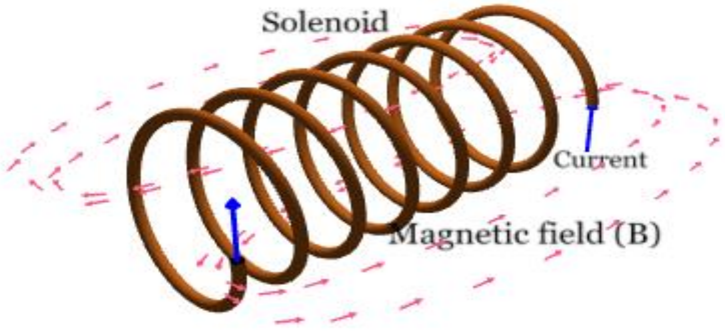


Figure 4.8 Screenshot of the magnetic field around a solenoid from ONLINE Lab simulations

4.1.3 Transformation-during-instruction

The CS suite (Figure 4.3) was selected to demonstrate the magnetic field around a loop. In this case CS changes in the values of the current could be made, and learners can observe the outcome or feedback and be able to generate a hypothesis, draw conclusions or formulate a model. The reason for using this CS suite as I wrote in my reflective journal was because

> *I could not find a suitable computer simulation to demonstrate the magnetic field around a loop and so I decided to use this computer simulation of two parallel line with current flowing in opposite direction to demonstrate the field around a loop. It really worked because the magnetic fields are the same around a loop and around two parallel wires with current flowing in opposite directions. In this computer simulation changes in the values of current could be made and learners can observe the outcome or feedback and be able to generate a hypothesis, draw conclusions or formulate a model (August 2015).*

4.1.4 Instruction

Figure 4.9 depicts a scenario or the set-up of the class during instruction. In this set-up, the computer simulations were projected from the teacher’s laptop onto the white screen which was located at the front of the classroom.

Figure 4.9 Classroom setting

The demonstration (though simple) was both *interesting* and *intriguing* to learners. Both the university lecturer and head of department (HOD) (critical friends) observed my lesson also commented on this demonstration. The university lecturer commented that it was a *good and practical demonstration and introduction to the abstract concept of magnetic field to learners*. The activity was meaningful, relevant and anchoring phenomenon for the learners to explain and construct a gapless causal explanation for the event (Stroupe, 2017). It was able to spark the learner’s interest. He said that he liked the demonstration and would use it with his pre-service teacher students. Something is interesting when it keeps their ‘attention’ because it is exciting or ‘has many ideas’ whilst intriguing when it is ‘unusual.’ The attention of the learners was drawn by the attraction of the iron fillings to the iron nail around which was wrapped an insulated wire connected to the cell. This (attraction) is usually associated with a magnet (learner’s prior experiences). However, because there was no magnet being used, the learners commented *wow it’s magic* (affective-wonder[13]). I interpreted magic as to mean that the phenomenon was unusual because it was not part of their daily life experiences.

The fact that they attributed the attraction of iron fillings to the current flowing in the wire suggested that the learners could not identify magnetism with current (Evaluation-during-

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[13] I interpreted ‘wow’ as to mean the phenomenon was surprising/intriguing and ‘magic’ as to mean that the phenomenon was unusual because it was not part of their daily life experiences.

instruction). Their definitions of magnetic field (from Grade 10) were limited and associated with the magnet only. The learners could not also explain the origin of magnetism from electrons as proposed by the domain theory (from Grade 10). Through the demonstration, I noticed areas where learner's knowledge was lacking. Learners did not have a robust understanding of the concept of magnetism. Therefore, the CSs that I had chosen were meant to address some of the areas. However, I was not sure about the learners' perceptions of them.

The use of CSs transformed the way I interacted with learners and the way I was able to explain the concepts to learners. As observed by my critical friend, the use of the CSs was central to the lesson. I noted in my reflective journal that CSs were *pedagogic media platforms to interact actively and engage learners in the learning activities. Not only were the computer simulations the object*[14] *of interaction but also a participant*[15] *in the interactions. The computer simulations were not only a source of content but the medium through which the content was delivered (reflective journal, August 2015)*.

The display of the CSs on the white screen was intended to provide learners with the opportunity to familiarise and internalise the features of the object/phenomenon. These processes assist learners to develop a mental picture of the abstract phenomenon *which make learning easier* because *CSs allow us to see this happening with our naked eyes* (FGD, 2015). In order to demonstrate narrative media (see section 2.9), the teacher projected the selected CSs on a white screen which was as the front of the class (see Figure 4.10).

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[14] Computer simulations provided resources to interact about (e.g., the display of the magnetic field around a straight conductor) where the teacher had to ask learners to describe what they were observing during whole class discussions.

[15] Computer simulations were a partner to interaction (e.g., the feedback given when certain parameters were varied) where the learners had to respond to the feedback.

Figure 4.10 Demonstration of the magnetic field around a straight conductor during instruction

I noted in my reflective journal that *CSs have an edge over textbook diagrams in terms of representational clarity* (August 2016), my personal evaluation of the tool as compared to textbooks as a teaching tool. It has an epistemic value to develop conceptual fluency in learners. **Representational clarity** means the quality of being clear and comprehensible of the representation, i.e., the representation reduces abstractness of the phenomenon. This definition can be contrasted to representational fidelity, which is the quality of being near to the real phenomenon. I found representational clarity to be an affordance of computer simulations which learners could utilise to "interpret correctly a complex discourse of words, symbols, diagrams, and pictures, all bearing a specific meaning that must be interpreted correctly if the student is to learn what is intended" (Laurillard, 2002:51). This lesson addressed the National Curriculum Statement (NCS) aim to produce learners that are able to "communicate effectively using visual, symbolic and/or language skills in various modes" (DBE, 2011:15). Learners suggested that seeing CSs save them from *imagining*[16] (FGD, 2015) and agreed *that imagining abstract things that you have not seen before or you don't know is difficult* because *your imagination might not be correct* (FGD, 2015). The affordances of CSs to *make the unseen visible* (reflective journal, August 2015). Their perceptual fidelity helped learners to grasp descriptions of abstract concepts, making it easier for them to assimilate new learning in the subject (Ndlovu, 2015).

Khezwo, a learner, contrasted textbook learning with the depth that she gained from CSs:

> *The computer simulations help to summarize what is in the textbook, because what will be explained in the textbook is too much and some of the words being used are difficult to understand…most of us learners when we read a textbook the aim is to cram without understanding. When you read from the textbook it is easy to cram… But if we are observing like on the projector it is easy because your understanding when you are seeing it happening is different from when you are imagining, sometimes your imagination might not be correct…but what you see happening is easy to understand as opposed to when you just read from the textbook. Computer simulations help us to understand the applications of the things that we will be learning in school. When we watch the simulations, it helps us not to forget because you would have seen it with your eyes… Sometimes the words that are used in the textbook are difficult to understand that you need a dictionary and the*

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[16] Imagining can mean that learners have to visualise or mentally simulate how the phenomenon looks.

> *way the dictionary explains might be difficult again such that you need someone to explain it to you. So, the computer simulations make it easy to understand better as opposed to reading from the textbook. You are able to describe what you have seen in your own words. When you read from a textbook it is easy for one to cram the whole passage that you are reading and reproduce it in the examination (FGD, 2015).*

While reflecting on Khezwo's utterance, one can get an impression that CSs have become digital textbooks that are able to "fill in gaps that a text leaves" (Pai, 2014:5). At the same time, there is a low-language demand placed on the learners as opposed to the textbook. They can complement the usual textbooks that learners normally use. This idea was also confirmed by other learners who said that viewing computer simulations enabled them to explain what was happening without the use of some of the technical words that are used in the textbooks. Thus, the learners' voice was used to express their ideas in non-academic language (Brown & Spang, 2008), imperfect language (Moschkovich, 2012) or utilize multiple languages to formulate and express ideas (Warren *et al.*,2001).

For example, when asked to describe the nature of the magnetic field around a straight conductor during a lesson, a learner had this to say*, as they move away from the current-carrying conductor, they expand*. When probed further to explain the learner had this to say *the field lines are close together near the wire and when they we move away from the wire, they are further apart.* In this way, that learners may have found an idiosyncratic disposition to making sense of the content being taught. Levrini *et al.* (2018) term it "learning appropriation" (p.101). According to Bakhtin (1981), appropriation:

> It [a word] becomes "one's own" only when the speaker populates it with his own intentions, his own accent, when he appropriates the word, adapting it to his own semantic and expressive intention. Before appropriation, the word […] exists in other people's mouths, in other people's contexts, serving other people's intentions: it is from there that one must take the word, and make it one's own. (p.293-294)

To overcome the lack of proficiency in the language of instruction, learners capitalise by cramming. This activity was alluded to by other learners who concurred that the language used in the textbook is not learner friendly.

> *When it comes to scientific terms in English, they are unique and sometimes hard for one to understand what is meant… (FGD, 2015)*

The fact that science terms are unique is evidenced in literature. Oyoo (2012, 2017) suggests that the language of science has two components: technical and non-technical. Oyoo went further to report that learners have problems with both technical and non-technical terms. It is no wonder that according to Khezwo the words used in textbooks are sometimes *bombastic* (FGD, 2015). I took the word 'bombastic' to mean technical. Therefore, without non-verbal reinforcement, the use of technical terms, which are usually abstract, presents difficulties to learners. Computer simulations can act as 'language brokers' in the learning of physical science by learners of low language proficiency.

The teacher, through guided inquiry, physically manipulated the CSs which helped the learners to see how the related variables interact to give rise to the phenomena (see Figure 4.11). According to Kirsh and Maglio (1994), physically manipulating a concrete model is a complementary action, which augments or substitutes for a mental process that a learner can perform in the world. I noted in my reflective journal that

> *What I did in stopping the simulation helped learners somehow to see how the field around each loop in the solenoid combine to form a resultant magnetic field. This enabled me to explain the magnetic field around a solenoid as resulting from the addition of the magnetic field around loops. (Reflective journal, August 2015).*

Successfully linking visual information to the textual resource provided in guided inquiry may be cognitively less demanding for learners, particularly those with low prior knowledge. Consequently, lessons that include the use of concrete models may help learners better learn how diagrams represent three-dimensional information and practice mentally simulating spatial transformations of molecular structures to improve understanding (Stieff *et al*., 2016). Thus, the crucial role of the teacher in guided inquiry has been confirmed in the findings of Kunnath and Kriek (2018), Wu and Huang (2007) and Siddiqui and Khatoon (2013).

Figure 4.11 Teacher manipulating the computer simulations during instruction

The visuals projected on the screen in the front of the class created an *open space*[17] (Reflective journal, August 2015) for dialogic discourse that ensued between the teacher and the learner. The conversational space is open in the sense that learners are afforded the freedom self-expression of their diverse ideas, thoughts, and feelings: so that the ideas of the teacher are not solely pursued. Learners are also provided with opportunities to express and reflect on their own perspectives and those of others on the scientific concept under discussion. Such classroom practices empowers learners position them as legitimate participants in discussions. One of the critical friends commented that *most of the talking was done by learners and the teacher provided guidance. The teacher constantly referred to the observations made by the learners*. This instructional practice was motivated by the desire to encourage learners "to be authors and producers of knowledge, with ownership over it, rather than mere consumers of it" (Engle & Conant, 2002:404). In the words of Tomlison (2003), the computer simulation was used to "stimulate language use" (p.2), namely the language of science. This benefit is another affordance of CSs. Therefore, the open space created by computer simulations is filled by both spoken and unspoken communication that needed to enable learners to cross borders into new territories of knowledge. One of the general aims of the CAPS (section 1.3d), is to produce learners that are able to communicate effectively using visual, symbolic and/or language skills in various modes (DBE, 2011). Related to this aim is the ability to collect, analyse, organise and critically evaluate information (*ibid*). Therefore, there is need to provide an open space for learners to publicly share and revise ideas without fear that their ideas might be dismissed. Talk is not only evidence of and a tool for scientific sense-making, but also scientific sense-making itself (Ryu & Sikorski, 2019). However, I noted in my reflective journal that

> *computer simulations are good graphical representations of scientific phenomena in which the teacher can engage learners to verbalise their thoughts, ideas and feelings during a reflective discussion. It creates and stimulates an interactional space for learners and the teacher to talk and think together. I am excited about this because it eliminates the domination of my voice as the teacher in the class. I see this potential as learners get used to learn with this epistemic tool. What is needed for now is to continue to encourage learners to participate. There is need for learners to communicate about their learning. There is a general attitude of*

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[17] The space is open in the sense that the teacher does not present to the learners predetermined notes, but learners are presented with an opportunity to say what they are thinking about the phenomenon/activity being discussed.

> *apathy among some learners when it comes to participating during discussions. There is a particular group of learners that always participate, and the rest are just quiet and contended by listening to the teacher or just copying notes (Reflective journal, August 2015).*

Talk in science classrooms is still “overwhelmingly monologic” (Alexander, 2001:65), and closed to learners. In South African classrooms, there is a strong authoritarian culture that does not encourage critical dialogue between teachers and learners (Stott, 2018). Moreover, the authority of the textbook is unquestioned. The learners responded to the questions which were raised by the teacher with the intention of eliciting their ideas in order to develop a cumulative and coherent picture of “scientific story” (Mortimer & Scott, 2003:102) through classroom talk.

Through the use of computer simulations, the teacher was able to deliberately change his way of asking questions. This process required the use of longer wait time to help learners think more deeply. They required more than a yes/no response but inferences rather than verbatim recall of what had already been discussed. Some questions may be: Can someone try to explain what is happening here? What is the physics behind this phenomenon? Why are the iron fillings being attracted to the nail when there is no connection between these materials? These questions were being rephrased (transformation-during-instruction) to help learners understand what was asked. At times, learners seemed to not understand the question itself.

The responses by learners when they are observing the phenomenon are different than when they are just imagining about the phenomenon. Learners were able to read and communicate the information represented by the computer simulation graphics. It has been shown that discussions that are computer-mediated elicit substantive comments from learners, which might require reshaping, re-accentuations, and reorganisation of ideas (Chi, Kang & Yaghmourian, 2017). I noted in my reflective journal that

> *learners were able to give valid descriptions of the magnetic field around the current-carrying conductors. One learner was able to give a description which I had not anticipated. He said that the field was non-uniform as evidenced by the fact that the circles were not equidistant, with the field lines near the conductor very close together while those far from the conductor were farther apart. He even suggested that the field was, therefore, stronger near the conductor while weak far away from the conductor. (Reflective journal, August 2015)*

I valued such self-expression by the learner for two epistemic reasons: firstly, it was meant to be a process in which ‘knowing’ was to be developed in individual learners. I wanted learners to develop the “epistemologies for,” rather than “epistemologies of,” science (Ko & Krist, 2019:980). The comment made by the learner was as valid as the one written in the textbook from a disciplinary perspective. It was infused with authentic terms (e.g., non-uniform, equidistant) and expressions that were not provided by the teacher or textbook. It was a substantive comment that showed that the learner was able to interpret the features of the magnetic field, evidence of learning appropriation. Secondly, by encouraging learners to express themselves, I wanted them to value their personal constructions of meaning in the same as they would the ones in textbooks. One learner had this to comment on why he enjoyed my lessons, *he is a good communicator and… he likes to hear our opinions…* (FDG, 2015). I took the word opinion to mean their contributions. There is evidence that learners are often found to unquestioningly accept opinions of the textbook or the teacher (Teo, 2016). Such an attitude or habit of mind is developed in situations where learners are ‘poured’ with information and researchers (Costa, Kallick, McTighe & Zmuda, 2020) concur that focussing on mastering subject-area knowledge alone will not be sufficient to prepare learners with the capabilities to think critically, demonstrate creativity and imagination, communicate effectively using various media, work collaboratively with others, and self-direct their own lifelong learning. When learners have the opportunity to interact with the visual model of the phenomenon they are studying, their level of understanding is enhanced.

During the discussions, learners raised two issues related to the enactment of CSs as a teaching and learning tool. Since the integration and enactment of CSs as a curriculum material is a function of the social interaction between teachers and learners (Ko & Krist, 2019), such issues are expected. Each technology has its associated social practice which requires the users to adapt or become enculturated in its social practices. As a result, learners need to adapt and change to the social practices of the use of CSs as a curriculum material. They need to develop new literacies consistent with the social practices of CSs. During the lesson, learners said that they wanted CSs that could teach them in the manner a teacher was doing (in other words they wanted the teacher to be replaced by the CSs). They also doubted the reality of the phenomena represented by the CSs especially the one for electromagnetic induction. These two issues got me reflecting: *Why would they want CSs that talk like a person? Why did they doubt what they were seeing being represented by the CSs*? *Why did the learners have such perceptions?* Learners asked if what the CS was representing truly existed in real life. Was it possible to light a bulb without any cell being connected to the bulb? What is apparent in the learners’ perceptions is an unfamiliarity with what I reckoned as the *new order* (reflective journal, 2015) of using technology when teaching and learning. Familiarity and experience with learning technology is important. Learners failed to realise the use of technology as a tool for inscribing and transporting science ideas to ease the process of learning.

Another thought that came to my mind was that maybe they were being bored. It is possible since in most of their lessons, they are used to hear the teachers' voices dominating the discourse, while the voice of the learner is not honoured. This situation was an indication to me that learners were seeking a new order of doing things where the learners' voice is also honoured (see Figure 4.12). The concept of voice encompasses not only the expression of thought but also the development of thought and a sense of epistemic agency (Oldfather, 1993).

Figure 4.12 Learner responding to a question during a whole class discussion

My engagement of this media form was meant to elicit learner ideas and identify or correct any misconceptions that learners might have. I noted in my reflective journal that

> *The discussions I had with the learners gave me an opportunity to elicit their ideas and to understand their thinking. I am particularly excited with the communicative power of computer simulations. They provide an environment for exploration through dialogue and questioning opportunities. When asking a question, I no longer need to evaluate whether the response is correct or wrong myself, other learners are able to confirm if it is wrong or correct. This makes the teacher no longer the arbiter, but multiple learner voices are allowed to speak. However, where it was necessary, I was called to correct wrong ideas that learners may have (August, 2015).*

While reflecting on the above reflection (retro-reflection) I could realise an interesting approach to questioning[18], which was shaped by the use of computer simulations. This

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[18] The following serves as an example. In a lesson on electromagnetic induction, instead of telling them what happens when a magnet is moved towards the solenoid, I was asking

approach was an attempt to move away from a monologic and authoritative discourse to a more inclusive and dialogic discourse. From a learner perspective, dialogic teaching affords them with greater authorship, meaning and more equitable opportunities to learn (Resnick, Asterhan & Clarke, 2015). In the previous reflective journal entry, a pattern of the interaction has been established between the teacher and learners. The teacher initiates the question for discussion, the learner responds, and the teacher seeks for the confirmation of the response from the other learners. The questions required learners to give more elaborate answers. What is notable is the way the questions are posed. Thus, the Initiate-Respond-Confirm (IRC) pattern is observed. This pattern of interaction has been seen to be repeated in subsequent lessons. As opposed to the Initiate, Respond and Evaluate (IRE) sequence (Candela, 1999), the IRC does not put the central locus of knowledge and power on the teacher. The teacher is a partner who positions himself as a facilitator. The act of seeking for confirmation from learners is to position themselves as co-constructors of knowledge in the learning process. The intention behind such participant framework is to both emotionally support and to encourage learners as they take differentiated and idiosyncratic forms of ownership of their learning (Levrini *et al*., 2019).

The teacher's interest in his integration of CSs into teaching is his belief that CSs can accelerate learner ability to understand science ideas. The CS's graphical affordance promotes retention as it provides learners with experiences, they might have difficulties in adapting from the textbook. These adapted occurrences leave a mental picture, making it easy for learners to remember. During a FGD, learners stated:

> *…because you also made it possible to bring thing that we can observe what you were saying through those simulations. Most of us didn't believe that the simulation was true. (FGD, 2015)*
>
> *…most of us we won't understand because will just read and cram for just us to pass, but if you can make it practically then we can analyse that it is true. We go and apply it in real life because like inducing the magnet from the current if you have lost a needle in the soil you can just go if you have a phone battery and a wire then you can induce the magnet. (FGD, 2015)*

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them what observations they were making when the magnet is moved towards the solenoid. It was not only the lighting of the bulb they referred to but also the moving of the electrons. The question does not require a yes/no but requires the learner to express their thoughts in their own words. The role of the teacher in this case is to participate in learners' discussion as a peer and to co-construct knowledge with the learners.

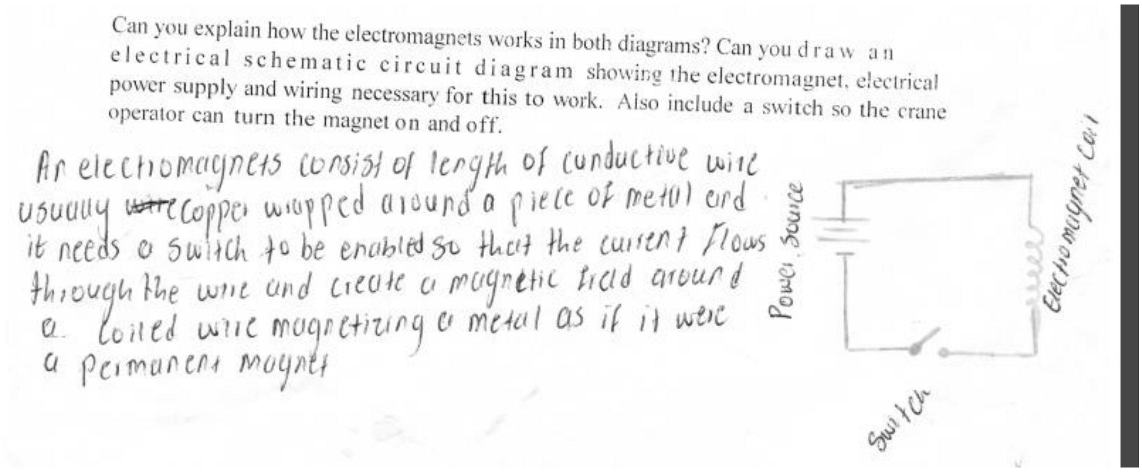
4.1.5 Evaluation-during-instruction

The responses by learners to the questions asked by the teacher showed that computer simulations were very helpful as evidenced in the following excerpts. The responses showed learners who were able to read and interpret the computer graphical display.

> *Learners were able to give valid descriptions of the magnetic field around the current-carrying conductors. One learner was able to give a description, which I had not anticipated. He said that the field was non-uniform as evidenced by the fact that the circles were not equidistant, with the field lines near the conductor very close together while those far from the conductor were farther apart. He even suggested that the field was, therefore, stronger near the conductor while weak far away from the conductor. I perceive that computer simulations can provide supportive guides which assist learners against going astray both scientifically and operationally (Reflective journal, August 2015).*

4.1.6 Evaluation

Learners were not able to complete the given task in the time allocated (about 10 minutes). The learners said they required more time as the activity was a bit challenging. The single group of learners who had managed to complete the exercise demonstrated sound understanding of the concept as revealed by their answer (see Figure 4.13)



Can you explain how the electromagnets works in both diagrams? Can you draw an electrical schematic circuit diagram showing the electromagnet, electrical power supply and wiring necessary for this to work. Also include a switch so the crane operator can turn the magnet on and off.

An electromagnets consist of length of conductive wire usually ~~wire~~ copper wrapped around a piece of metal and it needs a switch to be enabled so that the current flows through the wire and create a magnetic field around a coiled wire magnetizing a metal as if it were a permanent magnet

Figure 4.13 One group's answer to classwork activity (see worksheet Appendix 7)

4.1.7 New comprehension

Selection of various CSs is an important process of transforming content. It enhances the comprehensibility of content since different CSs have different features which can be used to adapt and tailor the content to the requirements of the curriculum. I noted in my reflective journal that

> *The various prompts and cues that are found within some computer simulations are intended to adapt and tailor our lessons to the needs of learners. Some of the*

> *computer simulations on the internet are meant to be used by learners in high schools as well as students in college or university. (August 2015)*

The process of searching for new CS is ongoing since there are new CSs with new features that are being designed. The selected computer simulations used in this lesson had limitations as it was not possible to change some variables (e.g., see Figure 4.1) for learners to observe the effect, for example, on the magnitude of the magnetic field, when the current is varied. Learners were therefore unable to hypothesise the relationship between current (I) and magnetic field (B) on their own.

Computer simulations are not only the medium to display the content but also the medium through which the content is delivered. Computer simulations provides supportive and engaging multimedia features (see figure 4.10) that permits content to be displayed pictorially and not through the use of abstract text. At the same time, computer simulations allow the teacher to engage in dialogic talk with the learners (see figure 4.9) as they explore the various graphical representations caused by changes to the initial state of the computer simulations. It has both pragmatic and epistemic value. The teacher no longer relies on the textbook as the only source for content. In my teaching experience I have found computer simulations to illustrate scientific phenomena better than explanations by the teacher, or textbook or any other curriculum material that I may have been disposed to. No matter how well a teacher explains scientific phenomena, the effect on student learning is not the same as when learners view it using computer simulations. Other curriculum materials do not explicitly demonstrate the dynamic nature of scientific phenomenon in the manner that computer simulations do.

4.2 Iteration 1 Lesson 2 Electromagnetic Induction

4.2.1 Comprehension

When planning for this topic I came across an activity that could help me introduce the difficult idea of generating current when no cell/battery was involved. The activity was an abstract one and could challenge or oppose learners' prior beliefs or conceptions. In this activity, I wanted learners to hypothesise a connection between magnetism and electricity, thereby assisting learners to see 'conceptual coherence' with the topic of magnetism which was taught earlier. Literature in science education reports that mainstream instruction leaves learners viewing science as an assortment of disconnected facts (Sikorski & Hammer, 2017) because of a lack of conceptual coherence. The argument for conceptual coherence is as follows: For students to construct deep, interconnected understandings of natural phenomena and see a "sense of unity" in science, the curriculum must be carefully sequenced to make those connections clear to students (NRC, 2012, p. 10)

4.2.2 Transformation (see section 4.1.2)

4.2.3 Transformation-during-instruction

Learners were sceptical of the reality of the phenomena represented by computer simulations (see Figure 4.5). I noted in my reflective journal that:

> *Learners seemed to have been overwhelmed with the ingenuity of computer simulations. The demonstrations of computer simulations appeared surprisingly impressive to stun the learners. Of all the comments that l got from learners l was struck by the comment that what the simulations were demonstrating were too good to be true and learners said they will only believe it if they can see it practically. I was compelled to look for an old model generator to demonstrate that the bulb can be lighted without a battery. This cannot be surprising considering that it is their first time to encounter learning with these tools. (August 2015)*

During the focus group discussions learners also confirmed my feeling when they said:

> *Most of us didn't believe that the simulation was true but as you brought that thing you were winding then the light started to glow that's where I started to believe that those simulations were correct. (FDG,2015)*

I have intentionally described it as sceptical to bring out the idea that learners did not believe or were doubtful or questioned the reality or 'truthfulness' of the phenomena represented by computer simulations. Thus, the use of computer simulations had an *overwhelming effect* on learners. An overwhelming effect is when the use of a tool tends to cause stupefaction on learners. The scepticism displayed by learners have also been noted by Wellington (1985) who accentuates that learners do not always believe that the laws and principles that simulations display will also apply in the real world. However, one gets a sense that such scepticism might arise from the novelty of computer simulations to novices. When learners get used or are exposed to such learning tools at an earlier stage, they will be acquainted with their features and operations.

4.2.4 Instruction (lesson 2)

Figure 4.14 Teacher demonstrating how a generator model works to light a bulb during instruction

Since learners found it difficult to suggest a possible way to light the bulb using a magnet and solenoid during the warm up activity, I decided to use computer simulations (Faraday's Law) to initiate the thinking process. The CSs had materials similar to the ones given in the activity. In this way, the CS was used as a *narrative media*. The intention was to narrate to learners how the phenomenon results or arises. Comprehending the dynamic phenomenon by relying on static diagrams in textbooks can be more challenging for learners. The diagrams drawn by learners revealed that they were not sure if the phenomenon exists, and if it exists, how it did arise. During the focus group discussion, one learner alluded to this idea when he said:

> *According to me, the lesson was to be so hard for us (if those things were not there), because we were not be able to see that does it really exist or not. So those simulations helped a lot because we were able to see physically using a projector screen, but if we were using the textbooks, we were not going to understand how the magnet will enter the coil and the current created, it was going difficult for us to learn this topic. (FGD,2015)*
>
> *Arali ri khou to vhona like the simulations zwivha zvi easy coz understanding yamusi tshithu tshi khou itea na understanding ya tshithu u khou imaginer or humbulela, sometimes na imagination I dovha I wrong atiri ndi to vha ndikhou to humbulela.mara zvithu zvine ni khou vhona zvi easy to understand u fhirisazvithu zwine ndi khou to imaginer…(but if we are able to see like the simulations, it is easy because your understanding when you see things happening compared to*

> *when you are just imagining is different, sometimes what you are imagining is not correct because you are imagining, but things that you are seeing are easy to understand more that things you are imagining… (FGD,2015)*

The learners pointed that CSs speak to them in way that makes them to understand, unlike the diagrams in textbooks. Although the concept is complex and abstract, science textbooks often oversimplify the dynamic and unobservable processes of how the magnetic field of the magnet and the induced magnetic field around the solenoid interact. They are able to interact with what they are being taught as opposed to only imagining.

Through discussions, learners were asked to verbalize their thinking, make observations of steps in the scientific phenomenon, and while the teacher providing "guidance consisting of accurate explanations to help them make sense of their observations" (Ryoo *et al*., 2019:6). In the process, learners were able to select relevant phrases and image sequences concerning electromagnetic induction, organising them into coherent causal chains of the steps in electromagnetic induction building what Mayer *et al*., (1999:321), called "internal connections". One learner stated:

> *Lesson yo vha ya vhudi eh! Ndo vhona zwi khwine ngauri muthu u thoma u vha interested uri like kharali hu khou pfi experimental, like hezwila zwa galvanometer, I tshi khou detector current uri magnet I vha I khou dzheniswa gai, ri vha ri sa khou sokou funziwa nga maipfi fhedzi ri vha ri khou vhona. Zwi ita uri na rine ri pfe ri tshi zwi funa. (The lesson was good. I felt (using computer simulations) was better because one become interested like that experiment where current was detected in the galvanometer, when the magnet is being inserted, we are not only taught verbally but we will be seeing it happening). (FGD, 2015)*
>
> *The computer simulations summarise whatever is written in the textbooks…with the computer simulations you are able to express your ideas in your own words which is different from reading in a textbook. Some of the words written in the textbooks are big such that they also need to be explained, that's why we end up cramming so that we can pass the exam (FGD, 2015)*

As compared to static diagrams in textbooks, computer simulations are dynamic and graphical media where the visual representations illustrated are capable of communicating to and assisting learners to understand the esoteric domain of a scientific field in an interactive and engaging way (Nghifimule & Schafer, 2018). Thus, computer simulations have a communicative power enabling learners to express their thoughts about any phenomena without fear. A learner stated:

> *Computer simulations are good representations because they can show movement. Physics is all about motion like in geometric optics where we learn about reflection and refraction of light rays, so using computer simulations we get to see those light rays moving. Also, in electromagnetic induction which is about the production of electricity due to motion, so with computer simulations we can see movement of the magnet and the solenoid in different conditions and they show us different readings on the voltmeter which shows that electricity is being produced, something which textbooks can't do. Masala. (FGD, 2015)*

The evaluative utterance by Masala provides a window in understanding the restrictive nature of textbook representations in assisting learners to build explanations of scientific phenomena. The action-consequence ability of computer simulations enables learners to develop understanding of fundamental scientific concepts.

Learners further suggested that:

> *…l am able to explain to others how current is induced by a magnet as it moves towards a solenoid. I can explain in a way they can understand (Taki, 2015).*
>
> *With computer simulations l am able to explain from the way l understand…(Dzanga, 2015)*
>
> *…I didn't believe that electricity can be generated in many things except water, wind which they are normal…. I start to believe that it is not all the time that electricity can be generated by battery or just electricity from Eskom, this lesson was very good, because we were observing something we don't know…(Godzwana, 2015)*
>
> *...we never knew that magnet could induce current and that current can be induced by magnetism, so it really taught us a lot. Now we know that maybe if we want a magnet, and we don't have a magnet we use current to induce magnet (Budeli, 2015)*

However, the critical friend felt that learners could have been placed in better organized groups when task was given so as to aid better interactions during group discussions. The critical friend felt that the warm up activity was not suitable for the level of learners in grade 11 and that it was too abstract for the learners and that I should find a simpler activity.

4.2.5 Evaluation-during-instruction

Computer simulations assisted learners to profile the scientific concept that was demonstrated. The responses given by learners described the phenomena of electromagnetism in a manner it can be described in any science textbook. However, the difference is that the descriptions were not coming from the teacher but the learners themselves. The teacher was facilitating by asking questions that addressed the content requirements of the curriculum. In this case the computer simulation was used to provide opportunities and context for talking science during instruction to avoiding teacher-dominance. I noted in my reflective journal:

> *The observations made by learners went a great way to assist them to articulate their ideas in a coherent manner. The responses elicited from learners demonstrated that they were making sense of what was being taught. The learners were able to identify the variables that affected the lighting the bulb. This was really encouraging. The learners were comfortable with the visual tool which made them to enjoy the lesson. (reflective journal, August 2015)*
>
> *I really welcomed the contributions by learners on the factors that affect the induced emf/current. The learners identified factors such as the strength of the magnet, the speed of the magnet/coil, the number of turns of the coil, the diameter of the solenoid. We were able to demonstrate this with the computer simulations. So instead of reading these in the textbook, they were able to experience their practical demonstration (virtual). Leaners were able to accurately interpret visual representations of scientific phenomena, a sense-making practice that is important in learning science. (reflective journal, August 2015)*

4.2.6 Evaluation

The learners felt that the warm up activity (Warm up Activity 1) was challenging and too difficult for them. They asked if it was possible; if I was able to demonstrate this phenomenon practically so that they could believe it was real. Learners failed to draw a circuit diagram in which a solenoid, cell and a bulb should be connected so that the bulb can light (see Figure 4.15). In these diagrams one can perceive the deficiencies in the conceptual knowledge of the learners. *(reflective journal, August 2015)*

After checking the diagrams and the explanations, it was clear that learners had no prior experiences with electromagnetic induction. Learners failed to find a link between magnetism and electricity even though the concepts of magnetism and electricity are taught in grade 9 and 10. Learners are inadequately prepared at the lower level especially in natural sciences in order to tackle physical science at grade 10-12 level. The diagrams given by the learner's evidence this situation (see Figure 4.15). One reason is that at lower levels learners are taught science by teachers who have not specialised either in physics or chemistry (Manqele, 2017; Munikwa, 2016). Buabeng *et al*. (2015) suggest that learners are restricted to a few opportunities to the teaching and learning of physics during their junior science courses.

For example, the following diagrams were proffered by the learners when asked to complete a circuit in the given materials will be able to light a bulb (see Figure 4.15). The representations are clear that the leaners made no errors or mistakes in constructing the diagrams.The diagrams are constructions of learner ideas that are deemed plausible to explain the scientific phenomenon. I have observed these diagrams from a number of learners in my experiences of teaching this topic. It has been highlighted in science education literature that learners come to learn science armed with a diverse set of alternative conceptions or misconceptions concerning natural phenomena and events (Correia *et al*.,2019). These alternative conceptions of phenomena and events are not consistent with the with the current knowledge of scientific phenomena.

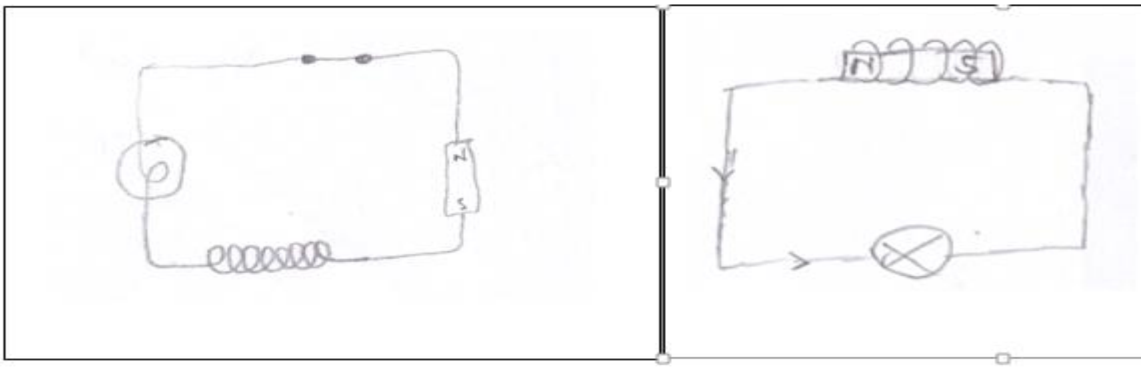


Figure 4.15 Learner responses to warm up activity (see work sheet Appendix 8)

A close analysis of the answers as evidenced by the diagrams (Figure 4.15) and explanations given by the learners reveal the following alternative conceptions:

1. A magnet/magnetic field can be a source of charge.

This conception was an attempt to make sense of the phenomenon from intuition. It is not entirely wrong because current is induced when there is a change in the magnetic field and can be used as a steppingstone to introduce learners to the correct conception. Hence Robertson, Scherr, and Hammer (2016) consider responsive teaching as involving sifting through the multitude of ideas that learners voice and recognizing those ideas that provide entry points for additional scientific reasoning.

2. A cell/battery is needed for current to flow.

The idea that a cell/battery is needed for current to flow is elementary prior knowledge familiar with the learners from previous learning. In my teaching experience I have noticed that learners are challenged by the idea that current can flow in a circuit where there is no cell/battery. It is an abstract idea/concept that may be not be logical, sensible, and valuable from the point of view of learners, it even challenges learners' intuition. However, learners need to develop a thorough understanding of abstract concepts to develop their ability to solve science problems. To respond productively to such learner ideas (alternative conceptions), Bell (1984) caveats teachers to consider them as an important and necessary stage of the learning process and not something which is intrinsically negative. This is critical because alternative conceptions are problematic in that they interfere with subsequent understandings if the learner attempts to use them as the foundation for further learning. Furthermore, they have been actively constructed by the learner and therefore have emotional and intellectual attachment for that learner, and consequently are only relinquished by the learner with great reluctance (Mestre,1989). Confrey (1990) asserts that alternative conceptions are considered to be "surprising, pervasive, and resilient" (p. 19), therefore, to address them teachers needs to marshal knowledge that is strongly dependent on the specific topic the learners are learning (Etkina *et al*., 2019) which results in the design of critical tasks of teaching (ToT) defined as the key activities through which teachers and learners enact practices that promote and support student learning (Ball, 2000).

In my instruction, I addressed the alternative conceptions that had been revealed in the learners' diagrams. Thus the knowledge of learners' alternative conceptions is critical to the formulation of responsive strategies for reddressing areas of misunderstanding by learners. In my reflective journal, I noted that

> *the curriculum documents or textbooks should highlight all the alternative conceptions that learners are likely to have as has been revealed in research or recorded in science education literature. This is very important. This is likely to assist teachers in their lesson preparations as to how they can tackle such wrong conceptions. Not many teachers have such knowledge of learners' misconceptions. Hence our teaching is not necessarily planned to eliminate such incorrect conceptions. Teachers should be capacitated in how they can adopt responsive teaching to dispense pedagogic justice. (reflective journal, 2015)*

4.27 New Comprehension

An understanding of learners' prior knowledge is an important aspect in enhancing the transformation of that content.

The process of searching and selecting computer simulations that can be used to achieve the objectives of the lesson is never ending. Therefore, computer simulations are not a supplementary component of teaching but rather as an integral part of teaching in this new context.

It seems as if the learners were overwhelmed by the information or the ideas and/or their beliefs were challenged by the representations. The learners are not only restricted to the view and interpretation of the teacher only or textbook. Thus, computer simulations provide room for independent thought. CS has the potential to discourage the teacher from presenting facts, concepts and /or procedural knowledge in a way that relegates the learner to a passive observer. However, the challenge is that learners are still used to or have been conditioned to this situation.

I discovered that the learners felt free to express their ideas because they were able to view what was happening and make sense of it. Readence, Bean and Baldwin (2004) refer to it as "graphic literacy" which is defined as the ability to read, interpret charts, maps, graphs and other visual presentations and graphical inscriptions (p.68). What is important is not the observing of the visuals but the ability to read the visuals and make sense of them.

The topic of electromagnetic induction is counter intuitive. This phenomenon was not identified as a common phenomenon in the everyday lives of the learners. In my next lessons, I decided that I will not give learners the same activity but either to find a model generator or to visit the science centre so that learners could have a practical experience of the phenomenon.

4.3 Iteration 2: Lesson 1- Magnetic fields around straight current-carrying conductors

The section highlights my and my learners' experiences of lesson one of the second iteration of my study. The study was completed with a new class of learners. The experiences with each of these classes were different, and they were instrumental in my planning and execution of my lessons. Since the aim of the study was to improve the way I teach with computer simulations, I compared the experiences between the classes or across the iterations. However, I synthesized the particular ways in which computer simulations were helpful. The focus is on the "didactical functionality" (Cerulli, Pedemonte & Robotti, 2006:245) of the technology and of "key concerns" (Artigue, Haspékian, Cazes, Bottino, Cerulli, Kynigos, Lagrange & Mariotti, 2006:387) of technology use.

4.3.1 Comprehension

From iteration 1, lesson one, I discovered alternative conceptions about the magnetic fields and considered them in my planning.

4.3.2 Transformation (see section 4.1.2)

4.3.3 Transformation-during-instruction

An opportunity was presented for the teacher to make the idea of the strength of a magnetic field more concrete. Having established the presence of a magnetic field around a current-carrying conductor from the previous warm-up activity, an opportunity was presented to make concrete the idea of the strength of the magnetic field. I asked learners as to what can be done to make the magnetic field stronger with reference to the magnetic field lines. Learners needed to hypothesise as to what would happen to the number of magnetic field lines. They did struggle to give me the correct answer. However, as I noted in my reflective journal:

> *I realised when I had asked the learners what can be done to increase the strength of the magnetic field that l could also ask the same question in a different and more practical way. I then asked the learners as what can be done to increase the amount of iron fillings that could be attracted by the iron nail (referring to the demonstration of the iron nail which was connected to the cell). (reflective journal, August 2016)*

It worked as learners were able to state that more iron fillings would be attracted if the current flowing in the circuit was increased. To demonstrate this phenomenon, the CS suite (see Figure 4.7) was used, where learners were able to answer my previous question on the increase in the number of magnetic field lines.

4.3.4 Instruction

The demonstration was intriguing and created interest in the learners. At first puzzled when they saw the iron fillings being attracted to the iron nail, some learners were said *wow* while others said it *was magic*. After watching the demonstration, learners stated that *science is real*. This realisation gave me the opportunity to ask for the scientific explanation of the phenomenon. Learners could not identify magnetic field as the cause of the attraction. They attributed the attraction to the flowing current. Learners could not establish links between the concrete situation (the attraction of the iron fillings) and abstract phenomena (magnetic field). They could not reason at the microscopic level- a challenge that has been highlighted in the examination diagnostic reports for the past years. This lack of understanding can be attributed to the way that science concepts are introduced to learners, especially at lower grades. It is critical the development of strong linkages between knowledge of concrete situations and abstract concepts be developed even in lower grades.

The critical friend suggested that the learners seemed to enjoy the lesson, as they were both attentive and participative. He even commended on the behaviour of the learners that it was *good and not disruptive*. *(reflective journal, August 2016)*

He further noted that "the interaction between teacher and learners was good. Learners meaningfully participated and contributed to the lesson".

In my reflective journal I noted:

> *The learners were providing good responses when l asked them to describe the nature of the magnetic field around a straight wire. This was very encouraging. Their participation showed that they were really engaged and followed what was happening. One learner said that the field lines were anticlockwise. When l changed the direction of the current, the field lines were no longer going anti-clockwise. This gave me the opportunity to introduce the idea of the right-hand rule to determine the direction of the magnetic field (reflective journal, 2016).*

The learners made these comments during the focus group discussion

> *Computer simulations make learning easier as certain things that we can't see with our eyes are demonstrated, for example magnetic fields. They also save time and speed up the process of learning and teaching as we avoid rubbing chalkboards and dust (FGD, 2016)*
>
> *They save time and they assist in learning by means of observation, everything is clear and understandable (FGD, 2016).*
>
> *They make me to easily visualize …in my mind. I get to experience a new way of learning (Vhuthu).*
>
> *Learning with computer simulations has been such a help to me because l gets to experience a new way of learning by visualizing what l am being taught (Zik).*

From the statements of the learners, one gets a sense of the efficacy of computer simulations in supporting learning. They are learning tools that learners are comfortable with in their learning. The idea of 'experiencing a new way of learning' suggests that learners are also developing new literacy consistent with learning with the technology.

4.3.5 Evaluation-during-instruction

Computer simulation prompts provide a stimulus for learners to say something. For example, during class discussion I asked learners to describe the nature of the magnetic field around a straight wire. One observant learner said that the field was anticlockwise. This learner was correct, because it depended on the direction of current flow. Thus, I had the chance to introduce the concept of the right-hand rule to determine the direction of the field.

4.3.6 Evaluation

I discovered that learners had forgotten about the principle of superposition, a concept that was taught to them in grade 10. When I had asked them to suggest how the resultant magnetic field around a solenoid (consisting of individual loops) occurred, it was an attempt to link the concept to the current idea to prior knowledge. Educators should deliberately assist learners make links with concepts that have been taught in earlier or future grades to promote conceptual progression. Many science textbooks have been found to contain too many topics with too few connections between these topics with many irrelevant activities (Sikorsi & Hammer, 2017). There are superficial connections (1) among the key ideas, (2) between the key ideas and their prerequisites, and (3) between the key ideas and other, related ideas (AAAS, 2002). Related to the concept of conceptual progression is conceptual coherence of the unit between concepts taught in different grades.

4.3.7 New Comprehension

The selected computer simulation was adequate in covering the prescribed content, and it was scientifically correct. They are effective tools for the transposition of content knowledge from the curriculum document to the learners. Computer simulations synchronises words and actions. Learners are able to s*ee what is meant,* rather than they trying to *imagine what is meant* when only described in teacher's words. CSs can facilitate dialogue and engage with learners in knowledge construction. They have a communicative power, allowing learners' voices to be heard. Computer simulations often develop new literacies.

4.4 Iteration 2: Lesson 2- Electromagnetic induction

Next are my and my learners' experiences during lesson 2 of the second iteration. These experiences stem from the interactions that I had with both the learners and the use of computer simulations. In these experiences, I did not detach myself from the phenomenon which might raise the issues of objectivity in my reporting. However, Freire (1970:26) contends that "One cannot conceive of objectivity without subjectivity. Neither can exist without the other, nor can they be dichotomized". I was able to understand that social constructivism and subjectivity are part of epistemological discussions (Romano, 2018). Knowledge depends on the scientific community where it is produced, where the subject is also the object of research. A corpus of data from my reflective journals and focus group discussions were obtained. From the data, one should not seek to generalize but rather to understand the object one is studying in a particular context.

4.4.1 Comprehension

Iteration 1, lesson 2 revealed alternative conceptions that learners held concerning electromagnetic induction. I considered these alternative conceptions in my planning. Because learners had difficulties with the warm up activity (Appendix 8), I decided to use a generator model to introduce the concept of electromagnetic induction.

4.4.2 Transformation (see section 4.1.2)

4.4.3 Transformation-during-instruction

Instead of using the warm up activity (see Appendix 8) which was used in the previous lesson (iteration 1), I used the model of the generator to introduce the concept of electromagnetic induction. Whilst the model was effective in demonstrating electromagnetic induction, learners had problems in explaining the physics behind the lighting of the bulb. Learners suggested a conversion of friction into electrical energy while others attributed it to heat being produced by the winding of the generator arm. I could *notice* that learners were trying to make sense of the phenomenon by putting together knowledge pieces from their prior learning experiences. Unfortunately, they did not possess a strong conceptual background to enable them to answer the question. Other learners asked what was inside the motor. Learners could not think or talk about the magnetic field and its related topics. They failed to link the activity with the previous lesson. This situation further supports the idea of 'siloing' knowledge that learners learn. Hence, there needs to be a deliberate effort on the part of teachers to make the link between the lessons. Physics must be presented as a coherent set of related concepts so that learners are able to decipher it as a collection of discrete facts, definitions, and algorithms.

4.4.4 Instruction

The iconographic nature of computer simulations adds a new dimension to teaching and learning. Learners were able to learn the content on magnetic fields and electromagnetic induction connected to important and meaningful situations and not through memorisation. The presentation of content-as-pictures (CAPs) is helpful in that it synchronises words and actions. The animated pictures permit learners to construct their own texts. Therefore, learners are able not only able to acquire information but communicate such information. Such teacher support embedded in computer simulation is necessary to engender the material practical for everyday use. In my reflective journal, I expressed my feeling of using computer simulations:

> *What I enjoy about teaching with computer simulations is that learners are not constrained to understand the content in the language of the teacher or the textbook author. Through 'seeing' the content learners are able to express it in terms that are familiar to them. Learners are not reduced to blind consumption of information as is normally the case during dictation of notes. (August 2017).*

I enjoyed the opportunity to engage learners in dialogic talk afforded through the use of computer simulation. Hence from the RTOP, one of the areas of my practice which have been identified as standing out were the communication and student/teacher relationship. Teaching approaches that promote communication between the teacher and learners and the development of trusting relationships with learners positively associated with instructional supports and effective classroom practices (Mikeska *et al*., 2017).

The National Research Council (NRC, 2012) proposed that changing instructional practice required programmes that included feedback on instructional practice. The following excerpt is my reflection on the discussion I had with the critical friend:

> *The warm up activity linked very well with the topic and helped bring back learners to the lesson. The critical friend believed that the activity was a good way to introduce the topic of electromagnetic induction. Though the concept is abstract but using this demonstration it will go a long way in helping learners to understand it in a practical way. (Reflective journal, August 2016)*

He further commented that *the use the projector helped draw learners' attention. They were focused on the subject matter throughout the lesson. The summary provided in through the power point presentation was good. It serves on time. The teacher focuses on explaining concepts rather than writing on the board.*

Learners had this to say:

> *Computer simulations makes information visible and save time for teaching. It makes me to understand physical sciences better due to the laboratory activities that we can see rather than reading from books. (FGD, August 2016)*
>
> *It is easy to learn new things I don't know as I can be able to see them rather than reading it in textbooks only. If it is about magnets, I can see the magnetic field, how they behave, which increase my knowledge. (FGD, August 2016)*

> *With computer simulations certain demonstrations are made such as electromagnetic induction rather than when a teacher is explaining using only a textbook and chalkboard. This is an enhancement to learning and it creates visual images in learner's minds. (FGD, 2016)*
>
> *What I like about computer simulations is that they play a major role on my understanding of physical sciences…I also like that it has become easy for me to discuss physical sciences with my study partners just because we see the simulations and understand better. (FGD,2016)*
>
> *What I like about computer simulations is that they can be used to explore and gain new insights. I also like that they increase the way we imagine things because they demonstrate things like in reality. (FGD, 2016)*
>
> *…they help us to understand electromagnetic induction, which is difficult to understand without observing, so with computer simulations it's easy. (FGD, 2016)*
>
> *I have found it easy to study electromagnetic induction even though it's not easy to understand. I did understand with the aid of computer simulations. Now as I speak, I am able to explain how current is produced by a magnet and a solenoid even to anyone. I can explain in a way they would understand. This simulation made it easier to understand things like fields, nobody can see fields, but computer simulations make it easy to visualise fields. So, I can say that indeed computer simulations have assisted me a lot. (FGD,2016).*
>
> *Unlike other chapters, the lessons were explicit as electromagnetism is a real-world application. I experienced the interaction between electricity and magnetism and how they give rise to devices found in t.v, radios and many others. (FGD, 2016)*

Whilst these perceptions cannot be generalised there is evidence that computer simulations are useful learning tools, they assisted or enhanced understanding of concepts and learners developed new literacies (e.g., understanding of concepts pictorially and not through the use of text; the ability to communicate what was represented) through the use of computer simulations. The computer simulations removed some of the hindrances to learning experienced by learners.

4.4.5 Evaluation-during-instruction

During instruction, an opportunity was presented to introduce idea of the change in direction of current. I wanted the learners to understand why the galvanometer was deflecting to either side when a magnet was moved towards or out of the solenoid. To demonstrate this idea, I made use of computer simulation in Figure 4.5. On this computer simulation, I was able to change the bulb and replace it with a galvanometer. When using the computer simulation with the bulb, learners would not be able to notice this effect because when the magnet is moving towards and away from the solenoid, the bulb still lights. During the demonstration, the learners identified that the galvanometer deflected to one side when the magnet moved towards the solenoid and deflected to the opposite site when the magnet was moved away from the solenoid. The difficulty came when I asked them to explain the observation. I noted in reflective journal:

> *The learners struggled to explain why the galvanometer deflected on one side when the magnet was moved into the solenoid and to the other side when the magnet was moved out. The answers suggested by learners revealed that were using intuition to try to join unrelated concepts to make meaning. One learner suggested that the deflection showed the strength of the current while another learner suggested the terminals were not the same, the north pole was representing the negative while the south pole the positive. (reflective journal, August 2016)*

4.4.6 Evaluation

The model generator (see Figure 4.16) showed me that learners were attempting to explain the phenomenon by intuition. They suggested that the bulb was able to light because of friction caused by the winding of the gears, while another learner suggested that heat generated by the winding of the gears was causing the bulb to light. It was clear that learners had no prior experiences with electromagnetic induction. Also, learners failed to find a link between magnetism and electricity. These concepts of magnetism and electricity are taught in Grades 9 and 10. However, learners are inadequately prepared at the lower level especially in natural sciences to tackle physical science at Grade 10-12 level.

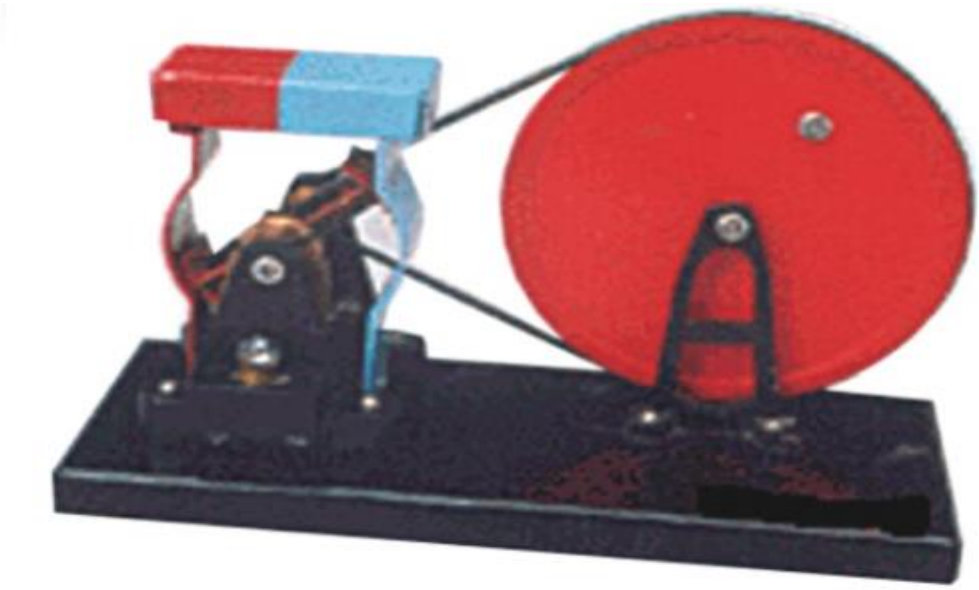


Figure 4.16 A generator model (Source: internet)

4.4.7 New Comprehension

The use of computer simulation involves learning about the tool (or knowledge of the tool) and the relation between the tool and the subject/content knowledge. Learners' contributions are made part of their notes so that they do not view science as a body of prescribed information to be memorised. Sikorsi and Hammer (2017) refer to it as "premeditated coherence" (p.930). Computer simulations have an epistemic value in learning abstract phenomena/concepts. Representational clarity and visualisation helped with concept formation. Not only is a computer simulation a visual amplifier but it also improves graphical quality and accuracy of scientific representation.

4.5 Iteration 3:

Lesson 1- Magnetic fields around current-carrying conductors

The first lesson of the third iteration focussed on magnetic fields around current-carrying conductors. This class was new, and it was their first time to be taught with computer simulations. In these experiences, it is not my intention to just observe and analyse without setting out to modify or generate changes to my teaching practices. The aim of the researcher's intervention is not only to generate new scientific knowledge but also to facilitate the process of change in his teaching practices. The process of change involves understanding the experiences of the learners as important actors who form part of the object of the research.

4.5.1 Comprehension

This process was informed by the experiences of the last two iterations. The alternative conceptions displayed by the learners were generally the same: (1) they could not link magnetism with electricity; (2) the attraction of the iron fillings was due to the flowing current, and they could not attribute it to the magnetic field created by the current. Learners had difficulties in linking the topic to prior learning. For example, they identified the magnetic field with only magnets. I considered this knowledge when I planned for the lesson. In addition to the CSs I used in the last two iterations, I downloaded other CSs which I used in this lesson.

4.5.2 Transformation (see section 4.12)

4.5.3 Transformation-during-instruction

During the class discussions on the nature of magnetic field around a current-conductor as displayed by the projected computer simulations, I discovered the shortcomings of these tools. I selected the computer simulations because variables such as current strength and current direction could be varied. However, when it came to describe the nature of the magnetic field, the learners perceived the magnetic field as uniform. Their argument was supported by the fact that spacing between the field lines seemed almost the same. From my reflective journal I noted:

> *During the class discussion I asked learners to describe the nature of the magnetic field around a straight wire and one learner said that the field was uniform. On further questioning as to why he said the field was uniform the learner said that the field lines were at equal distances apart. Indeed, by looking at the CS one gets the same impression because the field lines seem to be equidistant. I had to explain that the magnetic field was not uniform and bring out the limitations of such tools (August 2017)*

Such representation (see Figure 4.7) leads learners to develop incorrect mental pictures of the phenomenon or concept. I concur with Bell and Smetana (2013) who indicated that learners may form misconceptions if they do not understand a model’s limitations. Therefore, learners need to be alerted to the limitations of computer simulations as learning tools in this instance. The reason is compelling because learners in schools in rural areas rarely use technology in their learning. At the same time, because of their weak prior knowledge as a result of the low quality of learning experiences (Mlachila & Moeketsi, 2019), learners tend to be overwhelmed by technology to the extent that they may fail to recognise its weakness. It is therefore important when teaching with technology to plan how to address the limitations of technology or to deal with the wrong interpretations caused by the shortcomings of technology. Such situations can be disruptive to teaching and learning situations.

4.5.4 Instruction

Unlike in the previous iterations, learners requested that they be allowed to perform the demonstration themselves. They wanted to be involved as opposed to being passive. The desire by the learners to perform the activity might stem from curiosity (a conative learning experience) or the interest aroused by the activity. In countries such as the United States and Finland, their curriculum policies have set new standards that stress the value of designing science instructional practices that include learning activities that are interesting, challenging, and relevant to one’s future (Schneider *et al.*, 2016). The emphasis on the affective aspects of learning in addition to cognitive ones have been highlighted by Fortus (2014), and Singh, Granville, and Dika (2002) as important for engagement in science learning (Osborne, Simon, & Collins, 2003).

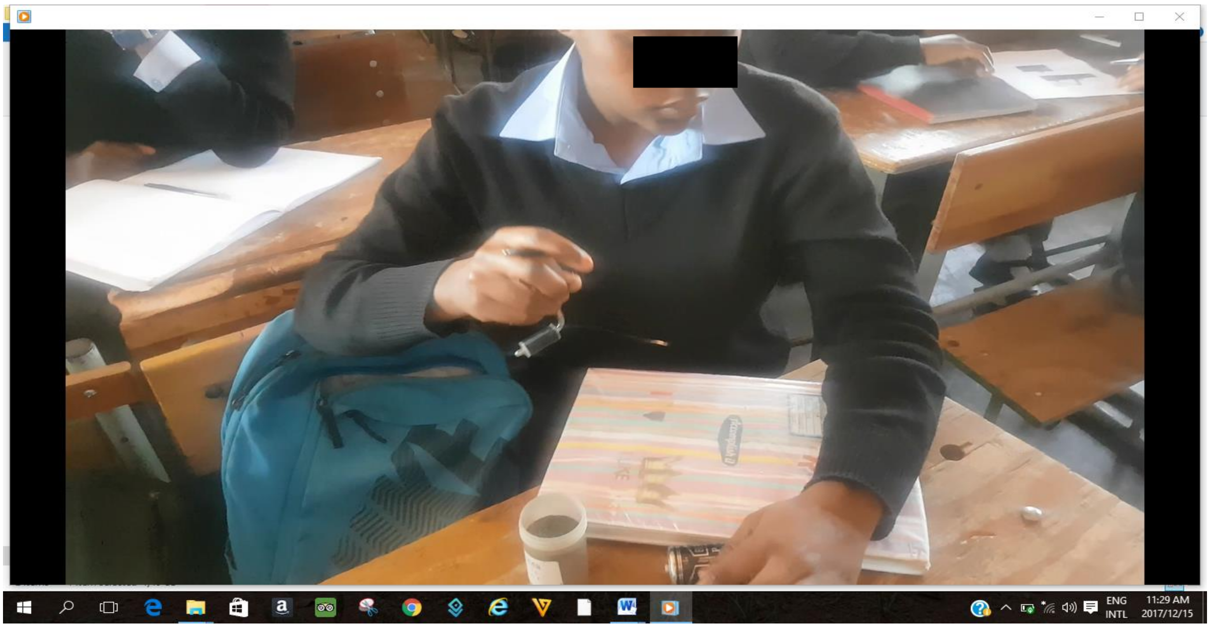


Figure 4.17 Learner attempting to carry out the demonstration (*conative experience*)

> *l discovered during the discussions with the learners is that some of the cues on the simulations are subject to wrong interpretation by learners as they try to make sense of them. Learners make sense of new experiences basing on intuition or prior learning. For example, during a whole class discussion, l asked the learners to describe the nature of the field around a straight conductor carrying a current. The learner said that there were more field lines towards the negative pole. While the negative sign was meant to represent the direction of current flow, to the learner he took it as representing a charge and the magnetic field lines being attracted to this charge. (August 2017)*

While other learners were able to describe the nature of the magnetic field as displayed by the visuals, one learner said that the magnetic fields lines are more toward the negative. While the visual (graphical interface) (see Figure 4.7) is meant to be intuitive, learners interpret them differently. The urge was to ask the learner as to what relationship exists between charges and magnetic fields. The learner's response did not match my own. However, as I reflected on what the learner said, I realised that the learner was trying to make sense of what he was seeing with reference to his prior knowledge, thus constructing new knowledge. As explained by Novak (1977), constructivism is a theory of learning which postulates that individuals learn by constructing new knowledge from prior experiences. Reflecting on this moment helped me see that I ignored or rather dismissed a response from a learner as not important to what I wanted the learners to understand.

> *I really welcomed Harry's question when he asked that question as to why the iron nail attract iron fillings when there was no physical contact between the battery and the nail*[19]*. What could have prompted him to ask such a conceptual question? It really got me thinking. It took me by surprise because I had not anticipated such a question considering that it's rare for my learners to ask questions. In fact, I had not planned to discuss this concept of mutual induction as it is not mentioned in the curriculum document. I am however glad for not missing that opportunity to provide an elaborated feedback which I hoped further deepened the understanding of the concept. (August 2017)*

The HOD felt that the warm up activity, though it took time, was a complete summary of the lesson. It took more than 10 minutes, although it had been planned to take 5 minutes. Learners were able to identify the lesson as practical and informative. The conclusion was drawn and linked with learners' observations and contributions. Important points were noted and expanded on the board.

Learners suggested that:

> *Learning with computer simulations has been such a help to me because I get to experience a new way of learning by visualising what I am being taught. Computer simulations takes us out of imagining giving us an opportunity to experience ideas practically. I also tend to remember things better after witnessing them and also have a better way of explaining them in the way I see them. (FGD, August 2017)*

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[19] The counter-intuitivity of the phenomenon piqued the interest of the learner. This curiosity was aroused from the perception that was made during the demonstration of the iron fillings being attracted whilst there was no physical contact between the iron nail and the insulated wires carrying the current from the cell. The curiosity had both perceptual and epistemic attributes. This is an example of a conative learning experience.

> *Computer simulations enable us to see the imaginary lines which we cannot see with our naked eyes and also help us to see the experiments that we should have done in the laboratory (FGD, 2017)*
>
> *Computer simulations assist in learning magnetic fields and electromagnetic induction because they show the fields in motion rather than in books because in books the fields are fixed (FGD, 2017).*
>
> *Basically, most of the concepts connected with magnetic fields and electromagnetic induction are abstract, so with computer simulations we are able to see things that are not visible… (FGD, 2017)*

4.5.5 Evaluation-during-instruction

An opportunity was presented to check whether learners could still recall/remember the concept of the principle of superposition. The concept was not referred in the current topic, but I wanted learners to have a link with the topic of magnetic field. I asked them to suggest the idea which we could use to add up the individual magnetic fields around the loops of the solenoid to form one magnetic field around the solenoid (as shown in Figures 4.8, 4.18). The difficulty the learners had in recognising the concept revealed to me that they had forgotten about it or had no idea. I noted in my reflective journal:

> *Learners failed to recall the principle of superposition when l asked them how the magnetic field around the loops of the solenoid were added together. Learners had no idea of the links between the topic and what they had done in grade 10. (reflective journal, 2017)*

Most physical science textbooks do not explicitly illustrate how the net magnet field around the solenoid occurs. The idea of the ‘principle of superposition’, a concept taught in Grade 10, is not stated in many physical science textbooks with respect to magnetic fields. Many learners were surprised to know that the idea which they were taught in Grade 10 about waves was also relevant in the topic of magnetic field. It is one of the cross-cutting concepts in physics. Identifying and teaching cross-cutting concepts is another dimension which educators should adopt, so learners can develop a robust understanding of scientific ideas. Identifying these cross-cutting concepts will help learners to see the unity of physics. According to Businskas (2008), this approach of making connections between concepts is referred to as instruction-oriented connection which is defined in terms of how educators linked new concept to prior learners’ knowledge. The learners should be able to find links between the topics they are taught. These links promote conceptual progression, the ability to relate or link ideas from one grade to another: linking superposition (a concept taught in Grade 10) to electromagnetic induction (a concept taught in grade 11). Therefore, making linkages between concepts promotes conceptual coherence and helps learners to avoid ‘siloing’ knowledge so that they fail not to see the relationships between science ideas, forming integrated understanding. However, the CAPS document is silent about these concepts. The educator made use of the animation (see Figure 4.18) to explain how the principle of superposition is applicable to explain the resultant magnetic field that is created when multiple loops are brought together.

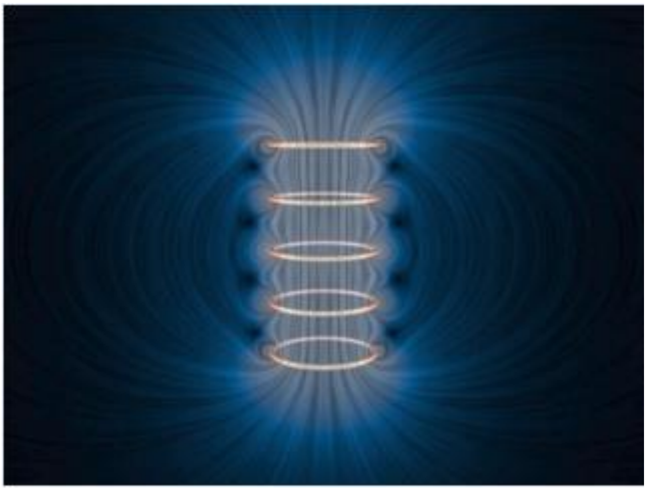

Figure 4.18 Magnetic field around a solenoid

In this animation, learners were able to see the magnetic fields around each loop and how they added to form the net magnetic field around the solenoid. The animation was also used to show the uniform magnetic field inside the solenoid as represented by the straight equidistant lines. This concept is difficult to explain in only words. Learners need a model to illustrate this phenomenon. Despite the transient nature of the phenomenon, l was able to pause the animation and let the learners observe.

4.5.6 Evaluation

In all the three iterations, I discovered that learners do not want to participate actively during lessons. There are only a few who would respond to teacher-initiated questions. This learning situation is their norm. Some learners have come to regard this as normal; there are some learners who are supposed to respond to these questions while others are just like passengers. However, taking guidance from Gergen and Gergen (2007:163), I wanted constructivist dialogues that shifted the attention from the teacher to coordinated relationships with and within the learners. While thinking about how I could foster these relationships, a thought came into my mind to ask the learners if they had personal laptops at home. To my surprise, I learned that some learners did have laptops. Therefore, in the future, I plan to invite learners to bring your own devices (BYODs) so that workstations can be formed, and all learners will be involved in the learning process. According to educational policy and curriculum documents, learners should interact in classrooms and learn through group interaction in the class (DBE, 2011). To engage the learners, I designed a computer simulation activity worksheet in PowerPoint[20] (Appendix 16) which contains all the questions that I have asked in the last three iterations. In this worksheet, the learners will first work in groups to respond to the set questions, and then they will discuss the answers in a seminar-like platform.

4.5.7 New Comprehension

By using computer simulations, teachers move away from using dictation and writing as the major forms of externalization. The teacher will gradually move away from learner writing to more learner discussion with reference to computer simulations as the new digital textbook

Computer simulations 'entices' learners to get involved easily as possible answers can be simulated from the graphical representations.

4.6 Iteration 3: Lesson 2 – Electromagnetic Induction

In the second lesson of the third iteration, these experiences are practice-based and unique since they were captured in an uncontrived setting, where there was no need of controlling variables. It was a normal class held during routine instruction. The behaviours exhibited by both actors are thus not controlled; they are natural to the context. The experiences were recorded. Through reflection, pragmatic knowledge can be generated that can empower the teacher researcher to effectively use computer simulations.

4.6.1 Comprehension

In the two iterations, learners had difficulties in linking electricity with magnetism (see Figure 4.15) and section 4.4.3. The drawings by the learners in iteration 1 lesson 1 and the suggestions given by learners in iteration 2, lesson 1 suggested that learners have deficient prior learning experiences in both natural and physical sciences. This knowledge was instrumental in my planning of the lesson.

4.6.2 Transformation (see section 4.1.2)

4.6.3 Transformation-during-instruction

> *Unfortunately, the Online computer simulation for the magnetic field around a solenoid which l had intended learners to observe failed to download. Maybe it was due to weak internet connection. I then had to use another one which l had*

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[20] It is now possible to embed (several of) the PhET computer simulations into a PowerPoint document.

> *used in the first and second iteration. The technology disappointed me, and l had not anticipated this during my planning. (reflective journal, August 2017)*

The failure of the intended computer simulations to download highlights the importance of the need to have a back-up plan during the planning phase so as not to disturb the flow of the lesson.

4.6.4 Instruction

The use of computer simulations to make available scientific ideas on the social plane of the classroom creates opportunities to engage learners in science talk. Making use of computer simulations to promote learners talk science in classrooms is one way teachers in rural areas can use. This is in line with calls for reforms in teaching approaches in science that are more learner-centred (DBE, 2017). I noted:

> *The use of computer simulations creates an open space for interaction that moves beyond just communication to meaningful engagement. The teacher does not tell learners what is happening but elicits their ideas as well as demonstrating them. The space of interaction created by computer simulation which I have termed 'zone of action' promotes certain actions (prompted, directed or spontaneous) in both the teacher and learners that enhances learning. In the zone of action, the teacher is positioned as a facilitator of learning. At the same time learners are not just passive recipients of information but positioned as active participants. (reflective journal,2017)*

> *Learners were able to suggest the variables that affected the brightness of the bulb. However, to check whether learners were able to relate with the lesson on magnetic fields, I asked them how the adding of many more loops affected the brightness of the bulb. One learner was able to suggest that adding many turns increased the strength of the magnetic field. (reflective journal, August 2017)*

> *Today I felt overcoming the front of class teaching inertia that has characterised my teaching practice as far as I remember. For a long time, I have always believed that my position is always supposed to be in front of learners. I had no idea what it is like teaching from any position besides the front. I can now see that any space in the classroom is teaching space. I felt closer to my learners when I am not in the front. (reflective journal, August 2017.*

[redacted]

Figure 4.19 Teacher interacting with learners during instruction

The HOD commented on the introduction of the lesson, linking previous knowledge with the current topic. It helped the learners to see the coherence in concepts that they are doing.

The learners stated:

> *Computer simulations makes me easily visualise physical sciences in my mind of which is not easy because things like electromagnetism is not something, we know how it occurs or how it works as we do not see them often. In physical sciences there are many things that we believe they occur, but we cannot see them like forces between molecules but however computer simulations allow us to see this happening with our naked eyes. (reflective journal, August 2017)*
>
> *Computer simulations assist us by letting me as a learner to see practically the representation of how the magnet to create electricity. The things I see on simulations are easily captured by my mind as they are in a diagram rather than notes explained by mouth of a person.*
>
> *They were one of the lessons l actually enjoyed because you tried making it practical, it was not only theory which was one good thing for us to understand the concepts.*
>
> *…we don't have more of the equipment that we need to perform all those experiments, but as my teacher tried to elaborate them on his computer and things like that. It was much fun or much more experimental when we observed it by our eyes, because whatever you observe by your eyes never goes and whatever you touch and do by yourself, you can never forget that.*

> *I would suggest that for computer simulations to be more effective we should use them in other subjects…We must see to it that we pass all subjects not physical sciences only. We are not expected to pass but to understand and computer simulations are helpful in that regard. (Vhuyani)*
>
> *They must be used in every learning area and not physical sciences only because learners are quick to understand things which they have seen than what they have read. (Sedzi)*
>
> *They must be used in every subject because they save time, and everything is understandable and clear. (Fhulu)*
>
> *I think computer simulations should be used in every subject like life sciences…geography…(Masala)*

4.6.5 Evaluation-during-instruction

When introducing the concept of electromagnetic induction, I asked the learners to explain what was causing the bulb to light. The various suggestions made by the learners revealed a lack of prior knowledge which they could use to construct an explanation. It was a moment of science talk which I used to engage learners. I noted:

> *During the lesson to demonstrate electromagnetic induction when demonstrating the lighting of a bulb using the model generator, I asked the learners to explain to me what was causing the bulb to light. Learners were suggesting that it was because of friction or heat that was being converted to electric energy which was causing the bulb to light. When asked to explain how friction or heat causes the bulb to light, the learners said that the winding of the arm of the generator creates friction, while another said it creates heat which then is converted to electrical energy. The learners attempted to join up ideas from previous learning to make sense of the phenomenon (reflective journal, August 2017)*

4.6.6 Evaluation

I discovered that in the last three iterations, learners could not complete the classwork that I gave them. They always complained about time, and they had to finish it as homework. This view of assessment is not consistent with most definitions (Black & Wiliam, 2009; CCSSO, 2008; William & Thompson, 2008). For example, the CCSSO (2008) reckons formative assessment as “a process used by teachers and students during instruction that provides feedback to adjust ongoing teaching and learning to improve students’ achievement of intended instructional outcomes” (p. 3). It has been established that less effective assessment practices tend to focus on gathering information on how much learners have learned (typically declarative knowledge stated as fact) or simply on the extent to which learners have completed the activity (Minstrell et al.,2011). As a result, I decided to change the assessment method and perhaps try to assess from the learners' perspective to determine what they have learnt and how. Many times, teachers assess from our perspective and never think about the learners' side. From the previous focus group discussions, learners were able to describe what they learnt. It was encouraging to note concepts which they had learnt, even with gaps in the knowledge and what might have contributed to their learning. As a result, I have decided that in my next lessons I will ask learners to complete the following four tasks which I have adapted from the work of the British Columbia Institute of Technology (nd). The learner responses to these tasks are interpreted for strengths to be built upon and problematic aspects to be addressed in order "to support and extend learning through which students can then incorporate new learning into their developing schema" (Heritage, 2010, p. 8). These tasks form what I call the **Assessment for Understanding** (AfU) framework and it aims at broadening our perspective on formative assessment. It extends beyond the simple identification of right and wrong answers and focussing on not just what, but also how learners are learning.

Task 1: Have we achieved our objectives

1. What was the most meaningful thing you learned in this lesson?

2. What questions do you have from what we have done?

Task 2: Lesson summary

Summarise in your own words the key points of what we have done in form of a concept map

Task 3: Key-words list

Can you write what you think could be the keywords of this lesson/topic.

Task 4: Grey area

Can you write down any aspect(s) which is/are not clear to you resulting from this lesson/topic?

At the heart of this framework lies the need to access, support and build upon learner thinking as it develops from naïve to more sophisticated (Minstrell *et al.*,2011). Instructional decisions should be based largely on what on what actually emerges from learner responses to assessment (Hall & Burke, 2003; Torrance & Pryor, 2001). Through these responses' teachers are able to identify subsequent instructional decisions and actions to address the identified learning needs.

4.6.7 New Comprehension

The use of computer simulations shifted my focus from what to teach (content) to thinking about how to teach (presentation of content). Computer simulations can play an important role than just a presentation tool to mediate interaction between the learner and content through discussion and interaction. The use of cues or prompts helps the teacher to focus on important concepts that learners need to understand. Computer simulations have the potential to discourage the teacher from presenting facts, concepts and /or procedural knowledge in a way that relegates the learner to a passive observer. The use of computer simulations shifts the focus away from the teacher, putting it towards the use of technology as a learning resource.

Computer simulations assists learners to express their ideas. As a result, they are not constrained to regurgitate what they read from the textbook.

Many times, learners are assessed on what teachers have taught and not on learners what they learnt. Current assessment is focussed on checking whether learners are able to regurgitate and parrot. In my reflective journal I noted that *such assessment is shallow and deficient to inform us whether to conclude learning has taken place* (reflective journal, 2017). Therefore, there is a need to change the teachers' focus on how they assess. The AfU framework can assist teachers to assess what learners have learnt and identify the gaps in learners' knowledge.

4.7 Conclusion

After three iterations, I discovered that no new ideas/thoughts could be established. It was time to end my interventions and reflect, interpret and discuss the findings. The experiences were formed through reflections on the collective use of instructional behaviours, cognitive engagements, and computer simulations that represent my idiosyncratic repertoires of practice (Gutierrez & Rogoff, 2003). These are real classroom experiences undergone by the teacher and learners in the process of implementing the intended/planned curriculum (see Appendices 4A & 4B). Creswell and Campbell (1935) and Kelly (2009) refer to it as the curriculum in practise, the lived or experienced curriculum, and an actual curriculum since it involves teaching and learning in the context of school or class. It is about how the teacher and learners practice the curriculum by bringing in their social reflection on their experiences. Relatively little is known about real-life classroom experiences particularly of science teachers (Hora & Ferrare, 2013) who integrate technology. Literature is silent as to how teachers in rural schools use computer simulations during the teaching and learning process. Therefore, the generated experiences are not in any way intended to generate new theory on how computer simulations should be used. Rather, they are used to reflect, in order to transform, empower and improve his instructional practice. Integration of technology into teaching and learning is multidimensional considering several dimensions such as epistemological and cognitive. Trouche (2005) emphasizes the need of reflecting on teachers' and learners' actions (experiences) during the teaching and learning process with ICT in their lessons in order to understand how technology is integrated and used in a particular context. The integration and use of technology in a particular context are situated practices that can be clearly articulated by the voices of teachers concerned. The voice and role of the teacher has been notably absent in publications about the innovative use and integration of technology into ordinary classrooms (Lagrange *et al.*, 2003) especially in schools in rural areas which are under-resourced. It is critical that research be carried in classrooms particularly of the few teachers who perceive pedagogical value in their use of ICTs to identify exemplary practice especially in rural schools which make up most of the South African schooling system. This contrasts with studies that have looked at technology integration in urban township schools (Chigona & Chigona, 2010; Chikasha *et al.*,2014; Kemker, 2007; Ndlovu, 2015) and well-resourced schools (Correia *et al.*,2019; Ibieta *et al.*, 2017). However, descriptions of repertoires of practice that illuminate nuances of how technology is integrated in classroom instruction in specific contexts are important to know in order to inform pedagogical intervention (Hora & Ferrare, 2013).

4.8 Section B

Research Question 2: What are the cognitive, affective and conation experiences of learners when computer simulations were used in the teaching of electromagnetism?

Data is presented to answer research question 2: What are the cognitive, affective and conation experiences of learners when computer simulations were used in the teaching of electromagnetism?

4.8.1 Cognitive experiences of learners

Different themes have been identified to illustrate the learners' cognitive learning experience. Learners were able to state explicitly or implicitly what they learnt. Learners' descriptions of what they have learnt during the teaching process and how they can apply that knowledge can be taken as evidence of cognitive engagement.

The following two themes have been identified: relation of electricity to magnetism and application of electromagnetism. This is an example of declarative knowledge.

In each of the themes, reference to the FGD is presented.

4.8.1.1 Relation of electricity to magnetism

The knowledge about magnetism being induced from electricity and electricity being generated from magnetism was **new** to the learners. Thus, the cognitive engagement by learners resulted in them **creating scientific ideas** about magnetism and electricity and the relationship between them.

> *…we never knew that a magnet could induce current and that current can be induced by magnetism, so it really taught us a lot. (Vhuyani, FGD, 2015)*

> *I didn't believe that electricity can be generated in many things except water, wind which they are normal, everyone knows that. About electricity being induced by magnetism it was my first time I heard about such thing. (Ntaku, FGD, 2017)*

> *I always (thought) that eh current is created from the battery only, but now I have learnt that even magnet can create a current. (Mushapi, FGD, 2017)*

> *According to me so I learnt a lot, so before I knew this topic of electro-magnetism, I always thought that eh current is created from the battery only, but now I have learnt that even magnet can create a current. So, this lesson helped me to know topic more that I didn't knew before. (Tshikombeni, FGD, 2016)*

These expressions may not be taken to be representative of all the learners, but they can give a general portrait of what the learners learnt. What the learners said is proxy of what they would have normally written in an assessment activity. What and how learners express themselves is a clear indication of what they have learned. What the learners expressed as what they learnt can be viewed as the curriculum-as-achieved. In this case, it was what the curriculum-as-intended/planned (see the objectives on the lesson plan-Appendix 4A & 4B).

4.8.1.2 Application of electromagnetism

The new knowledge gained had practical applications. Thus, the knowledge was strategic according to Shavelson *et al*., (2005). Learners were able to state the specific ways in which they could apply the taught knowledge. In addition to creating new scientific ideas, learners were also able **to connect the knowledge to the real world**. Learners were able to relate the knowledge learnt to common experiences or aspects of their daily lives.

> *Now we know that maybe if we want a magnet, and we don't have a magnet we can use current to induce magnetism…if you have lost a needle in the soil you can just go if you have a phone battery and a wire then you can induce magnetism, then you started looking for your needle, then the needle will be attracted to the magnet. (Akin, FGD, 2015)*

> *…we never knew that magnet could induce current and that current can be induced by magnetism, so it really taught us a lot. Now we know that maybe if we want a magnet, and we don't have a magnet we can use current to induce magnetism… (Vhuyani, FGD, 2015)*
>
> *Ndo guda uri hu na other ways ya u ita electricity besides u shumisa battery, and it can be a solution kha shango lashu. (I have learnt that there are other ways of generating electricity besides using battery and it can be a solution to our country). (Tebogo, FGD,2016)*
>
> *Oh! This topic, eh what you have taught us, I learned a lot, as you have said it's a bit challenging but with the help of simulation, eh I was able to notice how the current is induced when a magnet and a solenoid are moved relative to each other. So, simulations help me a lot to get more visual learning, more of visual experiences to know how these magnetic fields and stuff happened and even the right-hand rule it helps us to determine the direction of the current, where it is flowing, how it is, yah so it was great. (Mushaphi, FGD,2015)*

The ability to relate learnt material to common experiences or aspects of their daily lives is an aspect that is not included in curricular documents. However, it was an outcome of the implemented curriculum or rather the curriculum-as-achieved. In addition to learning about magnetic fields and electricity, learners were also able to identify an application of their scientific ideas. Learners also learned the concept of mutual induction. This concept was raised during the third iteration (2017), and as noted in my reflective journal, I will include it in my future lessons. The idea is applicable to devices such as transformers. Such examples should be included in the curriculum so that learners are able to relate to the phenomenon. For example, learners have mobile telephone chargers, but they have no idea as how these devices work. Concepts that learners are taught should have relevance and be applicable so that they make meaning to them. Therefore, examples such as these (mobile telephone chargers) should be included in the curriculum so that learners are able to relate the content they learn to real life experiences.

4.8.2 Affective experiences

Three themes describing the affective learning experiences of the learners emerged from the analysis of the FGDs. These themes are enjoyment, surprise/wonder, and personal relevance/practical.

4.8.2.1 Enjoyment

A learning experience is enjoyable when it evokes positive feelings in an individual. The learners felt that lessons were pleasant or palatable to them. Learners used words such as *fun, interesting, good, enjoyable, and exciting* which reveals positive feelings towards the learning experiences.

> *The lessons were fine, actually really interesting looking at the environment of learning. Though we had limited resources, we are glad you made an effort to make it realistic. (Akim, FGD, 2017)*
>
> *They were one of the lessons l actually enjoyed because you tried making it practical, it was not only theory which was one good thing for us to understand the concepts. (Mushaphi,FGD, 2015)*
>
> *…we don't have more of the equipment that we need to perform all those experiments, but as my teacher tried to elaborate them on his computer and things like that. It was much fun or much more experimental when we observed it by our eyes, because whatever you observe by your eyes never goes and whatever you touch and do by yourself, you can never forget that. (Ntakuseni, FGD,2017)*
>
> *The lessons were exciting, challenging and fun. (Dimpho, FGD,2016)*

4.8.2.2 Surprise/wonder

A learning experience can be regarded as surprising or wonder if it evokes some feelings of disbelief or amazement. Learners reported that generating magnetism from electricity and electricity from magnetism was a new and surprising phenomenon. Learners suggested that what computer simulations were demonstrated the phenomenon, which could not be demonstrated in real life. In their words it was "too good to be true":

> *About electricity being induced by magnetism it was my first time I heard about such thing, maybe I might have come across it in some cases without knowing it. (Budeli, FGD,2015)*
>
> *The lessons were fun, experimental, and enjoyable and it was full of a variety of things that we didn't believe. (Khezwo, FGD, 2017)*
>
> *At first when you brought those things (referring to computer simulations) I didn't understand what was going on… and there was a magnet which was being brought close to the coil and bulb started lightening, and I was like how come there is no battery there is nothing. How could such thing be happening…(Patrick)?*
>
> *I think at first when you brought those simulations, I didn't believe them I was just like these are the simulations that were made by scientists. There is no such thing, the one that I didn't believe most was that one, and there was a magnet which was being brought close to the coil and bulb started lightening… (Ntaku, FGD, 2017)*

> *Most of us didn't believe that the simulation was true but as you brought that thing which you were winding then the light started to glow that's where I started to believe that those simulations were correct. (Mushaphi, FGD)*

4.8.2.3 Relevance/practical

Relevance is found when the content is applicable to the needs and interests of the learner and the society. The learners suggested that the learning experiences were *practical*. They felt that the lesson was not only theoretical but also practical. In this sense, a practical lesson is when the concepts being taught have the capability of being put into effect:

> *When we did that lesson, it was practical, l get interested in knowing what happens when electricity is generated not just in the lesson but in real life… (Ntaku, FGD,2017)*

> *The lessons were practical, we are able to go and apply it in real life, like inducing magnetism from current. lf you have lost a needle in the soil you can just go if you have a phone battery and wire then you can create a magnet, then you can start to look for your needle…(Akin,FGD)*

4.8.3 Conative learning experiences

Two themes related to the conative learning experiences emerged from the analysis of FGDs. Learners suggested that the use of computer simulations created interest in the topic, interest in learning, and the desire to learn and achieve.

4.8.3.1 Interest in learning/topic

Despite the difficulties or challenges related to the learning of the topic of electromagnetism (see Zenda, 2016), learning with computer simulations stimulates the interest in learning the topic as stated by the learners:

> *…and I understood a lot about electro-magnetism, and I have seen that it is a very interesting topic, it needs someone who is so dedicated towards his studies. (Mushaphi)*

> *…enjoyable and it is full of variety of things that we didn't believe, like it makes those who don't believe in science to believe in science.*

4.8.3.2 Desire to learn

Learners suggested that the use of technology in general will create their desire to learn. They revealed that learning was boring in most school subjects because of the routinized and monotonous way of doing things in schools. As one learner stated:

> *Eh one thing on that if computers were used at school, I think those learners who are leaving school will not do so because learners really enjoy technology, so they*

> *will I think will not leave school where the computer is used for teaching. No learner will have that arrogance to live school, because school will be fun, very fun, because everything you are being taught you gonna see it, because they are saying this and that, if you add this and that you get this and you gonna see this and being done and being taught things you have never seen. Most of the learners drop out of school, because school subjects become boring because you have to learn more things, more things and theoretical things without getting that practical or version of what is really happening in real life. We just focus on books without being taught, like without seeing this, what is this, when is this being said to be like this, how does it look like …and another thing here is that if they are using computers, we can just take a video when a teacher is teaching so that when are at home you didn't understand well, you can just play a video and see so that you can remember what you have forgotten (Ntaku, FGD, 2017)*

A desire to learn is a critical disposition, suggesting that the lack of it might in some way contribute to the large numbers of learners in rural schools are dropping out of school (Vermeulen, 2019) because they see education as useless (Business Tech, 2015). Thus, learning experiences are failing to create the curiosity in learners to be interested in learning physical sciences or to go to school. A desire by learners to remain in school and to learn is very important to attaining high levels of scientific literacy.

4.9 Summary

An understanding of the cognitive, affective and conative aspects of learning experiences has practical implications. According to Nyamupangedengu (2016), knowing what learners like, enjoy or interests them is important information to assist educators to implement lessons that learners enjoy. Learners have much to say on how to create classrooms where they are not only motivated but interested in learning content (see section 4.2). The three aspects can be regarded as components of engagement. Past studies have shown positive impacts of curriculum materials on cognitive learning experiences (Belland, Walker, Olsen, & Leary, 2015; White & Frederiksen, 2013). However, the affective and conative dimension of learning experiences have received much less attention in science education literature and rarely considered by teachers in their instruction (Van Rooyen & De Beer, 2010). It is reported that the SA school system generally continues to neglect the affective (and I add, the conative) dimensions of learning (Buma, 2018). Hence, it is common to hear that school is boring (Hobden, 2016), the classroom has become a zone where learners switch off. This boredom has been attributed to the less developed PCK of science teachers in order to enable them to plan for both the affective and conative learning experiences (National Planning Commission, 2013). According to Schneider, Krajcik, and Blumenfeld (2005) teaching in ways that are powerful for student learning, will require most teachers to develop new knowledge and skills in teaching (p. 284). This change might be a challenge for physical science teachers in rural areas to accomplish. This study addressed some the challenges that teachers might have in creating rich learning experiences that are inclusive of the cognitive, affective, and conative elements of learners.

Teachers must be aware that classroom instruction should not only contribute to learners' cognitive experiences, but also to the other two learning experiences in order to realize their own life-values, self-growth and development. Classroom teaching should not separate our cognitive function from our life-as-a-whole body, focusing on the importance of cognition and treating complete beings as thinking machines (Ye *et al.*, 2017).

Chapter 5

Discussion of findings

5.0 Introduction

According to Creswell and Poth (2017) and De Vos *et al.* (2014), the chapter on the discussion of findings is aimed at exploring the phenomenon through identifying relationships and providing relevant explanations among the generated data. Therefore, discussion of findings is drawn from generated data (Chapter 4) and literature (Chapter 2). Zhao *et al*. (2002:483) state, “there is a conspicuous lack of attention to the complexities and intricacies of how classroom teachers actually incorporate technology in their teaching”, especially in resource-constrained contexts such as schools in rural areas. Therefore, the aim of the study is to explore the influence of a teachers’ technological pedagogical reasoning when using computer simulations in the teaching and learning of electromagnetism in a whole class rural setting.

This study followed an exploratory research design using the action research methodology underpinned by an interpretivist paradigm. As Laurillard (2012) argued,

> We cannot challenge the technology to serve the needs of education until we know what we want from it. We have to articulate what it means to teach well, what the principles of designing good teaching are, and how these will enable learners to learn. Until then we risk continuing to be technology-led. (p.5)

This resulted in the research questions namely:

1. Can the sub-processes suggested by model of technological pedagogical reasoning (TPR) be used to describe a teachers’ technological pedagogical reasoning when using computer simulations (CS) in the teaching of electromagnetism to students in grade 11?
2. What are the cognitive, affective and conation experiences of learners when computer simulations were used in the teaching of electromagnetism?

In answering the research questions, I used the transformed model of pedagogical reasoning and action by Smart (2016) as the theoretical framework. The model describes the processes carried by teachers during teaching as they transform their knowledge into formats that facilitate learning. In that process, several metaphors have been suggested to describe how the teacher views and uses technology as curricular material to mediate learning. However, what is clear is teaching with technology requires an understanding and discovering of the potential affordances of the curriculum materials (in this case the computer simulations) and considering how they could be used in relation to different aspects of the pedagogical reasoning process. Such an awareness is what allows teachers to be effective and confident in their use of technology-it enables teachers to perform pedagogical actions that addresses the needs of learners. Schön (1983:107) refers to this process as an ongoing robust “reflective conversation with situations”, in which teachers reflect within their contexts on their actions and understandings in an integrated multidimensional and multifaceted process (Holmberg *et al.*, 2018). Hence the context is the venue for reflection and learning in teaching situations. Actually, it has been suggested a deeper understanding of the context in which reflection occurs enhances the professional knowledge of teachers (Dimova & Loughran, 2009).

5.1 Discussion

Emerging research is showing ways in which the use of ICT seems to affect all aspects of teachers’ pedagogical reasoning (Pang 2016; Smart 2016). However, the ways technology affects aspects of teachers’ pedagogical reasoning are not the same. The way technology affects pedagogical reasoning of teachers is dynamic and context dependent. It is a situated practice that needs to be understood from the perspective of the concerned teacher. Therefore, there is a need to explore the processes that a teacher follows when describing his technological pedagogical reasoning when using CS. As a new ‘species’ (computer simulations) that is entering the ecosystem of rural school classrooms, it is important to establish what influences a teachers’ TPR when using computer simulations to enhance the transformation of content so that it can be accessible to learners in rural schools to facilitate learning. Rural school performance in physical sciences has been deficient (Manqele, 2017). Learners in such contexts are at risk of dropping out of school (Boon *et al.*, 2007) or fail to achieve in physical sciences (Zenda, 2016). An understanding of the process of teachers TPR using CS could inform other teachers to reframe their practice and transform the curriculum by moving beyond familiar and routinized traditional practices of teaching. This change, among other things, involves an understanding and discovering of the potential affordances of digital technologies such as computer simulations and consideration on how they could be used in relation to different aspects of their practice (Holmberg, 2014; Norman 2013). It also entails social, psychological and behavioural changes and interactions of the actors in the teaching and learning situations. As suggested by Lebrun (2007) the computer per se superimposed on traditional forms of teaching cannot significantly improve the quality or productivity of teaching.

Research Question 1: Can the sub-processes suggested by the model of technological pedagogical reasoning (TPR) be used to describe a teachers’ technological pedagogical reasoning when using computer simulations (CS) in the teaching of electromagnetism to students in grade 11?

Figure 5.1 is a schematic representation of how the data in Chapter 4.0 was constructed. A diagrammatic representation of how a process (TPR) is thought to occur has the potential to capture the unique features of a phenomena to enhance understanding and future actions. It has the potential to become the overarching framework that can initiate robust discussions or further research into the aspects of teacher practice that can offers the greatest promise for improving learner performance. Mpungose (2017) opines that thinking without expression is incomplete, therefore, "teachers should express their thinking about their experiences to others in order to develop the public" (Dewey, 1938:10). However, Cochran-Smith (2009) opines that the experiences should facilitate "learning from teaching" in order to develop the new skills for lifelong reflection and knowledge building (p.306). According to Dewey (1963), such experiences are educative[21]. The reconstruction of the experiences was a narration of my reflections on the four elements (learners, content, technology and the teacher) identified as central to professional practice. According to McDiarmid, Ball and Anderson (1989), all teachers undertake certain instructional tasks such as planning lessons and instructional units, responding to pupils' written work, asking questions, responding to pupils' questions and assertions, selecting and adapting curricular materials basing their action on certain considerations. These considerations and the decisions teachers reach reflect their TPR.

Reflection has long been cited as an important aspect of teachers' professionalism (Orlando and Sawyer 2013), and for the teacher in this study, reflection was embedded in the identified elements which facilitated his framing and reframing of his practice. These reflective narratives of my experiences are bound to the time/period of reporting. However, extrapolations can be made to shape future experiences or what Ottesen (2007), referred to as "imagined practice" (p.40)- an opportunity that allows teachers to conjure up a possible future that is not yet in place and that may never be put into place (Beauchamp, 2015). Learning occurs when an opportunity is given to reflect and communicate one's experiences. Clandinin and Rosiek (2007) opine that "lived experiences are a source of important knowledge and understanding" (p. 42). Dewey (1933) views reflections as a meaning-making process, a systematic way of thinking which requires attitudes that recognises the personal growth and its need to happen in the

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[21] Dewey (1934) considers an experience educative when it stimulates, enhances physical, intellectual, or moral growth. Furthermore, an educative experience should afford stimuli and opportunities for further development in new directions and should add to the general quality of one's life by "[arousing] curiosity, [strengthening] initiative, and [setting] up desires and purposes that are sufficiently intense to carry [one] over dead places in the future" (Dewey, 1934:14).

interaction with others. Rogers (2002) suggests that interaction is one of the most vital elements in the experiences, in order to enhance continuity in the development of practitioners. The four elements (learners, content, technology and teacher) are presented as separate entities for clarity but, there is mutual interaction between them.

The focus of this research is on a teacher's reasoning using narratives to stimulate reflection and dialogue on the process of adapting to technology in a resource constrained teaching and learning environment. This research aligns with Kearney *et al.,* (2012) who emphasise the importance of attending to the perspectives of individual teachers in order to establish strong and sustainable practices. Acknowledging the varied perspectives of teachers in their experiences with technology would be a more meaningful approach to supporting and developing instructional practice, as opposed to one which ignores the centrality of individualised understandings (Connelly & Clandinin 1999), or which solely focuses on technical expertise such as learning to use a new computer application (Orlando, 2014). Rolfe (2012) also stresses the importance of identifying individual pioneers within institutions to understanding the motivations and characteristics of potential user.

Teaching practices with digital technology is not a universal phenomenon that can be cloned, but an individualised situated practice. It has an idiographic component: those aspects that addresses the specific needs of the teacher. TPR is also an intricate interplay between content, learners, technology and the teacher concerned in a particular context. Wallace (2003) acknowledged that instructional practices are affected by the context where teachers perform their work. Hence Figure 5.1 is an attempt to highlight the mechanism (process) that an individual teacher works through in an attempt to frame and reframe his practice in a particular context. The framework appears as linear for clarity purpose but in practice the interweaving of the elements does not follow a well-defined pattern. This process seems to be an important missing ingredient in the literature on teachers' teaching practices with technology. Orlando (2014) highlights the value of acknowledging and building on the individualised ways that teachers reflect on and work in their particular contexts. Sound scholarly teaching meaningfully responds to the contexts in which these practices are situated (Kemmis 2009). At the same time, Green (2009) and Kemmis (2009) opine that a teacher's meaningful response to a context suggests learning will be enhanced. With this perspective, I am able to understand how these elements influence the sub-processes of comprehension, transformation, instruction and evaluation (see Figure 5.1). Thus, the framework (Figure, 5.1) foregrounds the understanding that TPR makes valid and important connections among the four elements and it’s the sub-processes to enable a teacher to frame and reframe his practice. The framework provides an avenue to evaluate how teachers use technology as a reasoning tool in their teaching and learning and bring light to an understanding of their TPACK (Niess & Gillow-Wiles, 2017). The current teacher knowledge challenge is to identify and describe a 21stcentury TPR process teachers teaching in rural schools in a developing country.

As illustrated in Figure 5.1, the focus is not on technology as a stand-alone entity, but on ways in which it interacts with the other elements during the TPR sub-processes. When the teacher considers how to use the computer simulations, he does so in the context of the other elements. Thus, incorporating computer simulations is a complex task requiring a deep consideration of how the digital tools can interact with the other identified elements. The technology becomes a pedagogical reasoning tool, “a tool that mediates a teacher’s action, proving clear and detailed principles regarding learning that can be easily translated into teaching practice” (Seale & Cooper, 2010:1110). For teachers to develop TPR, they need educational experiences in which they integrate the new technology in order to engage learners in a particular content during routine instruction. Such an experience engages the teacher in reflecting on his own experiences in “ecologically embedded settings of real classroom practices, real students and real curricula” (Confrey, 2000:100). Such a process can induce significant enduring change that is important in developing mental models of teaching with technology or rather models of utilisation. Krauskopf, Zahn and Hesse (2012) suggest that teachers need opportunities to develop mental models that are “more situated and specific than general beliefs or declarative knowledge about technologies” (p. 1195). This is critical because classrooms are real and specific contexts where teachers use technology when teaching.

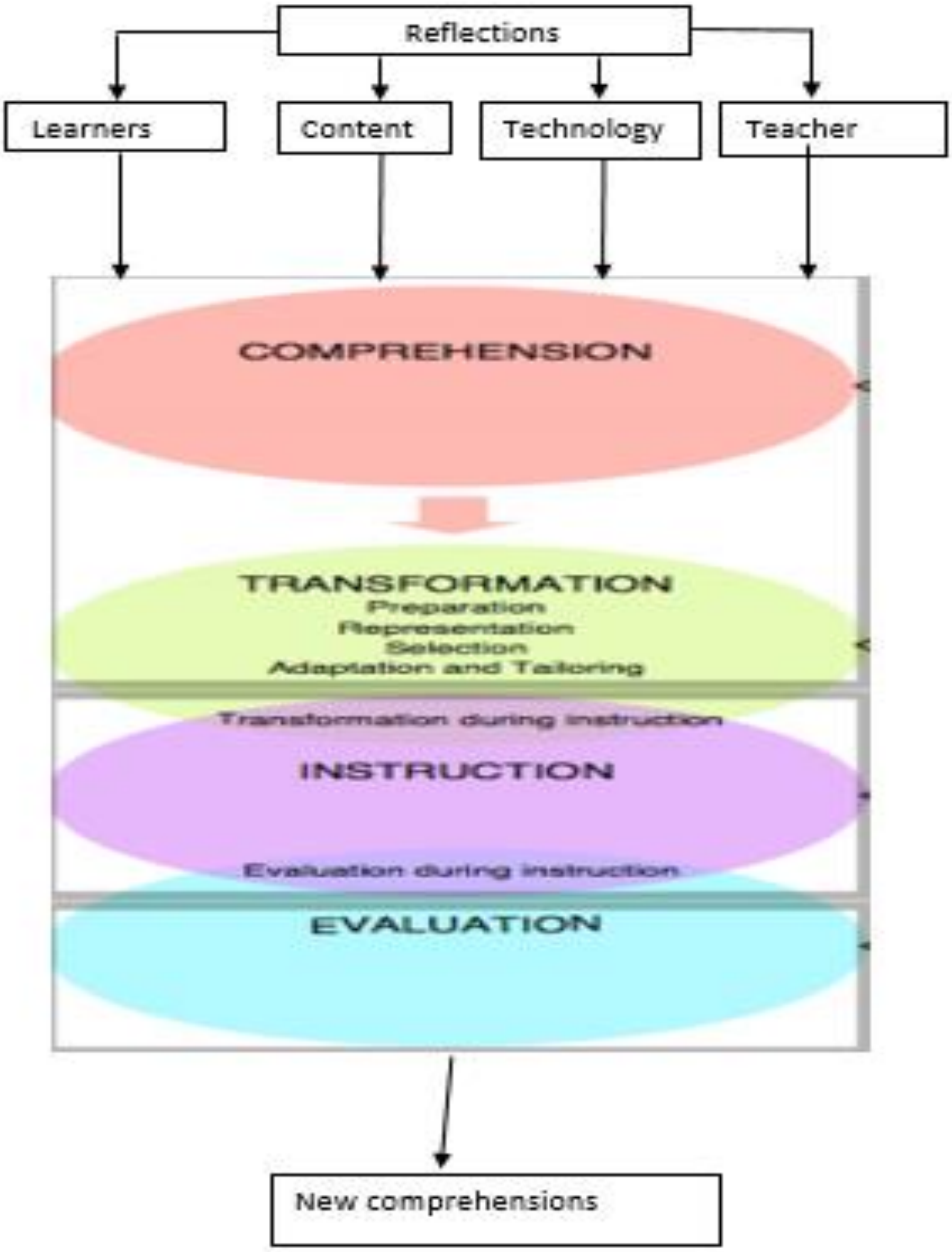

Figure 5.1 Process for describing teachers' TPR (adapted from Smart, 2016)

When reflecting on technology as reasoning tool, I consider how it relates to the other three elements. The same applies with the rest of the elements. The teacher’s ability to reflect on these elements in a particular context is key to their ability to transform his practice. According to Maynes and Hatt (2015), when the teacher can name and describe what they do, they have the advantage of understanding the impact of specific actions in an instructional context on specific outcomes in student learning.

The reflection on content is formal because the national curriculum policy is formal. At the same time, the curriculum policy and research expect teachers to use creative learner-centred learning methods when teaching with digital technologies. This situation suggests that when teachers are driven by a formal reflection, they are addressing their content needs because they should know details about the discipline or subject (Bernstein, 1999; Taylor, 1993). At the same time, reflection on learners is formal because at the end of the lesson, teachers need to evaluate whether the objectives of the lessons have been achieved. The reflections on learners are not only focussed on the cognitive outcomes but also the affective and conative outcomes. This perspective is hinged on research (Munns, 2007; Symth & Fasoli, 2007), which documents that teaching practices should engage the learners' cognitive, affective and conative needs to achieve both epistemic/social justice and academic achievement. Zyngier (2007) refers to it as transformative engagement.

During the time of Shulman (1987), no mention of the influence of technology was directly considered in relationship to pedagogical reasoning. Thus, reflection on technology is an addition when thinking about TPR. According to Niess and Gillow-Wiles (2017), the present pedagogical challenge presented by an increased access to multiple technologies is the developing of an understanding of the influence of multiple technologies on teachers' TPR. Teachers need to reflect on how the varied digital technologies influences their TPR. According to Orlando (2014), teaching with technology is a personal and complex process that require teachers to reflect and identify those affordances that meaningfully respond to the context and contribute to the teachers' commitment to reflection and renewal of practice. Popejoy (2006) asserts that the effective use of technology in teaching and learning requires thought, experimentation, and a willingness to spend the time to develop and refine strategies until they are proven to be effective. However, the reflections on technology are informal because there is no national policy guiding the use of technology while teaching in schools. In fact, schools do not have their own policy on the use of technology in teaching and learning. There are no standards that have been formulated to guide the use of various technologies by teachers during teaching and learning. At the same time, the curriculum policy is implicit when it comes to the use of digital technology in teaching and learning. Therefore, teachers are entirely free to integrate it as seen fit. This makes the use of technology in teaching and learning problematic as teachers have to choose which voice they value and why. Kriek and Coetzee (2016) confirm that using technology effectively in the classroom is not easy, as it requires careful planning and identification of suitable technology, conducive for learning. This planning and identification of suitable technology considers the elements identified in Figure 5.1, the content, the learners and the teacher. Furthermore, it is not only the ‘use’ of technology (choice of appropriate technology), it is also about ‘how’[22] and ‘why’[23] the technology is used to facilitate understanding (Kriek & Coetzee, 2016). This rationale is what makes the teaching with technology in pedagogically effective way a complex challenge for teachers. It is not a skill that can be taught through workshops. It is a wisdom of practice that is situated and constrained by contextual factors.

The use of technology by teachers is guided by personal interests, instructional goals. Hence, it differs from one teacher to another. However, informal reflections can become the basis for formal reflections. Teachers are concerned with their practices during the teaching and learning process in their routine instruction. Therefore, there is need to reflect upon oneself. The reflection on oneself is personal, it is about self-development via the interrogation of self-actions, and it encourages personal morals and positive attitudes in the teaching and learning process (van Manen, 1991). Personal (or self-) reflections calls for the teacher to sit and evaluate if their practices or actions are according to their profession (discipline/education) (Meierdirk, 2016). They need to reflect on their instructional roles and how these roles affect learning. They need to reflect on how technology mediates their actions and how this involvement affects the practice. The act of self-reflection has also been reported in the action research by Indraganti (2019), which she refers to as dialectical reflection. The interaction of the reflections on the four elements are needed in order to improve the process of teaching and learning (Khoza, 2016). They act as filters through which the technological pedagogical reasoning (TPR) process occurs (as illustrated in Figure 5.1).

The teacher as a practitioner in the meaning-making process, draws from his experiences derived from interaction with by each of the identified elements during each phase of the TPR process. These experiences can be captured when one observes teachers as they perform instructional tasks or through the narratives that teachers provide after teaching (Clark & Yinger, 1979). By consistently reflecting on these experiences, teachers can develop new understandings which they incorporate into their practice with their learners. Unfortunately, many PD activities do not adequately consider how teachers make sense of their experiences (Drago-Severson 2012). New comprehension results from an interpretation of the teachers’ experiences and their own personal actions in such a way

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22 The ISTE has formulated a set of standards along seven dimensions to act as a guide in how teachers can integrate technology into their practice. However, current policies in South Africa do not give explicit guidance on the form of ICT usage in specific teaching activities.

23 The use of technology should be guided by instructional goals

that they develop new understanding for personal development (Boud & Walker, 1998). Subsumed within new comprehension is a rich instructional repertoire of instructional strategies which ultimately expand and enrich the professional presence and personal professional confidence of teachers' use of technology. Research has evinced that teachers are not competent and do not have the confidence to teach with ICT in their specific subjects in South Africa (Mlitwa & Kesewaa, 2013; Ndlovu & Lawrence, 2012).

5.1.1 Comprehension

Research has shown that the first process of (technological) pedagogical reasoning, namely comprehension, requires teachers to understand their content in order for them to transform it "into forms that are pedagogically powerful and yet adaptive to the variations in ability and background" (Shulman, 1987:15). During the time of Shulman when technology was not as pervasive as it is now, content was confined to textbooks. Transforming this content required teachers to critically understand this information in several ways within and outside the content area, while understanding the purposes for teaching it and how to present it in ways accessible to learners. In technological terms, comprehension takes another dimension since technology transforms the forms and processes of knowing and creating knowledge (Pelgrum & Law, 2003). Content is no longer secured from only the textbook. Now, it can be resourced from digital technological resources like computer simulations. Thomas Edison's statement in 1913 that "Books will soon be obsolete in schools. Scholars will soon be instructed through the eye" (Cuban, 1986:11) is being realised. The content is no longer textual but pictorial and animated, a new dimension to learning available to learners. Learners alluded to the fact that visual learning is a new dimension to their comprehension. Content presented in the form of animated pictures makes abstract phenomena (such magnetic fields and electromagnetic induction) more concrete for learners. Nxumalo-Dlamini and Gaigher (2019) have confirmed this phenomenon. Instead of relying solely on the textbook as an important content resource (Navy *et al.*, 2018), a practice not recommended in curriculum reform literature (Charalambos & Philippou, 2010; Remillard & Bryans, 2004), teachers in South Africa, especially in rural areas, should also consider using computer simulations when planning for physical science lessons. Computer simulations can be used, recalling Papert's (1999) terminology as an informational resource and tool to explore science content to be taught. One instructional goal for using computer simulations in this study is for inquiry. Opfer, Kaufman and Thompson (2016) report that teachers in developed countries are increasingly likely to use digital instructional resources as sources of content to enhance their curriculums. Comprehension now involves an understanding of digital technological resources and how they can be used as a source of content. Schwarz *et al.*,

(2008) suggest that digital resources (such as computer simulations) as curriculum materials reflect multiple ideas, values, and meanings about content and teaching. Hence, Smart (2016) contends that the comprehension of the digital technologies that can be used for teaching and learning is not a complex undertaking with contextual implications. How teachers read, interpret, and use them depends on the meanings they themselves construct and infer (Schwarz *et al*., 2008). This process greatly influences teachers' actions and learning outcomes. Correia, Koehler, Thompson and Phye (2019) provide preliminary evidence of the benefits of using computer simulations as a source of content in chemistry education. For example, the changing variables in the simulation helped students understand gas behaviour. The multiple images and working with the simulation lab helped learners visualize gas behaviour, and the design of the system made it easy for learners to understand content on gas behaviour.

In this study, technological pedagogical reasoning began by consulting the pacesetter (see Appendix 3) and the curriculum policy document (see Appendix 2). The pacesetter lists the topics to be taught during each quarter while the curriculum policy document outlines the content to be covered and suggested activities. The core content of physical sciences subject is prescribed by the Department of Basic Education (2011). In this study, the same content (i.e., electromagnetism) was used for the three iterations. When the teacher had a clear idea of the topics and content to teach, he had to consider what specific materials to collect and use during instruction, how to add them into lesson plan and which class setup to use. The school did not have the materials to carry out the suggested activities. Hence the teacher had to search the internet[24] to look for appropriate computer simulations as source for interactive content. The computer simulations were selected because of the relevance of the digital resources to the curriculum, the appropriateness of the technological tools to deliver content requirements and the capability of teacher to use them without unforeseen difficulties. Since the available computer simulations were not specifically designed for the physical sciences curriculum for South Africa, the teacher had to select those suites which would meet the requirements of the curriculum. The teacher did not use a textbook but developed his own content based on the computer simulations downloaded from various sites on the internet and my knowledge of previously teaching the same content. Developing own content based on curriculum documents are not normally done in rural schools in South Africa, as data has to come from the pockets of the teachers themselves. Holmberg *et al.,* (2018) indicated in his study

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24 In the curriculum policy document, alternatives such as the use of internet resources should be mentioned so that teachers are aware of such resources.

that none of the eight teachers made use of a course textbook or any other kind of pre-ordered course material; instead, they used ICT to find web-based content and create their own teaching materials. The internet was adjudged to be a curriculum source of authentic, up-to-date and relevant teaching materials. However, teachers need to have a criterion for selecting the computer simulations in order to choose those that meet the requirements of the curriculum (see section 4.1.2.3). With a wide range of content available for teaching through the internet and through resources such as computer simulations, the search for content is taking on a whole new meaning (Smart, 2016). The textbook is no longer the only curricular resource to select the content for teaching in South Africa. Teachers in Emos' (2015) study felt that teaching following the textbook plans did not meet their learners' learning needs. The same observation was made by teachers in Ni Shúilleabháins's (2015) study who opined that traditional textbook questions did not always meet the learning objectives of their lessons. There is an assumption among textbook authors that there is a one type of teacher or one homogeneous group of learners and they "miss the local opportunities and issues which could easily bring relevance and meaning to the teaching" (Emo, 2015:174). Computer simulations are new curricular materials that teachers in rural schools can use to communicate about scientific phenomena to learners.

After selecting the computer simulations, the teacher in his TPR had to think of the particular ways in which to use the selected CS during instruction. The physical sciences curriculum policy advocates for a learner-centred approach that is inquiry-based (DBE, 2011). Matewos *et al*. (2019) concede that one potential tool to support teachers in implementing any curriculum innovation is through the use of standards-aligned curriculum materials. Unfortunately, CAPS do not provide the curriculum guidelines or standards as to how teachers should implement the advocated approach. Moreover, many teachers are unfamiliar with learner-centred pedagogies espoused in the Curriculum and Assessment Policy Statements (Ndlovu, nd). Recent studies indicate that, although teachers underwent training on how to employ learner-centred instruction that is inquiry-based, they have stuck with their traditional teaching practices (Msonde, 2011). Even professional development activities on the use of computer simulations through modelling have not yielded positive results (see Gonczi *et al.*, 2016). Many of the top-down initiatives intending to promote learner-centred learning that is inquiry-based have largely failed to factor in teachers' experiences and school realities on the ground (Meena, 2004). In many cases, teachers are left alone to experience top-down initiatives without having clear ideas and guidance on how best to implement learner-centred inquiry-based learning especially, in overcrowded classes which dominate many of the resource poor public schools in developing countries (Msonde & Msonde, 2019).

Therefore, in order to achieve this goal of implementing learner-centred inquiry-based approach in respect of physical science education, teachers have to be competent in selecting and structuring learning activities, integrating technology and facilitating class discussions in ways that are exciting and thought provoking (Buma, 2018). The teacher had to design/plan a locally attuned approach to teach the identified content (see section 4.1.2.2). In addition, the teacher had to identify the affordances of computer simulations, such as the perceived and actual properties of digital tools that indicate the possible actions that are available to a user, because they are often multifaceted and opaque in the sense that they are not immediately apparent (Bannan, Cook & Pachler 2016; Kaptelinin 2014). This study has revealed that these affordances are identified and becomes familiar through reflecting on the changes to practice brought by repeated use of the technology. According to McLuhan and Fiore (2005) these affordances are "not passive wrappings, but are, rather, active processes that are invisible" (p.5). The change includes attitudes, knowledge and skill development and shifts in instructional practices. Teachers' TPR requires familiarity with the computer simulations and the ability to understand the messages being communicated, i.e., their communicative power. Holmberg (2019) presents a caveat that working out how to take advantage of the affordances of ICT is not simple and straightforward but is a process that takes time. Starkey (2010) concedes that teachers were more likely to use digital technologies to enhance student learning when they were experienced in the use of digital technologies specifically subject specialist areas. The affordances of computer simulations are more 'relational attributes' in that the affordances do not come as a 'menu', but rather one takes cognisance of their existence during use. Teachers' TPR are uniquely different as informed by affordances that can be perceived in the same tool by different teachers depending on their pedagogical intentions.

Smart (2016) contends that comprehension will benefit when national curricular materials include identified suitable digital technologies. Comprehension of technology for pedagogical purposes involves comprehending how these technological tools facilitate, or afford and/or constrain different pedagogical intentions, choices and actions (Holmberg, 2019). They must seek how to use the affordances of computer simulations for pedagogical purposes in order to enhance comprehension. As suggested by Mishra and Kohler (2006), "teachers need to develop technological pedagogical knowledge (TPK) to engage with the affordances and constraints of particular technologies in order to creatively repurpose these technologies to meet specific pedagogical goals of specific content areas" (p.1032).

5.1.2 Transformation

In Starkey's (2010) model of teacher pedagogical reasoning and action for the digital age, the transformation process is referred to as enabling connections such as selecting appropriate resources and methods to enable learners to make connections between prior knowledge and developing subject knowledge, and transforming existing knowledge into teachable content, enabling opportunities for students to create, critique and share knowledge. In Smart's (2016), study transformation involved teachers using their technologies to access and download from the state curriculum materials website and modify the material before uploading their version to the school management system. For the participating teachers, their transformation focused on adapting and tailoring the state curriculum materials to suit their students and what digital technologies were available to them in their classroom for teaching and learning (*ibid*).

For this study, the TPR sub-process of transformation involved preparations (see section 4.1.2.1), representation of the lesson (see section 4.1.2.2), and the selection of the suitable computer simulations (see section 4.1.2.3). In all the three iterations, the processes of preparations and representations of the lesson were not changed because the content and the aims of the lessons had not changed. However, the selection of computer simulations was on-going[25] in order to select computer simulations necessary for learner to appropriate the critical aspects of the subject. Hence, the technology knowledge (TK) of teachers is ever changing. As new features are being introduced to computer simulations, teachers must acquire the latest information about the technology. Additional computer simulations were sought when a limitation with the use of the selected computer simulations were encountered. However, past researches (Ekberg & Gao, 2017; Hammond *et al.*, 2011) have revealed that one of the challenges is the time it takes for teachers to find digital resources before each lesson. Teachers already have a heavy workload (Kale & Goh, 2014), so there is no extra time for searching for digital resources. Another challenge is that teachers do not have access to all the ICT resources they need (Kale & Goh, 2014). For example, some of the computer simulations are for commercial purposes, so they are not for free. The selected computer simulations when downloaded from the internet were

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[25] Changes are being made to computer simulations to enhance their efficacy and efficiency by introducing new features. In the course of this study new features were introduced to PhET simulations in which they can now being embedded in PowerPoint, a feature which was not there when this study began.

saved on my laptop from where they were projected onto the white screen. Smart (2016) identified the sub-processes of adaptation and tailoring as important to transformation of content. The selection of a number of computer simulations was designed for the adaptation and tailoring of the content to meet the requirements of the South African curriculum. In the study by Nxumalo-Dlamini and Gaigher (2019), the teachers involved used three suites of computer simulations in order to meet the content requirements of the Eswatini curriculum. The selected computer simulations had different features which helped in adapting and tailoring the content to the local context. Since computer simulations have not been designed for a specific curriculum TPR necessitates the adaptation and tailoring of the digital technology to 'contextualise' and enhance the transformation of the content through the specifications identified by the teacher. The adaptation and tailoring of content are important for promoting learning efficiency or the efficacy of instructions so that learners develop a holistic understanding of science concepts.

On the other hand, learners just as the teachers also reason pedagogically about the teaching that they experience. They do go through the pedagogical reasoning and action of transformation of content. My argument stems from the fact that for meaningful learning to take place, the content has to be transformed in a manner that makes sense to the learner. This process can happen when they are discussing in groups explaining to each other the phenomena at hand. From the learners' statements during the focus group discussions, I was able to suggest affordances of computer simulations that transformed the content (see section 4.1.2.5).

Firstly, the learners suggested that the graphical visuals of computer simulations enhanced their understanding of the topics (see section 4.1.2.5). Learners suggested that the representation of phenomena by computer simulation was lucid without abstruseness (see section 4.1.2.5). This clarity did not exist with diagrams in textbooks. This aspect is called 'representational clarity' (see section 4.1.2.5). The property of clarity of material is an aspect that addresses my personal needs as a teacher in my practice, especially when teaching abstract ideas. The ability to reflect on the affordances of technology in helping learners understand ideas is a critical aspect of TPR, since there are no standards or guides on how to use technology.

Secondly, learners were able to describe what they were observing in their own words (see section 4.1.2.5), which was different from the same words used in their textbook. Nyamupangedengu (2016) stated that learners undertake the evaluation of the teaching process, reflect on the teaching and learning process, and the development of a new comprehension.

When consulting both the pacesetter (see Appendix 3) and curriculum policy document (see Appendix 2), I am confronted by time frames that have been set to teach each topic. This situation presents challenges to TPR. Instead of focussing on whether learners have understood, teachers' TPR becomes concerned with covering the topic in the prescribed time in the pacesetter (see Appendix 3) to prepare learners for common tests which they write at the end of the quarter. Teaching becomes content focused as opposed to learner-centred. After discussing with critical friends, I determined that the time prescribed is just a guideline which should not necessarily determine and dictate TPR.

Finally, the end process of the transformation process was the drafting of the lesson plans (see Appendices 4A & 4B). According to Bates (2015), there is no universal way to teach with technology which fits all contexts; therefore, these lesson plans are just guides which were informed by the teachers' TPR. These lesson plans give teachers a chance to try and see whether their TPR will work and what adjustments can be made during the curriculum implementation. These opportunities are given to teachers for professional learning from their teaching, especially when implementing new curricular resources. According to Fullan (2007),

> Teachers of today and tomorrow need to do much learning on their job, or in parallel, with it-where they constantly can test out, refine and get feedback on the improvements they make. (p. 297)

This situation is critical considering the diverse obstacles to learning physical sciences in low-quintile South African schools. These obstacles include but are not limited to a poor command of the language of learning and teaching (LOLT) (Pretorius, 2015); low levels of prior knowledge and skill of learners and teachers; a general attitude of apathy; and inefficient use of time (Van der Berg, Spaull, Wills, Gustafsson, & Kotzé, 2016).

5.1.3 Instruction

As the proponent of pedagogical reasoning, Shulman (1987) described the instructional phase as the "observable performance of the variety of teaching acts" (Shulman, 1987:17). TPR includes different aspects of teachers' mediated actions and interactions with learners to support learning, including the design of learning activities. During instruction, Smart (2016) observed two significant cross-over processes that occur for different purposes: transformation-during-instruction (T-d-I) and evaluation-during-instruction (E-d-I). Teachers performed evaluation-during-teaching in terms of asking students questions to check for understanding during the lesson. In terms of transformation-during-teaching, teachers shared how their uses of digital technologies did not go as planned and how they were required to change what they were doing. Smart (2016) has specified T-d-I and E-d-I as important components of TPR, especially when working with digital technologies.

In this study, the teacher performed T-d-I for six reasons: (1) non-availability of a suitable computer simulation, (2) the scepticism/disbelief displayed by learners towards computer simulations, (3) failure by the learners to comprehend a particular question, (4) the limitations of computer simulations, (5) wrong interpretations of the cues on the computer simulations by learners and (6) the failure by the computer simulations to download from the mobile internet used by the teacher. The T-d-I were performed in all the six lessons of the three iterations. In the study by Ocak and Baran (2019), T-d-I has been referred to as troubleshooting and has been observed in lessons where teachers are using technology. These were not planned actions. There were moments that arose during the course of teaching that required the teacher to make an immediate decision about how to respond without disturbing the flow of the lesson. Such moments can be described as "bumpy moments" (Romano, 2004:665). In any lesson, T-d-I is not planned but should be expected to arise. On a minute-to minute basis in the classroom, teachers must make instructional decisions concerning T-d-I. The decisions made during T-d-I should be based on their impact on students' learning (Darling-Hammond, 1992) and should contribute to students' teaching (Darling-Hammond, 2006). Hence, opportunities to teach with technology should be situated in the real practice of teachers not through workshops, so that they are able to experience the complexity and ambiguity of real classroom challenges.

The ability to perform T-d-I reveals indicators of teachers' TPACK in their actual teaching processes. Examining teaching in actual practice has significant implications for understanding teachers' TPACK when the teachers' TPR processes are built around classroom instruction. However, Ocak and Baran (2019) report that little is known about observed indicators of teachers' TPACK in science classrooms, particularly about the issues that involve concurrent and unplanned instructional decisions related to technology integration.

Some of the antecedents to T-d-I could be attributed to the fact each iteration was completed with a new class of learners who had no experience in learning with computer simulations, and others could be attributed to the technology itself. The use of technology and the technology itself can present opportunities for the teacher to transform (content)-during-teaching. Because of these reasons, the teacher through his TPR had to intervene and come up with an alternative to avert the disruption of the planned lessons. As suggested by Smart (2016) if the digital technologies fail, as in availability or in helping students understand, teachers must act very quickly in order to transform what they were going to teach into a new form to be able to continue the lesson.

In this study, the teacher performed E-d-I for two purposes. It was meant to check for prior knowledge and keep track of learners' comprehension of the concepts. I needed to know this information in order to decide on how to move forward with the lesson. In all the lessons and iterations, the teacher performed E-d-I for the same purposes. When checking for prior knowledge, the teacher wanted to link the information with the current topic. For example, the principle of superposition was considered applicable or could be linked the addition of the magnetic field around a solenoid. During the E-d-I, the computer simulations were used as a media to link the concepts. The teacher was able to judge whether the learners understood the concepts because the learner's response were easily verified by demonstrations of using the computer simulations. Learners were asked to describe the nature of the magnetic field around a straight current-carrying conductor. According to Erstad (2012), emerging technology is providing new spaces and resources for mediated communication. Hence the mediacy of computer simulations was cardinal to TPR.

It can be seen from Figure 5.1 that the two processes of T-d-I and E-d-I do not occupy the whole instructional period. Smart (2016) does not explain what happens during the remaining period of the instructional phase. Beyond T-d-I and E-d-I, little is known about how teachers enact instruction with computer simulation to purposefully construct opportunities for learners to participate in science (Stroupe, 2017). There is evidence that there were activities besides T-d-I and E-d-I that occurred in the class during instruction, the teacher interacted with learners or learners interacted among themselves. These other interaction-during-instruction (I-d-I) involve interactions between the learners with computer simulations or between the teacher and learners. Beauchamp (2011) posits that the use of technology creates opportunities for technology-mediated interactions which are either planned or spontaneous. Different categories of interactions have been identified in literature: **technical** interactivity between learners and ICT, **pedagogical** interactivity between teachers and learners (Smith, Higgins, Wall, & Miller, 2005) and **conceptual** interactivity between learners and ideas and concepts (Moss *et al*., 2007).

For example, when the learners observed the phenomenon on a white screen while the teacher is described and explained major ideas of a scientific concept, there were both conceptual and pedagogical interactivity. During FGDs, the learners suggested that *learning with computer simulations enable us to know some things that are not seen like* *magnetic field…*(FGD, 2017). Another learner suggested that *it is easy to learn things I don't know when I am seeing them rather than reading about them in a textbook only. If it is about magnetic fields, I can see the magnetic field like how they move, behave and so on, which increases my knowledge* (FGD, 2016). In another FGD, the learner asserted that learning with computer simulations *makes learning easier as certain things that we can't see with our eyes are demonstrated, for example, magnetic fields. This speeds up the process of learning and teaching* (FGD, 2015). In all these cases, there is evidence of conceptual interactivity where computer simulations acted as a "mediating artefact" (Engeström, 2001:29) in the learning process. As suggested by learners *that we don't want to be taught but we want to see things by our eyes* (FGD, 2016), such experiences contribute to their motivation to learn and to interest in their learning.

During pedagogical interactivity, I noted in my reflective journal that

> *The discussions I had with the learners gave me an opportunity to elicit*[26] *their ideas and to understand their thinking. I am particularly excited with the communicative power of computer simulations. They provide an environment for exploration through dialogue and questioning opportunities. When asking a question I no longer need to evaluate whether the response is correct or wrong myself, other learners are able to confirm if it is wrong or correct**.** This makes the teacher no longer the arbiter but multiple learner voices are allowed to speak. However where it was necessary I was called to correct wrong ideas that learners may have. (August, 2015)*

The following quote also presents another pedagogical interactivity where I noted that:

> *I really welcomed the contributions made by learners during the class discussion on the factors that affect the induced emf/current. I am not sure if this was going to be possible by using static 2D diagrams. As compared to static diagrams in textbooks, computer simulations are dynamic representations that can communicate science ideas to learners in a clear manner. From observing computer simulations visuals, they were able to identify the factors that affected*

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[26] To *elicit* means to draw out or entice forth a response. Therefore, eliciting is a move that the teacher did to engage and draw out or entice forth learners' ideas or reasoning. In the process, he scaffolded learners to construct knowledge. In eliciting ideas from learners, the teacher principally engaged in three forms of whole class dialogue with learners: talking to, talking with, and thinking through ideas with learners (Benus, 2011). This is different to lecturing in the sense that learners do not have to answer questions only but also give their ideas.

> *the magnitude of the induced current/emf. The fact that we were able to test their hypotheses deepened the level of the discourses. Learners were able to make links between the action and response. This activity was relatively effortless on my part when trying to explain what was happening. The discussions were really engaging, rich and the contributions of high quality. I was able to elicit learners' thoughts on the phenomena. (reflective journal, August 2016).*

A key feature of reform-oriented science instruction is the prominence of discourse to promote deep understandings of science phenomena (Wernner & Kittleson, 2018). This feature resembles what Doerr *et al.* (2013) term "harvesting learners' ideas" (p.113). Harvesting is a teacher-learner interaction intended not necessarily for E-d-I but rather to gather learners' ideas for one or more of the following purposes: (1) to make the learners' ideas public (in other words what they think about what they are observing)[27], (2) to explicitly gather learner's ideas to use in summarising the concepts explored in the computer simulation, (3) to gather ideas for sorting out discrepancies or revising conflated concepts[28] (Doerr *et al*., 2013) and (4) to link learners' ideas with future concepts[29]. According Mercer, Hennessy, and Warwick (2010), teacher-learner interactions in which a teacher and learners explore and generate ideas and questions together are dialogic in nature. Thus, by using computer simulations I wanted learners' developing ideas to occupy the classroom dialogic space and to "tell them [learners] that their changing ideas are what science is about" (Stroupe, 2017:920). The textbook presents science ideas as a product of the author and not as a product of the interaction of many scientists. As can be noticed from my reflective journal, the harvesting of the learners' ideas was an open, inclusive and transparent from the learners' perspective, taking place in a whole class setting (Doerr *et al.*, 2013) and conducted in a way provide to learners with the opportunity to engage in an epistemic discourse. Through the use of computer simulations, the teacher managed to engage learners by making them talk, reason and argue their ideas beyond yes or no answers. In the end, I avoided what Littleton (2010:286) terms "script recitation":

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[27] It is common practice with teachers that they ask learners questions to check for correct answers, but they never consider learners' ideas in the set of notes that they are given to copy.

[28] The ideas that learners hold but are not elicited during instructional dialogic talk may remain in their repertoire of ideas even if they are not scientifically sound (Lee *et al.*, 2010).

[29] The concept of electromagnetism is applicable to generators, a topic taught in Grade 12. However, no mention of generators is made in the grade 11 curriculum, yet it is related/linked to the topic in the grade 12 curriculum.

dictating pre-prepared notes/content to learners in a factual way thus giving them a static image of science and an authoritative and orderly picture of how the world works. To learners it was a new way of learning hence they complained that, *I can't copy notes; if I copy notes then I will not understand what is being taught* (FGD, 2017). The roles of learners shifted from just copying notes[30] to being active participants in the learning process requiring them to perform several functions. However, learners were expecting that learning would occur in the usual traditional way and that the teacher would be responsible for dictating notes all the time. Some learners found it a "radical departure" (Ko & Krist, 2019:913) from the kind of teaching and learning that has typified other learning areas. Juuti, Loukomies and Lavonen (2019) have also confirmed that learners who are used to more authoritative teacher talk may become confused. From my experiences, I have seen a tendency by learners to regurgitate everything they are given as notes or written in the textbook without an attempt to understand what they have been given or is written in the textbook. Learners have come to associate teaching and learning as script recitation. Manqele (2016) and Zenda (2017) have lamented the practice which they identify as the way of teaching and learning in schools in rural areas.

5.1.4 Evaluation

According to Shulman, evaluation involves the "checking for understanding and misunderstanding that a teacher must employ while teaching interactively, as well as more formal testing and evaluation that teachers for to provide feedback and grades" (Shulman, 1987:17). Smart (2016) distinguishes between evaluation-during-instruction and evaluation-after-instruction. As explained earlier, evaluation-during-instruction involve verbally checking for student understanding/misunderstanding through questioning. On the other hand, evaluation-after-instruction includes a variety of approaches where most teachers give their learners informal/formal tasks where learners are supposed to complete individually and submit for assessment.

In terms of evaluation-after-instruction, in both lessons 1 and 2, 15 minutes were apportioned for group work where learners completed the given classwork activity (see Appendix 8, 9). In all the three iterations, learners could not manage to complete the given work, lamenting that they needed more time to complete the task, and those learners who completed the task did not do it well. The learners suggested that it was difficult and

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[30] On the issue of copying notes one learner suggested that they could use their mobile telephones either to record the lesson or take snapshots of the important points, later they can listen to this information or revise them at home since they would have enough time. Unfortunately, the regulations of the department of education does not allow learners to bring their mobile telephones to school.

required more time. After the three iterations, I decided to change how I assess my learners. As suggested earlier in Chapter 4, many times teachers assess what they have taught and not what learners have learnt. Therefore, this study suggests that teachers need to assess what has been learnt, using the assessment for understanding framework (AfU) (see Appendix 13).

5.1.5 New comprehension

While Shulman (1987) considered new comprehension as a process, Smart (2016) contends that new comprehensions is not a process but a change in knowledge where “it is a new understanding that has been enhanced with increased awareness of the purpose of instruction, the subject matter of instruction, and the participating teachers (Wilson, Shulman, & Richert, 1987:120). On the other hand, Webb (2002) in her model suggested that new comprehension did not symbolize a process, rather represented it as a data flow from reflection to comprehension. However, no explanations were provided for this process. Starkey’s (2010) model included new comprehension as a process. This study found that obtaining new comprehension is a process because a change in something (e.g. knowledge) occurs through a process. Every TPR cycle results in new insights/information/knowledge that becomes the starting point of the next cycle. In Chapter 4 (section 4.1), I presented narratives of my experiences over three iterations. These experiences are from my reflective journals but structured according to Smart’s (2016) model. After reflecting on the experiences, I learnt insights that have developed through each TPR cycle. These new insights (skills and knowledge) inform the future cycles of my TPR when teaching the same content again. New comprehension is the beginning and/or influence the new cycle of TPR. The TPR process is a sequential flow that has a beginning and an end as suggested by Smart (2016). However, Endacott and Sturtz (2015) view pedagogical reasoning as not occurring in a sequential manner.

In the sections that follow, I give a summary of the new comprehension that I have gained in the processes of comprehension, transformation, instruction and evaluation as I reflected on the experiences on these processes. They may not be new in the sense of the term, but they are new to my practice. These new comprehensions have enlarged my instructional repertoire, while enhancing my professional presence and professional confidence. A teacher’s professional presence in the classroom projects a sense that the teacher is in charge, has a direction and is guided by a sense of purpose (Maynes & Hatt, 2015). Professional competence is the outcome of the coexistence of professional presence and professional confidence. A teacher in the 21st century is expected to be digitally competent in a range of technologies which have proliferated in today’s digital world (McKnight, O'Malley, Ruzic, Horsley, Franey, & Bassett, 2016). According to the national policy, *The Framework for Teacher Education* of 2011 (revised 2015), digital competence is considered as foundational to the integration of ICT in teaching and learning.

5.1.6 New comprehension from my teaching

5.1.6.1 Comprehension

Comprehension occurred on two levels: Comprehension of content and comprehension of technology and these two are not mutually exclusive of each other during TPR. Furthermore, the comprehension of content should also include the learners' misconceptions on that topic and the future application of the topic in their real lives. The learners' ideas that were identified in this study were that a source of electromagnetic force (emf) is always needed for current to flow and that a magnet/magnetic field can be a source of current [in the same way as a battery/cell causes charges in a conductive path to flow through it]. This finding is not surprising considering the weak prior knowledge caused by learning deficiencies in the system of education in South Africa (see Mlachila & Moeletsi,2019; Stott, 2018). However, these learner ideas can be productive in many cases and teachers need to consider them and be able to build on students' original ideas to help them learn (Etkina et al.,2018). Electromagnetism can be applied to real life application, such as mobile telephone chargers should be included in the curriculum. It is not surprising to know that a learner is unaware of how the mobile telephone charger works, yet they use these devices daily. The curriculum policy document should also list the documented misconceptions that learners have in the topic so that teachers are aware of such and how they can tackle them. Planning a lesson from the perspective of the learner and identifying their misconceptions/prior knowledge forms an important part of teachers' knowledge of content, and it becomes more and more relevant to teachers to identify the prior knowledge that was required of students for a particular topic and to incorporate that knowledge within the lesson (Ni Shúilleabháin, 2015). Secondly as suggested by Smart (2016), the searching and selection of appropriate technology (in this case computer simulations) becomes an important sub-process of transformation. In this study, the selection of appropriate computer simulations is one crucial factor to the success of a lesson, as CS are both sources of interactive and digital (animated) content and the very medium[31] of communicating the content to learners. An added advantage of the medium is that it is interactive capturing the learners' interest. It is not static like the blackboard.

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[31] The use of the term 'medium' is consistent with Romiszowski's (1988:8) conceptualisation of medium as a carrier of messages, from some transmitting source to the receiver of the message.

They can be used to assist learners to understand the esoteric domain of a scientific field (Nghifimule & Schäfer 2018). De Beer (2013) concludes that interactive computer simulations can engage learners and assist educators to teach a difficult concept in science, provided they are able to choose the suitable ones and plans the lesson properly. However, Bishop and Denley (2007) feel that "student engagement does not come without effort…but comes through unpredictability, surprise, fun, humour, stories and being prepared to do odd things" (p.40). Their protean nature is a resource and advantage for teachers in schools in rural schools that are plagued and incapacitated by shortages of teaching and learning materials. The selection of appropriate computer simulations requires in-depth knowledge of content and technology. Nxumalo-Dlamini and Gaigher (2019), that teachers' content knowledge should be prioritised during their training in order to enhance the selection and effective use of computer simulations.

5.1.6.2 Transformation

Teacher learning is enhanced in the context of their practice. Developing the knowledge and skills of teaching with technology requires teachers to practice teaching with technology in the context of their classrooms. Teachers are presented with opportunities to experiment new things, explore innovative and creative alternatives and the ability to reflect on their own practices (McKenney *et al.*, 2015) thereby identifying areas which need reframing. Having the time to experiment and learn about the digital technology is important to enhance its effective use in practice. The testing of the technological tool as suggested by Ekanayake and Wishart (2014) and Smart (2016) is another critical aspect of transformation. Testing of tools is best done through practice in actual classroom setting so as "to increase automaticity and psychological ease" as stated by Gonczi *et al.* (2016:112). An intimate familiarity with technology is critical to the effective use of that technology during instruction. It requires an understanding of the affordances of the tool. The affordances of computer simulations may or may not be explicit or accessible to teachers. There are many icons, cues and/or prompts that can be used by teachers to transform (adaptation and tailoring) the content to meet the requirements of the curriculum. Familiarity with a technology gives the teacher an understanding of all the affordances and "what to expect when using the tool in a classroom, which reduces their anxieties during implementations" (Bell & Gresalfi, 2017:514).

5.1.6.3 Instruction

In this study, computer simulations were used for three instructional goals: (1) inquiry, (2) communication and (3) motivation. A computer simulation was used as an inquiry tool to support learners in dynamically exploring the scientific phenomena of magnetic field and electromagnetic induction. This tool supports learners in understanding the macro and micro features of the scientific phenomena. The tool is also an interactive medium through which content on magnetic field and electromagnetic induction is communicated to learners. The triad formed among the teacher, learners and computer simulation creates a matrix of multiple relations in a community of practice which increases the complexities of interactions in the classroom. It creates categories of interactivity (conceptual or pedagogical) for communicating the content on magnetic field and electromagnetic induction. For the learners, computer simulations "stimulate language use" (Tomlison, 2003:2). Learners are able to express themselves, communicating their ideas using familiar or adopted words[32]. It does not constrain the learners to understand scientific ideas/concepts using abstract text. There are obstacles for learners learning physical sciences in low-quintile South African schools. They include a poor command of the language of learning and teaching (Pretorius, 2015). The use of computer simulation can be a viable solution to this challenge. Stott (2018) advises that low language-demand resources are useful in the South African low-quintile context at developing understanding of scientific concepts by learners.

Another affordance identified as important to learning is representational clarity which promotes graphic literacy (Readence *et al.*, 2004). Learners suggested that computer simulations display scientific phenomena in a way that they can understand as opposed to the way it is portrayed in textbooks. For example, the learners suggested that *it is easy to understand new things that I don't know as I can see them rather than reading it from the textbook only* (FGD, 2017). Learners expressed that computer simulations are also able to display those elements of a phenomena that cannot be seen, e.g. *they (computer simulations) make learning easier as certain things that we can't see with our eyes are demonstrated* (FGD, 2016). These displays support learners in generating models to explain scientific phenomena.

As a teacher, computer simulations area medium for orchestrating communication through dialogue with the learners. Computer simulations can give teachers opportunities for initiating dialogue with learners such as question asking. Every demonstration/action with computer simulations comes with potential questions. Question asking is a term that refers to both the generation of new questions and reformulation of given questions (Cai & Hwang, 2002). These questions included **explanatory** questions to get reasons like Why does the bulb lights when the magnet and the solenoid move relative to each other?;

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[32] In one lesson on magnetic field, one learner said that the magnetic field around a straight wire carrying current is 'expanding'. The term 'expanding' was adopted and was intended to mean that the magnetic field lines were not equally spaced.

probing questions like Why do you think the bulb does not light when the magnet is held stationary inside the solenoid?; **leading** questions: to introduce new ideas like why does the deflection of the galvanometer changes direction when the magnet moves in or out?; and **hypothetical** questions used to infer what if, and if this, then what?, like what will happen to the magnetic field when the magnet is cut into two halves? **evaluative** questions to determine whether the learners agrees with my point of view in light of their knowledge like what is causing the current to flow when a magnet is moved towards the solenoid? And **interpretive** questions seeking learners' ideas on their interpretation of phenomena like why the magnetic field lines are closer near to the conductor while they are wide far from the current-carrying conductor? The various states/representations that can be demonstrated by computer simulations are a potential bank of questions for teachers to initiate dialogue with their learners. In practice, many science teachers and textbooks have been found to ask low–level questions that primarily lack an adequate number of processing-level and output-level questions (Huang, Norman & Cai, 2017). Learners lamented that it *is really boring just sitting in class, listening to the teacher just teaching from the book and we like to see things for ourselves* (FGD, 2016). This study propose that computer simulations can create environments for generating questions that engenders teacher–learner dialogue that is more learner-centred, where learners are given ample opportunities to contribute their ideas (Resnick, Asterhan, & Clarke, 2015). It has the potential to stimulate or support learners' interest in learning (Juuti, Loukomies & Lavonen, 2019). However, the ability to generate questions requires a solid content knowledge (CK) of the subject. Dialogic teaching is indispensable for meaning making in science classrooms (Scott, Mortimer & Aguiar, 2006).

5.1.6.4 Evaluation

When reflecting on the assessments that I gave to the learners, I discovered that my aim was to evaluate my teaching insofar as the objectives of the lessons were attained. Therefore, giving learners classwork after teaching was largely intended to evaluate my teaching (for accountability purposes) and not learning. According to Maynes and Hatt (2015), accountability-focused assessment directs attention toward the teaching while authentic assessment foci direct teachers' attention toward the learning. Figure 5.1 identified four elements that interact to influence the TPR: content, learners, technology and teacher. Assessment should be given considering the identified four elements. Black and William (2009), Purvis *et al*. (2011), and Reddy and le Grange (2017) concur that assessments should made to address the needs of teachers, learners, and the content taught. Teachers are increasingly being encouraged to arrange opportunities to gather assessment data (Earl, 2010) and conduct assessments that is embedded and non-intrusive (Maynes &

Hatt, 2015). The learner has a role in self and peer assessment. In this way, teachers can identify gaps in the learners' knowledge and be able to assist them appropriately.

5.1.6.5 Contribution of my study in terms of processes that a teacher follows to describe his technological pedagogical reasoning.

In light of the evidence presented, Figure 5.1 is an alternative approach or strategy to reflection to help teachers in their practice. According to Palliotet (1995), reflection is a complex task and one that may be added. At the same time, Pellegrino and Gerber (2014) opine that there is no single method of reflection that is more effective than another to improve practice and positively impact learning. Since teaching is a situated practice, there is need to consider alternative approaches considering the various challenges that teachers encounter in their contexts. There is a lack of knowledge about how teachers learn and transfer their knowledge into practice in the classrooms (Solheim, Ertesvåg, & Berg, 2018). However, learning by reflecting is the most representative activity that teachers can use to improve their instructional practice. This framework makes explicit the actions on which to reflect on (i.e. comprehension, transformation, instruction and evaluation), and these actions are influenced by the four elements identified. Thus, reflection occurs during planning, instruction and post-instruction. At the same time, every action that occurs during each phase of teaching (comprehension, transformation, instruction and evaluation) involves the interaction of the actors (teacher, learners, computer simulations and content). This is different to how Smart (2016) presented it in her model. The model lacks clarity on what to consider when reflecting about planning, instruction and post instruction. There is evidence in a study by Navy *et al*., (2018) that teachers in South Africa rely mainly on the textbook when planning. Also, their reflection is mostly content centred. This simplistic view and linear approach to teaching reduces learning to the accumulation of facts only as opposed to the development of critical thinking skills.

A survey of the literature on teaching shows that planning is central to effective teaching (e.g., Dewey, 1933; Kosnick & Beck, 2009). Effective teaching should provide opportunities engage learners in developing and enjoying a sense of competence and mastery of the curriculum (Valenzuela, 1999). Therefore, it should not only focus on content but on other intervening variables that contributes or influences other dimension such as the affective and conation. Teaching is non-linear but a complex process involving the interaction of various elements as illustrated in Figure 5.1. The results of this study add to the literature on how teachers can improve their knowledge through reflection-on-action (Schön, 1983) in consideration of the elements identified especially in a resource-constrained environment. Through this aided reflection, teachers can recognise aspects of their TPR and how it develops in particular contexts.

Research question 2: What are the cognitive, affective and conation experiences of learners.

According to King and Pringle (2019), learners' perceptions of their learning experiences provide unique insights into the teaching and learning process, particularly for learners who have been marginalized in formal schools. Van Manen (2014) defines experience as how events, situations, and phenomena are perceived and interpreted by individuals, as they describe their personal thoughts, emotions, and feelings in the context of their involvement in a particular activity. In this case the particular activity is that of learning. This definition identifies factors that influences how learning experiences are generated by learners. The perceptions of the learners of their learning experiences is a cognitive activity that was influenced by factors that can be identified from van Manen's (2014) definition. The first factor is the context in which the phenomenon is occurring. The context here refers to the teaching and learning environment which included the school and the classroom where the phenomenon of teaching and learning occurred. The second factor was the capturing of the teaching phenomena through learners' senses (perception). Shuell (1996) posits that the manner in which the learner perceives, interprets, and processes information about the various things that happen during a lesson is the primary determiner of the learning experiences acquired by learners. Perception predisposes a learner to perform certain actions in a learning environment. The third factor that contributed to the generation of students' experiences was the interpretation (sense-making) of the perception. Nyamupangedengu (2016) also refers to this as "mentation" (p.200). This is a cognitive process involving reflecting and making sense of the phenomenon. The fourth factor that had an influence is their prior learning experiences. These factors interact to generate learning experiences as represented in Figure 5.2

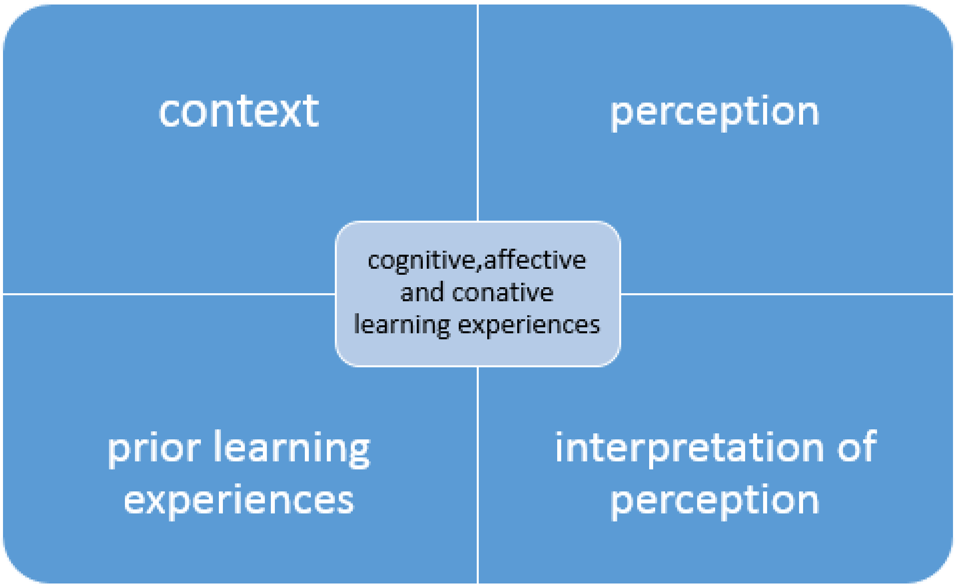


Figure 5.2 How learner's learning experiences are generated.

The descriptions given by learners of the perceptions of their learning experiences (cognitive, affective and conative) are understood to be influenced by the four factors.

5.1.7.1 Cognitive experiences

Learners suggested that they had learnt much from the lessons. Phrases like *I have learnt*, *I have gained*, *now I know* were used by the learners to express the conceptual knowledge that they gained from the lessons. In this study, what the learners said they learnt is proxy of the actual learning. Learners suggested that they learnt that *current induces magnetism* while at the same time *current can be induced from magnetism* (see section 4.4, Objective of the curriculum). They also stated the procedural knowledge they had gained in terms of the applications of the phenomenon of electromagnetism (see section 4.4**,** as related to the objective though not specified/referred to in the curriculum). The findings of this study contribute to the literature on the benefits of computer simulation to learning. It has been reported that one of the important benefits of learning with computer simulation is facilitation of learners' conceptual understanding of scientific phenomena (Correia, Koehler & Phye, 2019). Learners suggested that the graphics (dynamic representations) of the computer simulation helped them to visualize what was happening like the magnetic fields and how current is induced when the magnet is moved towards the solenoid. I concur with other researchers that visualisation lower the cognitive effort of imagining (Fong, 2013; Höst, Schönborn, & Palmerius, 2012) especially when they are not familiar with the scientific phenomenon and overcomes the deficiency in understanding when reading from the textbook (Hoeling, 2012; McElhaney, Chang, Chiu, & Linn, 2015). In this case, the use of computer simulations enabled the learners to describe in their own words what was happening, confirming the findings of McElhaney *et al.* (2015) that dynamic representations contribute to learners' explanatory accounts of phenomena.

5.1.7.2 Affective experiences

Learners seemed to have been satisfied with the lessons. They expressed that the lessons were interesting, fun, (an element of enjoyment), experimental/practical and at the same time full of surprise/wonder (see section 4.5). Similar findings have been made by Correia, Koehler and Phye (2019) where several students mentioned that their learning experience with computer simulations was fun, educational and at the same time a different way of learning. Learners found learning with computer simulations to be more interesting and motivating when compared to other learning modalities, as also revealed in Alessi and Trollip (2001). Terms such as interesting, fun, liked, enjoying have a positive connotation and are likely to be associated with positive learning experiences as suggested by Tsybulsky (2019). According to the theory of "positive key experiences" (Yair, 2003, 2008:35), such experiences are considered a requisite component contributing to the success of any learning intervention, including the use computer simulations. Even disregarding cognitive-related outcomes, learners' positive affective experiences can be considered a beneficial and relevant outcome in and of itself, given that school learners in South Africa perceive science as boring and irrelevant (Govender, 2017; Hobden, 2017; Osborne, Dillion & Nuffield Foundation, 2008). The South African school system generally continues to neglect the affective educational outcomes (Buma, 2018) even though they constitute an important factor that contributes to learner well-being (Goetz, Pekrun, Hall, & Haag, 2006). Research has revealed that secondary school learners not only perceive physical sciences in general as a difficult and demanding subject, buts how lack of interest in the subject (Angell, Guttersrud, Henriksen, & Isnes, 2004; Barmby, Kind, & Jones, 2008; Jenkins & Nelson, 2005; Kessels, Rau & Hannover, 2006; United Nations Educational Scientific & Cultural Organisation, 2010).

5.1.7.3 Conative experiences

There is a growing consensus among researchers globally that mastering content knowledge alone will not be sufficient to prepare the present generation of learners as life-long learners. Voices both within and outside of schools are calling for a more expansive and innovative brand of teaching that provide learning experiences that will prepare learners with the capabilities to think critically, demonstrate creativity and imagination, communicate effectively using various media, work collaboratively with others, and self-direct their own lifelong learning (Costa *et al*., 2020). Some studies have identified the benefits of using ICT in the classroom for motivating learners to learn science (Correia, 2019; Ndlovu, 2015). These studies revealed that learners reported a positive learning experience when taught with technology and described it as worth their time. Alessi and Trollip (2001) assert that learners often find simulations to be motivating than other learning modalities. Learners expressed that the use of computer simulations motivated them to do not only well in school but also be motivated to stay in school. On the other hand, learners expressed an interest in the topic/lesson (see section 4.6). This finding is critical considering the study by Bahou (2017) that revealed that learners find it boring to attend class where teachers relied on textbooks as the teaching/curriculum tool. Boredom is a state that implies a lack of curiosity, and curiosity is defined as a desire for acquiring new knowledge and new sensory experience that motivates exploratory behaviour (Berlyne, 1954; Litman & Spielberger, 2004). The scepticism displayed by learners especially on the computer simulation to demonstrate electromagnetic induction can be taken as evidence that the learners' curiosity was piqued. Berlyne (1954) refers to it as perceptual curiosity. According to Karadeniz and Degirmencay (2020) perceptual curiosity is engendered by new, complicated, eccentric, suspicious or confusing stimulus models. At the same time, the curiosity aroused by the learners during the lessons (see figure 4.17) is referred to as epistemic. Epistemic curiosity includes the testing of questions and prepositions which are triggered by conceptual uncertainty or complex ideas (Berlyne, 1954).

Because the learning experiences that learners are exposed to are failing to pique their curiosity, learners react with a threat response as suggested by Maslow (1943), which is what research has found in bored learners- they leave school. Masitsa (2005) comments that a high dropout rate, poor academic performance, and demotivated learners are observable features among schools in rural areas in South Africa. Schulze and Steyn (2007) corroborated that secondary school learners in rural areas are not motivated to learn because school is boring. Hence, the use of technology is one dimension that teachers can possibly adopt to mitigate such features which have characterised rural schools however, I acknowledge that this change is a complex process and cannot be improved by the use of technology only.

5.1.7.4 Contribution of my study in terms of cognitive, affective, and conative learning experiences of learners

The findings from this study are significant and have bearing on learner experiences. The learning experiences of learners are important to both instructional planning and the creation and improvement of learning environments. Positive learning experiences contribute to successful and memorable educative experiences. In this study computer simulations were used by teachers not only as medium to communicate content but also as an object to engage, motivate and create interest in learners. Thus, computer simulations can possibly contribute to the cognitive, affective, and conative learning experiences. These learning experiences are mediated by the four factors namely the context of learning, prior learning experiences, perception and the interpretation of the perception. Thus, learning experiences are not the same across all subjects. The learner experiences are malleable, they will change when one of the factors identified in Figure 5.2 changes. However, these learning experiences are integrated and do not exist independent of each other, but they influence each other in one way or the other.

5.2 Recommendations

My research provides an example of how one physical science teacher in a rural school incorporated technology as reasoning tool into his practice. My experience as a Physical science teacher in a rural school has often been a position of isolation. However, through my work in this case study, some general and very specific recommendations for technology use can be made.

Recommendation 1

Teachers should search and select freely available computer simulations on the internet when planning for their lessons. There are sources of interactive digital content (digital books). Computer simulations are conceptual-rich learning resources (to teach specific topics) that can supplant the use of textbooks in schools in rural areas. When deciding which computer simulation to select and use, it is crucial to consider the content requirements, the learners, and the context of teaching. There are a variety of digital resources that are available on the internet which are freely available to a teacher for their use when planning for teaching.

Recommendation 2

The use of computer simulations mitigates some of the challenges that rural teachers and learners in schools encounter. This study has found that the use of computer simulations in a rural school can be beneficial to both teaching and learning. The teacher was able to engage learners, elicit and address learner ideas about scientific phenomena, present learner with scientific ideas provide enhanced learning environments for all. Therefore, the use of computer simulations mitigates some of the challenges that teachers and learners face.

Recommendation 3

Teaching is a situated activity, and most of the professional development activities for teachers do not consider the context and the challenges that are faced by individual teachers. Classroom practices should be informed by an ‘insider perspective’. Classroom action research can address the concerns of the individual teacher, and, it is a valid way of generating pragmatic knowledge that empowers the teachers involved.

Recommendation 4

Teachers in schools in rural areas need to conduct action research on their own teaching as a form of professional development. For support and guidance on how to carry out action research, teachers need to form professional learning communities (PLCs). The provincial department or the district officials should promote these PLCs as an alternative form of professional development.

Recommendation 5

There is need for professional development where teachers can experience the use of subject-specific technology as they must have practical experience of using the technology so that they see the affordances of the tools.

Recommendation 6

Despite the pressures that teachers face in terms of content coverage as stipulated in policy documents, the focus of assessment should be on learning as opposed to teaching. Subject advisors together with teachers should be capacitated by the university lecturers in how they can design effective formative assessment tasks that focus on learning.

Recommendation 7

Teachers should use computer simulations not only to communicate content but also as an object to engage, motivate and create interest in learning by learners.

5.3 Limitations of the study

The following are the limitations associated with this study:

- methodological limitations- the size of the sample that was involved in the study is not representative of the learner population in South Africa. The sample size was very small. Therefore, their views and learning experiences with computer simulations cannot be generalised to the larger population of learners attending school in rural areas in South Africa.
- interpretive limitations- Our way of viewing reality and what we see is affected by our experiences. However, one cannot be neutral and divorce himself from his experience and place the interpretation of the phenomenon in the research. In the process of constructing reality, I believe it is important to acknowledge that our way of seeing the world is limited by our experiences and this influences how we interpret our experience of phenomenon. Whilst attempts have been made to ensure that the conclusions are valid, the nature of action research is such that the interpretation and analyses cannot be generalised to any situation.
- limitations associated with the choice of the simulations- the experiences of this study are associated and limited to the computer simulations chosen to teach the topics of magnetic field and electromagnetic induction to learners in grade 11. The experiences cannot be therefore taken to be representative or characteristic of all the topics in physical sciences or other subjects which they are doing.
- limitations with the theoretical framework- the framework focusses much on the teacher, which makes it to be teacher-centred. All the sub-processes identified describe the actions of the teacher while no mention is explicitly made of the actions or processes undertaken by learners during the learning process. It has been suggested that learners also carry out pedagogical reasoning. At the same time, the

framework does not identify the categories of learning experiences that can be achieved in any cycle of TPR.

5.4 What I have learnt.

The experiences accrued from this study have been educative. I had the opportunity of reflecting and re-reflecting on the actions and experiences and their implications on my practice. The experiences have had an impact not only on my knowledge or beliefs but also on my attitude towards teaching. The experiences have led me to believe that class teaching should be more responsive than reactive. It needs to respond the diverse learning needs of learners as well as the changes occurring in the external environment so that it has significant value in the lives of both teachers and learners. Learners spent most of their time in the classroom therefore the quality of the learning experiences directly affects their current and future learning and development. At the same time, for teachers, class teaching constitutes the greater component of their working lives and its "quality directly affects their perceptions and attitudes towards their careers, their professional development and their realization of the value of their own lives" (Ye et al., 2018, p. 357).

I have also learnt that change is not something school management enforces from the top. Top-down imposed policy decisions on ICT integration into instructional practices are technocentric, general and not responsive to the teacher's perspectives (Jimoyiannis, 2010). Change cannot be effected by policy but policy can be influenced by change. Change at the school level is initiated by changes in individual classrooms. The words of Martin Luther King (Jr) that "I alone cannot change the world, but I can cast a stone across the waters to create many ripples" find expression in this study. Change is not revolutionary but rather evolutional. The integration of technology as reasoning tool into teaching and learning does not bring radical changes to the processes but rather small changes that gradually increases with experience. Practice makes perfect. Learning to teach with technology is an effective way to teaching with technology. Learners' marks may not change suddenly after integrating technology into teaching and learning, but skills and attitudes do.

5.5 Conclusion

In the introduction to this study, I described the challenges I encountered when I started teaching at my new school, which became my space of professional autonomy defined thus "as the space in which the teacher is required to act in light of the context and the specific situations within that context" (Smith, 2007:235). The lack of teaching and learning resources made working in that context a struggle. The instances of frustration and uncertainty which I grappled with in my lessons became the beginning of a beautiful academic journey. My purposeful intention of using technology was not purely an academic pursuit but the desire to develop practical knowledge to solve specific problems related to my practice and enhance quality of learning especially in rural contexts. My supervisor then advised me to conduct an action research of my classroom. This PhD study has been a long journey where the priority has not been only on the acquisition of knowledge but also on the development of skills, competencies, and capabilities which have assisted in improving my teaching practice. To that effect, I have received messages from my former learners who suggested that my teaching brought a change to their learning and their attitudes to science.

At the same time through this research, I have gained more insight into the complex nature of teaching with technology and the shift in the roles of a classroom teacher in this regard and those of the learners. Through this study my perceptions and attitudes towards teaching have transformed. Teaching with technology is not revolutionary that it could/might frighten teachers because the focus is not on technology but how technology can improve practice. It is rather a complete paradigm shift, a change of both mindset and culture engendering all aspects (see figure 5.1) contributing to the creation of engaging opportunities for deeper learning for both the teacher and learners. It should be perceived or approached as a research activity where the teacher is always seeking for opportunities or evidence that can be used to reframe practice hence improve learning. When thus conceptualised, teaching would encourage teachers to be curious about, collect data regarding, and then create alternative pathways to improve their practice (Teddlie & Tashakkori, 2009). In this study teaching was carried as a learning exercise to achieve what Bandura (1997) calls mastery experiences. Such professional learning experiences were authentic and embedded in subject matter, involving active sense-making and problem solving and connected to the teachers' own practice (Moon, Passmore, Reiser & Michaels, 2014). It is recommended that professional learning experiences for teachers should include these dimensions because often many PD appears fragmented and divorced from the issues of improving practice in the context in which teachers work (Little 2006). Tschannen-Moran and Hoy (2007) assert that mastery experiences have the most powerful influences upon teachers' self-efficacy. Research has attributed the development of a robust PCK (see Grossman, 1990; Kind, 2009; van Driel & Verloop, 1998) and topic specific professional knowledge (TSPK) (Cook Whitt, 2016) to mastery experiences. This experiential knowledge is highly situated and often tacit.

During the teaching experiences observations and reflections were instrumental as they acted as the vehicle for learning in the context where teaching was done. The reflections were grounded in lived reality as opposed to imagined reality, which render them pragmatic. This explain the reason why Beauchamp (2015) caveats that teachers need to be encouraged to have confidence in their own experiences as this is a basis for their learning and their understanding of their own practice. She further argues that teachers need not rely solely on the dictates of those establishing the parameters of their reflections. Thus, the reflections narrated in this study embodied my beliefs, emotions, feelings, and values that acknowledges my individual identity. Researchers (Kelchtermans, 2009; Thompson & Pascal, 2012) argue that conceptualising of reflection that is emancipatory and individualises teaching should have depth and breadth. According to Kelchtermans (2009), depth refers to the need to move reflection beyond the level of action to the level of underlying beliefs, ideas, knowledge, and goals – in other words to the personal interpretative framework with its self-understanding and subjective educational theory (p. 269). At the same time Thompson and Paschal (2012) view breadth as referring "to the broader sociological context and includes such factors as power relations, discrimination and oppression" (p. 321). Such reflections in the context of workplace are productive in that they enhance the professional knowledge of practice of practitioners (Dimova & Loughran, 2009). Whilst the reflections were bound to the two lessons (of magnetic field and electromagnetic induction), the lessons learnt can be transferred to other topics.

If one embraces constructivism as a learning theory (as espoused in science education literature), then the use of technology as a primary teaching tool blends/fit comfortably. Smart's (2016) model is then a robust framework that teachers can use to integrate technology into their practice.The framework can serve as a professional development model for self-directed learning for teachers in deprived contexts. It provides structure to the use of technology in teaching in ways that are amenable to analysis and development. It identifies the major aspects of teachers' practice that they can employ the affordances of technology to create opportunities for deeper/meaningful learning defined as learning that transcends beyond acquiring facts and formulas to helping learners develop the capacity to think critically, cooperate, collaborate, and communicate within and across disciplines (DBE, 2011), as well as to develop habits of mind (see Costa *et al*., 2020) generally not fostered by rote instruction. The affordances are both epistemic and pedagogical. They have a pragmatic value to the practice of teachers. However, the affordances are potential, depending on how they can be manipulated by the user to add value to their pursuits. In this study, the affordances provided by technology for TPR were relational, uncovered through an active interaction with the technology and the learners as well. The use of technology in teaching does not come with a 'how-to-do' manual, hence their use by individual teachers is idiosyncratic. At the same time, there are social practices that are associated with the use of technology. Both teachers and learners need to be encultured in the social practices in order to meaningfully engage the technology in teaching and learning. For the learners the affordances created opportunities for making **O**bservations, **D**iscussions, **E**xplaining and **R**easoning with **T**echnology or ODERT. Through ODERT, learners were engaged in three phases: (1) **A**cquiring necessary information; (2) to **G**enerate acceptable scientific models and (3) to **E**valuate the generated scientific model or alternatively AGE. This learning sequence constituted the learning experiences in all the lessons. The learning experiences had cognitive, affective and conative dimensions.

Through the whole process of TPR, the teacher-researcher constructs knowledge through interpretation, action, and reflection. The teacher-researcher interpretive capacities play a great role in constructing intersubjectivity. I have come to realise that in a 21st century classroom teaching, learner participation is not a dominant aspect but a logical consequence of teaching. It (teaching) not only contributes to learners' growth and development or satisfies the mission that other assign to them but is also the realisation of the teachers own life-values, self-growth, and development (Ye, *et al.*, 2018).

References

Abell SK (2008) Twenty years later: Does pedagogical content knowledge remains a useful idea? *International Journal of Science Education*,30:1405-1416

Abd-El-Khalick F and Akerson, V (2007) On the role and use of “theory” in science education research: A response to Johnson, Sutherland and Sowell. *Science Education* 91(1): 187-194.

Abotsi AK, Yaganumah N and Obeng HE (2018) Dropouts issues and its economic implications: Evidence from rural communities in Ghana. *Journal of Economics and Economic Education Research* 19(1), 1–13.

Adamson SL, Banks D, Burtch, M, Cox F III, Judson E, Turley JB et al. (2003) Reformed undergraduate instruction and its subsequent impact on secondary school teaching practice and student achievement. *Journal of Research in Science Teaching*, 40(10): 939–957.

Alhendal D Marshman M and Grootenboer P (2015) Kuwaiti science teachers’ beliefs and intentions regarding the use of inquiry-based instruction. *International Journal of Science and Mathematics Education*,14 :1455-1473

Akpınar, E (2014) The use of interactive computer animations based on POE as a presentation tool in primary science teaching. *Journal of Science and Technology Education*, 23: 527–537.

Alexander, RJ (2001) *Culture and Pedagogy: International Comparisons in Primary Education*. Oxford, UK: Blackwell.

Aliusta, G.O. and Özer, B. (2016). Student-centred learning (SCL):roles changed?, *Teachers and Teaching*. DOI: 10.1080/13540602.2016.1205014

Allensworth, E, Ponisciak, S and Mazzeo, C (2009) *The Schools Teachers Leave: Research Report*. Chicago USA: Consortium on Chicago School Research, University of Chicago

Allright, D (1988) *Observation in the classroom.* London, UK: Longman.

Allwright D and Bailey KM (1991) *Focus on the language classroom: an introduction to classroom research for language teachers*. Cambridge, Cambridge University Press.

American Association for the Advancement of Science (1989) *Project 2061: Science for All Americans*. Washington, DC: American Association for the Advancement of Science.

Anderson GL and Herr K (1999) The new paradigm wars: Is there room for rigorous practitioner knowledge in schools and universities? *Educational Researcher* 28(5): 12-21.

Anderson MJ and Freebody K (2012) Developing communities of praxis: Bridging the theory practice divide in teacher education. *Journal of Education,* 47: (2) 359–378.

Angeli C, Valanides N and Christodoulou, A (2016) Theoretical considerations of technological pedagogical content knowledge. In: Herring M, Koehler M and Mishra P (eds) *Handbook of Technological Pedagogical Content Knowledge for Educators*. New York, USA: Routledge, pp.26-52.

Angell C, Guttersrud Ø, Henriksen EK and Isnes A (2004) Physics: Frightful, but fun: Pupils' and teachers' views of physics and physics teaching. *Science Education,* 88(5):683-706.

Antrop-González R and De Jesús A (2006) Toward a theory of critical care in urban small school reform: Examining structures and pedagogies of caring in two Latino community-based schools. *International Journal of Qualitative Studies in Education*, 19:409–433.

Appleton J, Christenson S, Kim D and Reschly A (2006) Measuring cognitive and psychological engagement: Validation of the student engagement instrument. *Journal of School Psychology* 44: 427-445.

Appleton K and Kindt I (2002) Beginning elementary teachers: Development as teachers of science. *Journal of Science Teacher Education*, 13(1): 43–61

Arif, MA (2002) Teachers as researchers. *Al-Hikmat* 22: 43-54.

Arrifin TF, Bush T, and Nordin, H. (2018) Framing the roles and responsibilities of excellent teachers: Evidence from Malaysia. *Teaching and Teacher Education* 78: 14-23.

Artigue M (2002) Learning mathematics in a CAS environment: The genesis of a reflection about instrumentation and the dialectics between technical and conceptual work. *International Journal of Computers for Mathematical Learning* 7(3): 245-274.

Artigue M, Haspékian M, Cazes C, Bottino RM, Cerulli M, Kynigos C, Lagrange J and Mariotti M (2006) *Towards a Methodological Tool for Comparing the Use of Learning Theories in Technology Enhanced Learning in Mathematics*. TELMA Deliverable 20-4-1: Kaleidoscope Network of Excellence. Available at http://telearn.noe-kaleidoscope.org /warehouse/Artigue-Kaleidoscope-2006.pdf

Aydin S Friedrichsen PM Boz Y and Hanuscin DL (2014) Examination of the topic-specific nature of pedagogical content knowledge in teaching electrochemical cells and nuclear reactions. *Chemistry Education Research Practice*,15:658-674

Avgitidou S (2014) *Teachers as Researchers and Reflective Practitioners. Supporting Professional Learning for a Co-operative and Participatory Education*. Athens, Greece: Gutenberg.

Babbie E and Mouton J (2001) *The Practice of Social Research*. Cape Town: Oxford.

Babione C (2015) *Practitioner Teacher Inquiry and Research*. San Francisco, USA: Jossey-Bass.

Bakhtin M (1981) *The dialogic imagination*. Austin, USA: University of Texas Press.

Balfanz R, Herzog L and MacIver D (2007) Preventing student disengagement and keeping students on the graduation path in urban middle-grades schools: Early identification and effective interventions. *Educational Psychologist* 42:223-235.

Ball DL (1991) *Knowledge and reasoning in mathematical pedagogy: Examining what prospective teachers bring to teacher education*. Unpublished doctoral dissertation. Michigan State University, East Lansing, USA.

Ball DL and Cohen DK (1999) Developing practice, developing practitioners: Toward a practice-based theory of professional education. In G Sykes and L Darling-Hammond (eds.) *Teaching as the Learning Profession: Handbook of Policy and Practice*. San Francisco, USA: Jossey-Bass, pp.3-32.

Bandura A (1997) *Self-efficacy: The exercise of control*. New York: Freeman.

Bannan B Cook J and Pachler, N (2016) Reconceptualizing design research in the age of mobile learning. *Interactive Learning Environments*, 24(5): 938-953. DOI: 10.1080/10494820.2015.1018911

Barak M and Dori YJ (2011) Science education in primary schools: Is an animation worth a thousand pictures? *Journal of Science Education & Technology*, 20: 608-620.

Barendsen E and Henze I (2017) Relating teacher PCK and teacher practice using classroom observation. *Research in Science Education*. DOI 10.1007/s11165-017-9637-z

Barmby P, Kind PM and Jones K (2008) Examining changing attitudes in secondary school science. *International Journal of Science Education* 30(8): 1075-1093.

Beauchamp C (2015) Reflection in teacher education: Issues emerging from a review of current literature. *Reflective Practice*, 16(1) :123-141

Beauchamp G (2011) Interactivity and ICT in the primary school: Categories of learner interactions with and without ICT. *Technology, Pedagogy and Education*, 20(2): 175-190.

Bell AW (1984) Short and long term learning - experiments in diagnostic teaching design. Eighth International Conference for the Psychology of Mathematics Education, Sydney.

Bell A and Gresalfi M (2017) Teaching with videogames: How experience impacts classroom integration. *Technology Knowledge and Learning* 22: 513–526. DOI: 10.1007/s10758-017-9306-3

Bell A, O'Brien, D and Shiu, C (1980) Designing teaching in the light of research on understanding. In R. Karplus (Ed.), Proceedings of the *Fourth International Conference for the Psychology of Mathematics Education*. Berkeley USA, pp. 119-125.

Bell RL and Trundle KC (2008) The use of a computer simulation to promote scientific conceptions of moon phases. *Journal of Research in Science Teaching* 45(3): 346-372.

Bell RL, Smetana L and Binns I (2005) Simplifying inquiry instruction. *The Science Teacher* 72(7): 30-33.

Belland BR, Walker AE, Olsen, MW and Leary H (2015) A pilot meta-analysis of computer-based scaffolding in STEM education. *Journal of Educational Technology & Society* 18(1): 183-197.

Bennett LH, Athanases SZ and Wahleithner JM (2016) ‘Like a ball and glove’: Teachers’ conceptions of the promise and challenges of conducting classroom inquiry. *Action in Teacher Education* 38(1): 49-69.

Berliner DC (1987) Learning about learning from expert teachers. *International Journal of Education Researcher* 18(32): 463-482.

Berlyne DE (1954) A theory of human curiosity. *British Journal of Psychology*,45:180-191

Bernstein, B. (1999). Vertical and horizontal discourse: An essay. British Journal of Sociology of Education, 20(2), 157–173

Biggs J and Tang C (2007) *Teaching for Quality Learning at University*. Maidenhead, UK: McGraw Hill.

Birt J and Cowling M (2018) Pedagogy before technology: A design-based research approach to enhancing skills development in paramedic science using mixed reality. *Information* 9(2). http://dx.doi.org/10.3390/info9020029

Bishop K. and Denley P (2007) *Learning Science Teaching: Developing a Professional Knowledge Base*. Maidenhead, UK: Open University Press.

Bishop SR, Lau M, Shapiro S, Carlson L, Anderson NB, Carmody J and Devins G (2004) Mindfulness: A proposed operational definition. *Clinical Psychology: Science and Practice*, 11(3): 230-241.

Bismack AS, Arias AM, Davis EA and Palincsar AS (2014) Connecting curriculum materials and teachers: Elementary science teachers’ enactment of a reform-based curricular unit. *Journal of Science Teacher Education*, 25(4): 489–512.

Black P and Wiliam D (2006) *Inside the Black Box: Raising Standards through Classroom Assessment*. London, UK: Granada Learning.

Black P and Wiliam D. (2009) Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability*, 21(1):5-31.

Bloor M, Frankland J, Thomas M and Robson K (2001) *Focus Groups in Social Research*. London, UK: Sage Publications.

Boon RT, Fore I, and Rasheed C (2007) Students' attitudes and perceptions toward technology-based applications and guided notes instruction in high school world history classrooms. *Reading Improvement* 44(1):23-45.

Borko H and Livingston C (1989) Expert-novice differences in teaching: A cognitive analysis and implications for teacher education. *Journal of Teacher Education* 40(4): 36-42.

Boud D and Walker D (1998) Promoting reflection in professional courses: Thechallenge of context. *Studies in Higher Education*, 23(2):91-206.

Bourdieu P (1991) *Language and Symbolic Power*. Cambridge, USA: Harvard University Press.

Bransford JD, Brown AL and Cocking RR (2000) *How People Learn: Brain, Mind, Experience, and School* (expanded edition). Washington, DC: National Academy Press.

British Columbia Institute of Technology (no date) Developing learning outcomes. Available at: http//:champlain.instructure.com/courses/200147/ (accessed 2019 August).

Brown BA and Spang E (2008) Double talk: Synthesising every day and science language in the classroom. *Science Education* 92(4): 708-732.

Brown SA and McIntyre D (1993) *Making Sense of Teaching*. UK: Open University.

Bruner JS (1966) *Toward a theory of instruction*. Cambridge, MA, USA: Harvard University Press.

Buabeng I, Conner L and Winter D. (2015) The lack of physics teachers: 'Like a bath with the plug out and the tap half on'. *American Journal of Educational Research* 3(6): 721-730.

Buma AM (2018) Reflections of science teachers in a professional development intervention to improve their ability to teach for the affective domain. *African Journal of Research in Mathematics, Science and Technology Education,* 22(1):103-113.

Buma A and Nyamupangedengu E (2020) Investigating Teacher Talk Moves in Lessons on Basic Genetics Concepts in a Teacher Education Classroom. *African Journal of Research in Mathematics, Science and Technology Education*, 24:1, 92-104

Burke PJ and Kirton A (2006) Insider Perspective: teachers-as-researchers. *Reflecting Education*, 2(1): 1-4.

Business Tech (2015) 8 reasons why kids drop out of school in South Africa. Available at: bussinesstech.co.za/news/general/88810/8-reasons-why-kids-drop-from-school.

Businskas, A (2008) *Conversations about connections: How secondary mathematics teachers conceptualise and contend with mathematical connections*. Unpublished doctoral dissertation, Simon Fraser University, Burnaby, UK.

Bybee RW, Taylor JA, Gardner A, Scotter, PV, Powell JC, Westbrooks, A and Landes N (2006) *The BSC 5E Instructional Model: Origins, Effectiveness and Applications*. Colorado Springs, CO, USA: BSCS.

Caillods F and Postlethwaite TN (1989) Teaching and learning conditions in developing countries. *Prospects Quarterly Review of Education* 19(2): 169-190.

Calandra B, Brantley-Dias L, Lee JK and Fox DL (2009) Using video editing to cultivate novice teachers' practice. *Journal of Research on Technology in Education*, 42(1): 73-94.

Calhoun E (1994) Action research for school improvement. *Educational Leadership* 59(6): 18-24.

Canbazoglu Bilici S, Guzey SS and Yamak H (2016) Assessing pre-service science teachers' technological pedagogical content knowledge (TPACK) through observations and lesson plans. *Research in Science & Technological Education* 34(2): 237–251. doi:10.1080/02635143.2016.1144050

Candela A (1999) Students' power in classroom discourse. *Linguistics and Education* 10(2): 139–163.

Capps DK, Shemwell JT and Young AM (2016) Over reported and misunderstood? A study of teachers' reported enactment and knowledge of inquiry-based teaching. *International Journal of Science Education*, 38(6):934-959.

Cardon P. (2000). At risk students and technology education: A qualitative study. *Journal of Technology Studies* 26(1): 49-57.

Carr W and Kemmis S (1986) *Becoming Critical*. London, UK: Falmer Press.

Caswell DS and Campbell HL (1935) *Curriculum Development*. New York: American Book Company.

Ceberio M, Almudi JM and Franco A (2016) Design and application of interactive simulations in problem solving in university-level physics education. *Journal of Science Education & Technology* 25(4): 590-609.

Cerull, M, Pedemonte B and Robotti E (2006) An integrated perspective to approach technology in mathematics education. In: *Proceedings of the IV Congress of the European Society for Research in Mathematics Education CERME 4, IQS* (ed M Bosh), Sant Feliu de Guixols, pp. 1389-1399. Sant Feliu de Guixols, Spain: Fundemi Business Institute.

Chadwick S (2017) Changing histories: Strengthening teacher agency and improving education through action research in Botswana. *Educational Action Research* 25(5): 755-769. DOI: 10.1080/09650792.2016.1235502

Chang MJ (1999) Does racial diversity matter? The educational impact of a racially diverse undergraduate population. *Journal of College Student Development* 40(4): 377-395.

Chan HKK & Yung BHW (2015) On-site Pedagogical Content Knowledge development. *International Journal of Science Education*37(8):1246–1278

Charalambos C and Philippou G (2010) Teachers' concerns and efficacy beliefs about implementing a mathematics curriculum reform: Integrating two lines of inquiry. *Educational Studies in Mathematics* 75(1): 1-21. doi: 10.1007/s10649-010-9238-5

Chavunduka K (2005) *Improving science education in Zimbabwe: The role of resource teachers in professional development*. PhD Thesis University of Twente. Netherlands.

Chi MT, Kang S and Yaghmourian, DL (2017) Why students learn more from dialogue-than monologue-videos: Analyses of peer interactions. *Journal of the Learning Sciences* 26(1): 10-50. DOI:10.1080/10508406.2016.1204546

Chigona A and Chigona W (2010). An Investigation of Factors affecting the Use of ICT for Teaching in the Western Cape Schools. 18th European Conference on Information Systems (pp. 1-12). Pretoria: ECIS.

Chigona A and Davids Z (2014) Educators' motivation on integration of ICTs into pedagogy: Case of disadvantaged areas. *South African Journal of Education* 34(3): 1-8.

Chikasha S Ntuli M Sundarjee R and Chikasha J (2014) ICT integration in teaching: An uncomfortable zone for teachers: A case of schools in Johannesburg. *Education as Change,* 18(1):137-150

Chisholm L (2000) *A South African curriculum for the 21st century. Report of the Review Committee on Curriculum 2005*. Available at: http://citeseerx.ist.psu.edu/viewdoc/download? doi=10.1.1.361.5200&rep=rep1&type= pdf

Chisholm L and Leyendecker R (2008) Curriculum reform in post 1990s sub-Saharan Africa. *International Journal of Educational Development*,28(2) :195-205

Christiansen I, Bertram C and Land S (2010) *Understanding Research*. Pietermaritzburg: UKZN Faculty of Education.

Churchhouse RF, Cornu B, Ershov AP, Howson AG, Kahane JP, van Lint JH et al. (1984). The influence of computers and informatics on mathematics and its teaching. An ICMI discussion document. *L'Enseignement Mathématique*, 30(4): 161-172.

Clandinin DJ and Rosiek J (2007) Mapping a landscape of narrative inquiry: Borderland spaces and tensions. In: Clandinin DJ (ed) *Handbook of Narrative Inquiry*. London, UK: Sage, pp. 35-75.

Clark CM and Yinger RL (1979). Teachers' thinking. In: Peterson PL and Walberg HJ (eds.) *Research on Teaching: Concepts, Findings, and Implications*. Berkeley, CA, USA: McCutchan, pp. 231-263.

Cobern WW, Schuster D, Adams B, Applegate B, Skjold Undreiu A and Gobert JD (2010) Experimental comparison of inquiry and direct instruction in science. *Research in Science & Technological Education* 28(5): 81-96.

Cochran-Smith M (2009) Teacher educators as researchers: Multiple perspectives. *Teaching and Teacher Education*, 21(2005): 219-225.

Cochran-Smith M, Villegas, AM, Abrams LW, Chavez-Moreno LC, Mills T and Stern R (2016) Research on teacher preparation: Charting the landscape of a sprawling field. In: D. H. Gitomer DH and Bell CA (eds.) *Handbook of Research on Teaching* (5th ed). Washington, DC: American Education Research Association. pp. 439-547.

Codrington G and Grant-Marshall S (2011) *Mind the Gap: Own Your Past, Know Your Generation, Choose Your Future.* Johannesburg: Penguin Books.

Coffey AM (201) Using video to develop skills in reflection in teacher education students. *Australian Journal of Teacher Education* 39(9): 86-97.

Coghlan D (2007) Insider action research doctorates: Generating actionable knowledge. *Higher Education,* 54:293-306.

Coghlan D (2010) Insider action research: opportunities and challenge. *Management Research News* 30(5): 335-343.

Cohen L, Manion L and Morrison K (2000) *Research Methods in Education* (5thed.). New York: Routledge Farmer.

Cohen L, Manion L and Morrison K (2013). *Research Methods in Education*. England: Routledge.

Cohen L, Manion L and Morrison K (2011) *Research Methods in Education* (7th ed.). New York: Routledge.

Collins RP Litman JA and Spielberger CD (2004). The measurement of perceptual curiosity. *Personality and Individual Differences*, 36: 1127–1141.

Confrey J (2000) Leveraging constructivism to apply to systemic reforms. *Nordic Studies in mathematics Education* 8(3): 7-30

Confrey J (1990) A review of research on student conceptions in mathematics, science and programming. *Review of Research in Education* 16:3-56.

Conle C (2001) The rationality of narrative inquiry in research and professional development. *European Journal of Teacher Education* 24(1): 2133-2146.

Connelly F and Clandinin J eds. (1999) *Shaping a Professional Identity. Stories of Educational Practice*. New York, USA: Teachers College Press.

Cook Whitt KA (2016) *A structural model of elementary teachers' knowledge, beliefs, and practices for Next Generation Science Teaching*. Doctoral dissertation, Wright State University.USA

Corey SM (1953) Action research in education. *The Journal of Education Research* 47(5): 375-380.

Correia A, Koehler, N, Thompson A and Phye G (2019) The application of PhET simulation to teach gas behavior on the submicroscopic level: Secondary school students' perceptions. *Research in Science & Technological Education,* 37(2): 193-217, DOI: 10.1080/02635143.2018.1487834

Corsaro WA (1997) *The Sociology of Childhood*. Thousand Oaks, CA, USA: Pine Forge Press.

Corso MJ Bundick MJ Quaglic RJ and Haywood DE (2013) Where students, teacher, and content meet: Student engagement in the secondary classroom. *American Secondary Education*, 41(3):50–61

Cothran DJ and Ennis CD (2000) Building bridges to student engagement: Communicating respect and care for students in urban high schools. *Journal of Research & Development in Education*, 33:106–117.

Council of Chief State School Officers (2008). Attributes of effective formative assessment. Washington, DC.

Craig PA Michel LV and Bateman RC (2013) A survey of educational uses of molecular visualization freeware. *Multimedia in Biochemistry and Molecular Biology Education,* Volume 41(3),193-205

Crawford BA (2000) Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching*,37(9):916-937

Creswell JW (1994). *Qualitative Inquiry and Research Design: Choosing among Five Traditions*. Thousand Oaks, CA, USA: Sage.

Creswell JW and Poth CN (2017) *Qualitative Inquiry and Research Design: Choosing among Five Approaches*. Los Angeles, CA, USA: Sage.

Cuban L (1986) *Teachers and Machines: The Classroom Use of Technology Since 1920*. New York: Teachers College Press

Cullen M and Brito CG (2014) *Mindfulness-Based Emotional Balance: Navigating Life's Full Catastrophe with Greater Ease and Resilience*. Oakland, CA, USA: New Harbinger Press.

Czajka CD and McConnell D (2019) The adoption of student-centered teaching materials as a professional development experience for college faculty. *International Journal of Science Education*, 41(5): 693-711

Dahar MA and Faize FA (2011) Mis-allocation of student teacher ratio, class size and per student expenditure leads to the wastage of resources and lower academic achievement: An issue of resource management. *International Research Journal of Finance and Economics* 62(3): 94-110.

Darling-Hammond, L. (1992). *Doing What Matters Most: Investing in Quality Teaching. National Commission on Teaching and America's Future*. Kutztown, PA, USA: Kutztown Distribution Center.

Darling-Hammond, L. (2000). Teacher quality and student achievement: A review of state policy evidence. *Educational Policy Analysis Archives* 8(1). Available athttp://bdgrdemocracy.files.wordpress.com/2011/08/teachereducation1.pdf

Darling-Hammond L, Chung Wei R and Andree A (2010) *How High Achieving Countries Develop Great Teachers*. Available at: https://edpolicy.stanford.edu/

Davies T (2013) Incorporating creativity into teachers practice and self-concept of professional identity. *Journal of Educational Change* 14:51–71. DOI 10.1007/s10833-012-9192-3

Davis WE and Broadhead GD (2007) *Ecological Task Analysis and Movement*. Champaign, IL USA: Human Kinetics.

De Beer IC (2013) *Experiences of learners when a computer simulation is used to aid teaching the photo electric effect*. M.Ed dissertation, University of Pretoria.

De Lange N Mitchell C Moletsane R Balfour R Wedekind V Pillay D & Buthelezi T (2010) Every voice counts: Towards a new agenda for schools in rural communities in the age of AIDS. *Education as Change*, 14:sup1, S45-S55

De Vos A, Delport C, Fouché C and Strydom H (2014) *Research at Grass Roots: A Primer for the Social Science and Human Professions*. Pretoria: Van Schaik Publishers.

Deaton CM, Deaton B and Koballa T (2014) Teachers' awareness of their diverse classrooms: The nature of elementary teachers' reflections on their science teaching practice. *Action in Teacher Education* 36: 211-233.

DeCoito I (2006) Innovations in science education: Challenges and changing teachers' roles and beliefs. *Canadian Journal of Science, Mathematics & Technology Education* 6(4): 339-350.

DeCoito I and Myszkal P (2018) Connecting science instruction and teachers' self-efficacy and beliefs in STEM education. *Journal of Science Teacher Education* 29(6): 485-503. DOI: 10.1080/1046560X.2018.147374

Delen I and Krajcik J (2016) Synergy and students' explanations: Exploring the role of generic and content-specific scaffolds. *International Journal of Science and Mathematics Education.* doi:10.1007/s10763-016-9767-1

Department of Basic Education [DBE] (2001) *National Strategy for Mathematics Science and Technology Education in General and Further Education and Training*. Pretoria: Author.

Department of Basic Education [DBE] (2004) *White Paper on e-Education: Transforming Learning and Teaching through Information and Communication Technologies (ICTs) Government Gazette No. 26734*. Pretoria: Author.

Department of Education [DBE] (2005) *National Curriculum Statement* (NCS). Pretoria

Department of Basic Education [DBE] (2007) *Guidelines for Teacher Training and Professional Development in ICT*. Pretoria: Author.

Department of Basic Education [DBE] (2011) *Curriculum and Assessment Policy Statement Grades 10–12 Physical Sciences.* Pretoria: Government Printing Works.

Department of Basic Education [DBE] (2015) *Department of Basic Education Vote No. 15 Annual Report 2014/15*. Pretoria: Government Printing Works.

Department of Basic Education [DBE] (2015) *National Senior Certificate 2015 Diagnostic Report*. Pretoria: Government Printing Works.

Department of Basic Education [DBE] (2016) *National Senior Certificate 2016 Diagnostic Report*. Pretoria: Government Printing Works.

Department of Basic Education [DBE] (2017) *National Senior Certificate 2017 Diagnostic Report*. Pretoria: Government Printing Works.

Department of Basic Education [DBE] (2018) *National Senior Certificate 2018 Diagnostic Report*. Pretoria: Government Printing Works.

Department of Higher Education and Training (2015) *Policy on the Minimum Requirements for Teacher Education Qualifications, as revised 2015*. Pretoria: Government Press.

Derry SJ, Pea RD, Barron B, Engle RA, Erickson F, Goldman R., … Sherin BL (2010). Conducting video research in the learning sciences: Guidance on selection, analysis, technology, and ethics. *The Journal of the Learning Sciences* 19(1): 3-53. doi:10.1080/10508400903452884

Desta D, Chalchisa D, Mulat Y, Berihum A and Tesera A (2009) Enhancing active learning through self-and peer reflections: The case of selected schools in Ethiopia. *Journal of International Cooperation in Education*12(1): 71-87.

Dewey J (1910) Science as subject matter and as method. *Science* 31(787): 121–127.

Dewey, J. (1933). How We Think: A Restatement of the relation of reflective thinking to the educative process: DC Heath and Company

Dewey, J. (1934). Art as experience. New York: G.P. Putnam’s Sons

Dewey, J. (1938). *Education and Experience*. New York: Simon and Schuster.

Dierking RC and Fox RF (2016) Changing the way I teach: Building teacher knowledge, confidence and autonomy. *Journal of Teacher Education* 64(2): 129-144.

Dimova Y and Loughran J (2009) Developing a big picture understanding of reflection in pedagogical practice. *Reflective Practice: International and Multidisciplinary Perspectives*, 10:205–217.

Doerr HM, Ärlebäck JB and O’Neil AH (2013) Teaching Practices and Exploratory Computer Simulations. *Computers in the Schools* 30(1-2):102-123. DOI:10.1080/07380569.2013.765308

Dörfler W (1993) Computer use and views of the mind. In: C. Keitel C and K. Ruthven K (eds.*) Learning from Computers: Mathematics Education & Technology. NATO ASI Series F: Computer and Systems*. Berlin, Germany: Springer, pp. 710-735.

Drago-Severson E (2012) New opportunities for principal leadership: shaping school climates for enhanced teacher development. *Teachers College Record*, 114 (3):1–44.

Dudu WT (2015) Facilitating small-scale implementation of inquiry-based teaching: Encounters and experiences of experiment multipliers in one South African province. *International Journal of Science and Mathematics Education*. DOI:10.1007/s10763-015-9708-4

Duit R Gropengießer H Kattmann U Komorek M and Parchmann I (2012) The Model of Educational Reconstruction- A framework for improving teaching and learning science. In: D. Jorde and J. Dillon (Eds.) *Science Education Research and Practice in Europe: Retrospective and Prospective.* Rotterdam: Brill,pp.13-37.

Duquette C and Dabrowski L (2016) A study of classroom inquiry and reflection among pre-service teacher candidates. *McGill Journal of Education* 51(1): 575-595.

Earl L (2010) *Growing Success: Assessment, Evaluation and Reporting in Ontario Schools*. Toronto, ON, Canada: Queen’s Printer.

Edelson DC, Gordin DN and Pea RD (1999) Addressing challenges of inquiry-based learning through technology and curriculum design. *Journal of the Learning Sciences* 8(3-4): 391-450.

Ekanayake TM and Wishart JM (2014) Developing teachers’ pedagogical practice in teaching science lessons with mobile phones, *Technology, Pedagogy and Education* 23(2): 131-150. DOI: 10.1080/1475939X.2013.810366

Ekberg S and Gao S (2017) Understanding challenges of using ICT in secondary schools in Sweden from teachers’ perspective. *International Journal of Information & Learning Technology* 35(1): 43-55.

Elliot J (1993) *Action Research for Educational Change: Developing Teachers and Teaching*. Philadelphia, PA, USA: Open University Press.

Ely M (1991) *Doing Qualitative Research: Circles within Circles*. London, UK: The Falmer Press.

Emaliana I (2017) *Teacher-centred or student-centred learning approach to promote learning?* Jurnal Sosial Humaniora. 10(2):59-70

Emo W (2015) Teachers’ motivations for initiating innovations. *Journal of Education and Change* 16:171–195. DOI: 10.1007/s10833-015-9243-7

Endacott J and Sturtz J (2015) Historical empathy and pedagogical reasoning. *The Journal of Social Studies Research* 39(1): 1-16. Available at: http://www.sciencedirect.com/science/article/pii/S0885985X14000394

Engeström Y (2001) Expansive learning at work: Toward an activity theoretical reconceptualization. *Journal of Education and Work* 14(1): 133-156.

Engle RA and Conant FR (2002) Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction* 20(4): 399-483.

Entwistle N (1990) Introduction: Changing conceptions of learning and teaching. In: Entwistle N (ed) *Handbook of Educational Ideas and Practices*. London, UK: Routledge, pp. 662-680.

Etkina E (2010) Pedagogical content knowledge and preparation of high school physics. *Physical Review Physics Education Research* 6(8): 300-325.

European Students Union (2015) Overview *on student-centred learning in higher education in Europe*: Research Study available on http://bit.ly/2HumqGW (accessed on 7 December 2020)

Feiman-Nemser S (2001) From preparation to practice: Designing a continuum to strengthen and sustain teaching. *Teachers College Record* 103(6): 1013–1055.

Feng Y and Hew KF (2005) K-12 teachers’ pedagogical reasoning in planning instruction with technology integration. *AACE Journal* 16(1): 77-92.

Fernandez C (2014) Knowledge base for teaching and pedagogical content knowledge: Some useful models and implications for teachers’ training. *Problems of Education in the 21st Century* 60(2): 79-100.

Finn J and Zimmer K (2012) Student engagement: What is it? Why does it matter? In: Christenson S, Reschly A and Wylie C (eds) *Handbook of Research on Student Engagement*. New York: Springer, pp. 97-126.

FitzGerald E (2012) Analysing video and audio data: Existing approaches and new innovations. In: *Surface Learning Workshop 2012*, Bristol, UK, 18-20 March 2012.

Fogleman J, McNeill KL and Krajcik J (2011) Examining the effect of teachers' adaptations of a middle school science inquiry-oriented curriculum unit on student learning. *Journal of Research in Science Teaching* 48(2): 149–169.

Fong, S. F. (2013). Effects of segmented animated graphics among students of different spatialability levels: A cognitive load perspective. *Turkish Online Journal of Educational Technology-TOJET* 12(2): 89-96.

Fook J (2000) *Professional Expertise: Practice, Theory and Education for Working in Uncertainty*. England: Whiting and Birch Ltd.

Fortus D (2014) Attending to affect. *Journal of Research in Science Teaching* 51(3): 7-23.

Fredricks J, Blumenfeld P and Paris A (2004) School engagement: Potential of the concept, state of evidence. *Review of Educational Research* 74(2):59-109.

Freire P (1970) *The Pedagogy of the Oppressed*. New York: Continuum International.

Fullan M (2007) *The New Meaning of Educational Change* (4th ed.). New York: Teachers College Press.

Gardiner M (2008) Education in rural areas. In: *Issues in Education Policy Number 4*. South Africa: Centrefor Education Policy Development.

Garet MS, Porter AC, Desimone L, Birman BF and Yoon KS (2007) What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal* 38(4): 915-945.

Garrison D and Akyol Z (2009) Role of instructional technology in the transformation of higher education. *Journal of Computing in Higher Education* 21(1): 19–30.

Geddis AN and Wood E (1997) Transforming subject matter and managing dilemmas: A case study in teacher education. *Teaching and Teacher Education* 13(6), 611-626.

Gengarelly LM and Abrams ED (2008) Closing the gap: Inquiry in research and the secondary science classroom. *Journal of Science Education and Technology* 8(1):74-84. https://doi.org/10.1007/s10956-008-9134-2

Gergen JK and Gergen MM (2007) Social construction and research as action. In: Reason P and Bradbury H (eds) *The SAGE Handbook of Action Research: Participative Inquiry and Practice*. 159–171. London, UK: Sage, pp. 159-171.

Gibbs G (1998) *Learning by Doing: A Guide to Teaching and Learning Methods*. Oxford, UK: Oxford Further Education Unit.

Gibson J (1986) *The Ecological Approach to Visual Perception*. London, UK: Lawrence Erlbaum Associates.

Gibson JJ (1977) The theory of affordances. In: Shaw R and Bransford J (eds) *Perceiving, Acting and Knowing: Towards an Ecological Psychology*. Erlbaum, pp. 67-84.

Gilmer PJ (2010) *Transforming University Biochemistry Teaching Using Collaborative Learning and Technology: Ready, Set, Action Research!* New York: Springer.

Goetz T, Pekrun R, Hall N and Haag, L (2006) Academic emotions from a social-cognitive perspective: Antecedents and domain specificity of students' affect in the context of Latin instruction. *British Journal of Educational Psychology* 76(2): 289-308.

Gonczi AL, Maeng JL, Bell RL and Whitworth BA (2016) Situating computer simulation professional development: Does it promote inquiry-based simulation use? *Computers in the School*, 33(3): 133-152.

Goodlad J (1984) *A Place Called School*. New York: McGraw-Hill.

Govender P (2018) 500000 kids not at school, say it's 'useless'. *Times Select* 23 April 2018.

Gover A Loukkola T and Peterbauer H (2019) *Student-centred learning: approaches to quality assurance*. European University Association, Switzerland

Graham C (2011) Theoretical considerations for understanding technological pedagogical content knowledge (TPACK). *Computers & Education* 57(3): 1953-1960.

Grant L and Fine GA (1992) Sociology unleashed: Creative directions in classical ethnography. In: LeCompte M, Millroy W and Preissle J (eds.) *The Handbook of Qualitative Research in Education*. San Diego, CA, USA: Academic Press, pp. 405-446.

Graven M, Pence B, Hakansson S and Pausigere P (2013) Exploring the relationship between in-service mathematics teacher support and retention. In: *Proceedings of the Seventh International Mathematics Education and Society Conferenc*e (eds. M Berger, K Brodie, V Frith and K le Roux), pp. 117-120. Cape Town: MES 7.

Gray J and Campbell-Evans G (2002) Beginning teachers as teacher-researchers. *Australian Journal of Teacher Education* 27(1): 14-37.

Green B (1995) Understanding and researching professional practice. In: B Green (ed) *Understanding and Researching Professional Practice*. Rotterdam, Netherlands: Sense Publications, pp.119-139.

Greenwood DJ and Levin M (1998) Action research, science and the co-optation of social research. *Studies in Cultures, Organisations and Societies* 4(2): 237-261.

Grossman PL (1990) *The making of a teacher: Teacher knowledge and teacher education*. Teachers College Press, New York, NY, USA

Grundy S (1982) Three models of action research. In Kemmis S and McTaggert R (eds) *The Action Research Reader* (3rd ed.). Geelong, Australia: Deakin University Press.

Gu L and Yang Y (2003) School-based action research on teachers' professional development. *Exploring Education Development*, 6(5): 1-7.

Gudmundsdottir S and Shulman L (1987) Pedagogical content knowledge in social studies. *Scandanavian Journal of Educational Research,*31(2): 59-70

Gunes G and Baki A (2011) Reflections from application of the fourth grade mathematics course curriculum. *Journal of Education* 41(3): 192-205.

Gutierrez KD and Rogoff B (2003) Cultural ways of learning: Individual traits or repertoires of practice. *Educational Researcher* 32(5): 19-25.

Haberman M (1991) Pedagogy of poverty versus good teaching. *Phi Delta Kappan* 73(3): 290-294.

Haberman M (2010) 11 consequences of failing to address the 'Pedagogy of Poverty'. *Phi Delta Kappan,* 92(2): 45.

Haddow-Flood I and Wiens K (2013) *The Primary Report. A report on South Africa's Primary School landscape and the potential impact of Open Education Resources and Wikipedia as support for curriculum-aligned content creation and dissemination*. WikiAfrica Project.

Hall K and Burke W (2004) *Making formative assessment work: Effective practice in the primary classroom*. Maidenhead: Open University Press

Hall G and Ivaldi A (2017) A quantitative approach to understanding the role of lecture capture in student learning experiences. *Technology, Pedagogy & Education* 26(4): 383-394.

Halliday MA and Matthiessen CM (2004) *An Introduction to Functional Grammar*. London, UK: Bloomsbury.

Hamilton ML and Pinnegar S (2014) *Self-Study of Practice as a Genre of Qualitative Research: Theory, Methodology, and Practice*. Dordrecht, Netherlands: Springer.

Hammond M, Reynolds L and Ingram J (2011) How and why do student teachers use ICT? *Journal of Computer Assisted Learning* 27(3): 191-203.

Han X, and Feng Z (2015) Chapter 24: School-based Instructional Research (SBIR): An approach to teacher professional development in China In: *From Teacher Thinking to Teachers and Teaching: The Evolution of a Research Community*, pp. 503-525. Available at: http://dx.doi.org/10.1108/S1479-3687 (2013)0000019027

Handelsman J, Ebert-May D, Beichner R, Bruns P, Chang A, DeHaan R, Gentile J, Lauffer, S, Stewart J, Tilghman SM and Wood WB (2004) Scientific teaching. *Science* 304(5670): 521-522.

Handy C (1995) *The empty raincoat*. Reading: Arrow Books Ltd.

Hantzopoulos M (2013) Building relationships to engage at-risk youth: A case study of a New York public high school. In M. Matsumoto (Ed.), *Education and disadvantaged children and young people* (pp. 11–30). New York, NY: Continuum.

Hardy A 2019 *Capability Approach and Teacher Quality: An Analysis of Female Teacher Experience in a Rural, Malawian Community*. Doctoral Dissertation. East Tennessee State University

Hargreaves, A and Fullan M (2012) Teacher development and educational change. In: Fullan M and Hargreaves A (eds.) *Teacher Development and Educational Change*. London, UK: Falmer Press, pp. 1-9.

Heritage M (2010) Formative assessment and next-generation assessment systems: Are we losing an opportunity? A project of Margaret Heritage and the Council of Chief State School Officers (Paper prepared for the Council of Chief State School Officers). Washington, DC: Council of Chief State School Officers.

Harris J, Phillips M, Koehler M and Rosenberg J (2017) TPCK/TPACK research and development: Past, present, and future directions. *Australasian Journal of Educational Technology* 33(3): i-viii. https://doi.org/10.14742/ajet.3907

Hatton N and Smith D (1995) Reflection in teacher education: Towards definition and implementation. *Teaching and Teacher Education* 11(1): 33-49.

Henderson B, Meier DR, Perry G and Stremmel AJ (2012) The nature of teacher research. Voices of practitioners. Available at: https://www.naeyc.org/files/naeyc/file/vop/Nature%20of%20Teacher%20Research.pdf (accessed 23 April 2020).

Henderson C and Dancy M. (2007) Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics. *Physical Review Special Topics: Physics Education Research* 3(2): 102-114.

Hepp P and Laval E (2002) ICT for rural education: A developing country perspective. In: *Learning in School, Home, Community: ICT for Early and Elementary Education* (eds G Marshall and Y Katz) International Working Conference on Learning with Technologies in School, Home and Community, Manchester, UK, 27 October 2022, pp. 400-428. Manchester, UK: Sage.

Herek G (1995) Developing a theoretical framework and rationale for a research proposal. In: Pequegnant W and Stover E (eds.) *How to Write a Successful Research Grant Application: A Guide for Social and Behavioural Scientists*. New York: Plenum Press, pp. 85-91.

Hiebert J, Gallimore R, Gamier H, Givvin K, Hollingsworth H, Jacobs J et al. (2003) *Teaching Mathematics in Seven countries: Results from the TIMSS 1999 Video Study*. Washington, DC: National Center for Education Statistics.

Higher Education Quality Committee (HEQC) (2002) *Programme accreditation framework draft document for comment*. Pretoria: CHE

Hilton M and Honey MA (eds.) (2011) *Learning science through computer games and simulations*. Washington, DC: National Academies Press.

Hindle D (2007) *Guidelines for teacher training and professional development in ICT*. Pretoria: Department of Education.

Hobden,P (2016) "Same old thinking- same old results". Well the results are not good. Maybe now is time to think differently? Lessons from a 40 year learning journey. *Quality Projects in Education*. Durban, South Africa

Hoeling BM (2011) Interactive online optics modules for the college physics course. *American Journal of Physics* 80(4): 334-338. doi: 10.1119/1.3677652

Höst GE, Schönborn KJ and Palmerius KE (2012) Students' use of three different representations to interpret whether molecules are polar or nonpolar. *Journal of Chemical Education* 89(12):1499-1505.

Holmberg J (2014) Studying the process of educational design – revisiting Schön and Makin a case for reflective design-based research on teachers' 'conversations with situations'. *Technology, Pedagogy and Education* 23(3): 293-310.

Holmberg J, Fransson G and Fors U (2018) Teachers' pedagogical reasoning and reframing of practice in digital contexts. *The International Journal of Information and Learning Technology* 35(2): 130-142. https://doi.org/10.1108/IJILT-09-2017-0084

Hora, MT and Ferrare JJ (2013) Instructional systems of practice: A multidimensional analysis of math and science undergraduate course planning and classroom teaching. *Journal of the Learning Sciences* 22(2): 212-257. DOI:10.1080/10508406.2012.729767

Howie SJ, van Staden S, Draper K and Zimmerman L (2010) *An Evaluation of the Implementation of the FET Curriculum*. Pretoria: Centre for Evaluation and Assessment.

Hsu Y-S (2015) The development of teachers' professional learning and knowledge. In: Y-S. Hsu Y-S (ed) *Development of science teachers' TPACK: East Asian Practices*. Singapore: Springer, pp. 3-15.

Huang X, Lederman, NG and Cai C (2017) Improving Chinese junior high school students' ability to ask critical questions. *Journal of Research in Science Teaching* 54(8): 963-987.

Huitt W and Cain S (2005) An overview of the conative domain. *Educational Psychology Interactive*. Valdosta, GA, USA: Valdosta State University, pp. 1-20.Available at: http://www.edpyscinteractive.org/brilstar/chapters/conative.pdf

Hyo-Jeong S and Kim B (2009) Learning about problem-based learning: Student teachers integrating technology, pedagogy and content knowledge. *Australasian Journal of Educational Technology* 25(1): 101–116.

Ilomäki L, Kantosalo A and Lakkala M (2011) What is digital competence? In: Editor name (ed) *Linked Portal*. Brussels, Belgium: European Schoolnet. Available at: http://linked.eun.org/web/guest/in-depth3 (accessed 28 January 2015).

Indraganti M (2018) Enquiry-based learning workshop for deep learning in Middle Eastern classrooms – An action research approach. *Educational Action Research* 26(4): 603-625. DOI: 10.1080/09650792.2017.1379423

Isenbarger L and Zembylas M (2006). The emotional labor of caring in teaching. *Teaching and Teacher Education*, 22(1):120–134. doi:10.1016/j.tate.2005.07.

James A, Jenks C and Prout A (1998) *Theorizing Childhood*. Cambridge: Polity Press.

Jang S-J and Tsai M-F (2013) Exploring the TPACK of Taiwanese secondary school science teachers using a new contextualized TPACK model. *Australasian Journal of Educational Technology* 29(4): 566–581.

Janssen N and Lazonder A (2016) Supporting pre-service teachers in designing technology infused lesson plans. *Journal of Computer Assisted Learning* 32(5):456-467.

Jeff JJ, Marshal M, Smart M and Alstone K (2017) Inquiry-based instruction: a possible solution to improving student learning of both science concepts and scientific practices. *International Journal of Science and Mathematics Education* 15:777-796.

Jenkins EW and Nelson NW (2005) Important but not for me: Students’ attitudes towards secondary school science in England. *Research in Science & Technological Education* 23(1): 41-57.

Jewitt C (2012) Teachers’ pedagogic use of the technological possibilities of interactive whiteboards in UK secondary schools. In: *Research into Teaching with Whole Class Interactive Technologies (RITWIT) International Conference*, Cambridge, UK, 15 August 2012.

Jimoyiannis A (2010) Designing and implementing an integrated technological pedagogical science knowledge framework for science teachers professional development. *Computers and Education*, 55:1259-1269

Jita T (2016) Pre-service teachers’ competence to teach science through information and communication technologies in South Africa. *Perspectives in Education*, 34(3): 15-26

Johnson S, Hodges M and Monk M (2000) Teacher development and change in South Africa: A critique of the appropriateness of transfer of northern/western practice. *Journal of Comparative and International Education*, 30(2): 179-192

Kafyulilo A, Fisser, P and Voogt J (2016) Teacher design in teams as a professional development arrangement for developing technology integration knowledge and skills of science teachers in Tanzania. *Education and Information Technologies* 21(2): 301-318. doi:10.1007/s10639-014-9321-0

Kagan DM (1992) Professional growth among preservice and beginning teachers. *Review of Educational Research* 62(2): 129-169.

Kale U and Goh D (2014) Teaching styles, ICT experience and teachers' attitudes towards teaching with Web 2.0. *Education and Information Technologies*, 19: 41-60

Kaptelinin V (2014) *Affordances and Design*. Denmark: The Interaction Design Foundation.

Karacop A and Doymus K (2013) Effects of jigsaw cooperative learning and animation techniques on students' understanding of chemical bonding and their conceptions of the particulate nature of matter. *Journal of Science Education and Technology* 22(2): 186-203.

Karadeniz E and Degirmencay ŞA (2020) The Effect of the Science-Fiction Books on Arousing Curiosity about Science in Secondary School Students. *Journal of Turkish Science Education*, 17(2): 225-241.

Kasembe R (2011) Teaching science through the science technology and society (STS) lens in Zimbabwean high schools: Opportunities and constraints. *Zimbabwe Journal of Educational Research*,23(3) :314-348

Kattmann U, Duit R, Gropengießer H and Komorek M (1996) Educational reconstruction-bringing together issues of scientific clarification and students' conceptions. In: *Annual Meeting of NARST*, St. Louis, MO, USA, 16 April, 1996.

Kauffman PB and Mohan J (2009) Video use and higher education: Options for the future. Retrieved from http://library.nyu.edu/about/Video_use_in_higher_education.pdf

Kearney M, Schuck S, Burden K and Aubusson P (2012) Viewing mobile learning from a pedagogical perspective. *Research in Learning Technology*, 20(1):1-17. doi: 10.3402/rlt.v20i0.14406

Kelchtermans G (2009) Who I am in how I teach is the message: Self-understanding, vulnerability and reflection. *Teachers and Teaching: Theory and Practice*,15: 257–272.

Kelley L and Ringstaff C (2002) *The Learning Return on Our Educational Technology Investment*. San Francisco, CA, USA: WestEd.

Kelly AV (2009) *The Curriculum: Theory and Practice*. London, UK: Sage.

Kemmis S (2010) What is to be done? The place of action research. *Educational Action Research* 18(4): 417–427.

Kemmis S and McTaggart R (1988) *The Action Research Planner* (3rd ed.). Geelong, Australia: Deakin University Press.

Kemmis S and McTaggart R (1990). *The Nature of Action Research: The Action Research Planner*. Geelong, Australia: Deakin University.

Kennewell S (2001) Using affordances and constraints to evaluate the use of information and communication technology in teaching and learning. *Journal of Information Technology for Teacher Education* 10(1-2): 101-116.

Kessels U, Rau M and Hannover B (2006) What goes well with physics? Measuring and altering the image of science. *British Journal of Educational Psychology* 76:761-780.

Khoza' S (2016) Can curriculum managers' reflections produce new strategies through Moodle visions and resources? *South African Journal of Education* 36(4): 1-9.

Kim H (2017) Teacher learning opportunities provided by implementing formative assessment lessons: Becoming responsive to student mathematical thinking. *International Journal of Science and Math Education*. /doi.org/10.1007/s10763-017-9866-7

Kincheloe J (2003) *Teachers as Researchers: Qualitative Inquiry as a Path to Empowerment*. London, UK: Routledge-Falmer

Kincheloe J (2012) *Teachers as researchers (classic edition) Qualitative Inquiry as a Path to Empowerment*. Routledge Education

Kind V (2009) Pedagogical content knowledge in science education: Perspectives and potential for progress. *Studies in Science Education*,45(2) :169-204

Kirsh D and Maglio P (1994) On distinguishing epistemic from pragmatic action. *Cognitive Science* 18(4): 513–549.

Kleickmann T, Ritcher D, Kunter M, Elsner J, Besser M, Krauss S. and Baumert J (2013) Teachers' content knowledge and pedagogical content knowledge: The role of structural differences in teacher education. *Journal of Teacher Education*,64(1): 90-106.

Ko MM and Krist C (2019) Opening up curricula to redistribute epistemic agency: A framework for supporting science teaching. *Science Education* 103:979-1010.

Koehler M and Mishra P (2009) What is technological pedagogical content knowledge (TPACK)? *Contemporary Issues in Technology and Teacher Education* 9(1): 60-70.

Koehler MJ, Mishra P, Kereluik K, Shin TS and Graham CR (2014) The technological pedagogical content framework. In: Spector JM et al. (eds.) *Handbook on*

Research on Educational Communications and Technology. New York: Springer Science, pp.101-111.

Korthagen FAJ and Kessels PAM (2015) Linking theory and practice: Changing the pedagogy of teacher education. *Educational Researcher*,28(4): 4-17

Kotoka JK (2018) *An investigation of physics teachers' technological pedagogical content knowledge and their learners' achievement in electricity*. PhD Thesis. University of South Africa.

Kozhevnikov M and Thornton R (2006) Real-time data display, spatial visualisation ability and learning force and motion concepts. *Journal of Science Education & Technology* 15(1): 111-129.

Kozma R (1991) Learning with media. *Review of Educational Research* 61(2): 179-212. doi:10.3102/ 00346543061002179

Krajcik J (2016) How to engage learners to develop usable and lasting knowledge of STEM. In: *ISTE Conference on Mathematics, Science and Technology Education*, Kruger National Park, Limpopo, South Africa, October 2016.

Krajcik J Codere S, Dahsah C, Bayer R and Mun K (2015) Planning instruction to meet the intent of the Next Generation Science Standards. *Journal of Science Teacher Education*, 25(2) : 157-175

Kriek J and Basson I (2008) Implementation of the new FET Physical Sciences curriculum: Teachers' perspectives. *African Journal of Research in Mathematics, Science and Technology* 12(2): 63-76.

Kriek J and Coetzee A (2016) Development of a technology integrated intervention in tertiary education. *Journal of Baltic Science Education* 15(6): 712-730.

Kriek J and Grayson D (2009) A holistic professional development model for South African physical science teachers. *South African Journal of Education* 29(2): 185-203.

Kruger RA (1994) *Focus Groups: The Practical Guide for Applied Research* (2nd edition). Thousand Oaks, CA, USA: SAGE Publications.

Krumsvik R (2008) Situated learning and teachers' digital competence. *Education & Information Technologies* 13(3): 279-290.

Kuboja JM and Ngussa BM (2015) Affective learning and cognitive skills improvement: experience of selected schools in Arusha, Tanzania. *International Journal of Academic Research in Progressive Education and Development* 4(2): 38-54.

Laborde C (2002) Visual phenomena in the teaching/learning of geometry in a computer-based environment. In: Mammana C and Villani V (eds) *Perspectives on the Teaching of Geometry for the 21st Century*. Dordrecht, Netherlands: Kluwer Academic Publishers, pp.113-121.

Ladson-Billings G (2014) Culturally relevant pedagogy. *Harvard Educational Review*,84(1): 74-84

Lagrange J-B, Artigue M, Laborde C and Trouche, L (2003) Technology and mathematics education: A multidimensional study of the evolution of research and innovation. In: Bishop AJ, Clements MA, Keitel C, Kilpatrick J and Leung FKS (eds.), *Second International Handbook of Mathematics Education*. Dordrecht, Netherlands: Kluwer Academic Publishers, pp. 237-269.

Lansdown G (1994) Children's rights. In: Mayall B (ed) *Children's Childhoods: Observed and Experienced*. London, UK: Falmer Press, pp. 33-44.

Laparo KM, Maynard C, Thomason A and Scott-Little C. (2012) Developing teachers' classroom interactions: A description of a video review process for early childhood education students. *Journal of Early Childhood Teacher Education* 33(3): 224-238. doi:10.1080/ 10901027.2012.705809

Laurillard D (2002) *Rethinking University Teaching* (2nded.). New York: Routledge Falmer.

Laurillard, D. (2012). *Teaching as a Design Science: Building Pedagogical Patterns for Learning and Technology*. New York: Routledge.

Lebrun M (2007) Quality towards an expected harmony: Pedagogy and technology speaking together about innovation. Association for the Advancement of Computing in Education,15(2): 115-130

LeCompte M and Preissle J (1993) *Ethnography and Qualitative Design in Educational Research* (2nd ed.). San Diego: Academic Press.

Lederman N and Lederman J (2015) Is it STEM or "S&M" that we truly love? *Journal of Science Teacher Education* 24(8): 1237-1240. doi:10.1007/s10972-013-9301

Lee E and Luft JA (2008) Experienced secondary science teachers' representation of pedagogical content knowledge. *International Journal of Science Education* 30(5): 1343-1363. https://doi.org/10.1080/09500690802187058

Lee O, Llosa L, Grapin S, Haas A, Goggins M.2019.Science and language integration with English learners: A conceptual framework guiding instructional materials development. *Science Education* 103(2): 317-337.

Levrini O, Levin M, Fantini P and Tasquier G (2019) Orchestration of classroom discussions that foster appropriation. *Science Education* 103(2): 206-235.

Little JW (2006) *Professional community and professional development in the learning centered school*. Arlington, VA: National Education Association.

Lin HS, Lawrenz F, Lin SF and Hong ZR (2012) Relationships among affective factors and preferred engagement in service–related activities. *Public Understanding of Science* 22: 941-954.

Lin T-C, Tsai C-C, Chai CS and Lee M-H (2013) Identifying science teachers' perceptions of technological pedagogical and content knowledge (TPACK). *Journal of Science Education and Technology* 22(3): 325-336.

Lobarch AK and Tobin (1997) Constructivism as a referent for science teaching. Available at: http://www.narst.org/publications/research.cfn (accessed 2015 January)

Lockton M and Fargson S (2019) Disrupting the status quo: How teachers grapple with reforms that compete with long-standing educational views. *Journal of Educational Change* 20:469-494. Available at: https://doi.org/10.1007/s10833-019-09351-5

Loizos P (2008) Video, film and photographs as research documents. In: Bauer MW and Gaskell G. (Orgs) *Qualitative Research with Text, Image and Sound* (2nd ed.). Petrópolis, Brazil: Vozes, pp. 137-155.

Lortie DC (1975) *Schoolteacher*. Chicago, USA: The University of Chicago Press.

Loucks-Horsley S, Love N, Stiles KE, Mundry S and Hewson PW (2003) *Designing Professional Development for Teachers of Science and Mathematics*. Thousand Oaks, CA, USA: Corwin Press.

Luft JA Roehrig GH & Patterson (2003) Contrasting landscapes: A comparison of the impact of different induction programs on beginning secondary science teachers' practices, beliefs, and experiences. *Journal of Research in Science Teaching*, 40(1) 77–97.

Ma T and Komarova NL (2019) Object-Label-Order effect when learning from an inconsistent source. *Cognitive Science* 43: 2-25. DOI: 10.1111/cogs.12737

Mabila J, van Biljon J, Herselman M (2017) A sustainability framework for mobile technology integration in schools: The case of resource-constrained environments in South Africa. *The Journal of Community Informatics* 13(2): 59-86.

Macufe B (2019) Broken teachers, broken children – the high cost of matric. *Mail & Guardian*, 30 August.

Macupe B (2017) Laptops just ornaments for Eastern Cape teachers who are not trained to use them. *Mail & Guardian*, 5 October.

Maingay P (1988) Observation for training development or assessment. In: Duff T (ed) *Exploring in Teacher Training: Problems and Issues.* London, UK: Longman, pp. 135-149.

Makgato M and Mji A (2006) Factors associated with high school learners' poor performance: A spotlight on mathematics and physical science. *South African Journal of Education*, 26(2): 253-266.

Mäkitalo-Siegl K, Kohnle C and Fischer F (2011) Computer-supported collaborative inquiry learning and classroom scripts: Effects on help-seeking processes and learning outcomes. *Learning and Instruction* 21: 257-266.

Mangan A (2011) Moving towards student-centred learning: A case study. In: *International Conference on English Pedagogy, NCI*, Dublin, Ireland, 16 December 2011.

Manqele CM (2017) *An evaluation of learner-centred teaching as part of curriculum delivery in under-resourced schools*. PhD thesis, University of South Africa.

Marais P (2016) We can’t believe what we see: Overcrowded classrooms through the eyes of student teachers. *South African Journal of Education* 36(2): 201-211.

Mariotti MA (2001) Introduction to proof: The mediation of a dynamic software environment. *Educational Studies in Mathematics* 44: 25-53.

Marris P (1964) *The Experience of Higher Education*. London, UK: Routledge and Kegan Paul.

Marshall JC, Smart JB and Alston DM (2017) Inquiry-based instruction: A possible solution to improving student learning of both science concepts and scientific practices. *International Journal of Science and Mathematics Education* 15: 777–796. https://doi.org/10.1007/s10763-016-9718-x

Masitsa MG (2005) The principal’s role in restoring a learning culture in township secondary schools. *Africa Education Review* 2:205-220.

Maslow AH (1943) A theory of human motivation. *Psychological Review*, 50: 370–396.

Matewos AM, Marsh JA, Mckiben S, Sinatra GM, Le QT and Polikoff MS (2019) Teacher learning from supplementary curricular materials: Shifting instructional roles. *Teaching and Teacher Education* 83: 212-224.

Mathias H (2005) Mentoring on a programme for new university teachers: A partnership in revitalising and empowering collegiality. *International Journal for Academic Development*,10(2): 95-106

Mayer RE, MorenoR, BoireM and VaggeS (1999) Maximising constructivist learning from multimedia communication by minimising cognitive load. *Journal of Educational Psychology* 91(4): 638-643.

Maynes N and Hatt BE (2015) Conceptualizing how mature teachers can influence students' growth in learning. *Brock Education Journal* 24(2): 4-16.

Mavhunga E and van der Merwe D (2020) Bridging Science Education's Theory–Practice Divide: A Perspective from Teacher Education Through Topic-Specific PCK, *African Journal of Research in Mathematics, Science and Technology Education.* 24(1): 65-80.

McAdam R Mason B and McCrory J (2007) Exploring the dichotomies within tacit knowledge literature: Towards a process of tacit knowing in organisations. *Journal of Knowledge Management*, 11(2) : 43-59

McCrindle M (2004) Understanding Generation Y. Available at: http://www.learningtolearn.sa.edu.au/Colleagues/files/links/UnderstandingGenY.pdf (accessed 9 September 2017).

McDermott LC and Redish EF (1999) Resource letter: PER-I: Physics education research. *American Journal of Physics* 67(9):755-767.

McDermott LC and Shaffer PS (1992) Research as guide for curriculum development: An example from introductory electricity. Part 1:Investigation of student understanding. *American Journal of Physics*,60(11):994-1003

McDiarmid GW, Ball DL and Anderson CW (1989) Why staying one chapter ahead doesn't really work: Subject-specific pedagogy. In: Reynolds M (ed) *Knowledge Base for the Beginning Teacher*. Oxford, England: Pergamon, pp. 193-205.

McElhaney K, Linn MC, Gerard L, Ryoo K, Liu OL, Rafferty AN (2014) Computer-guided inquiry to improve science learning. *Science*, 344(6180): 155-156

McKenney S Kali Y Markauskaite L and Voogt J (2015) Teacher design knowledge for technology enhanced learning: an ecological framework for investigating assets and needs. *Instructional Science*, 43(2):181-202. https://doi.org/10.1007/s11251-014-9337-2.

McKnight K, O'Malley K, Ruzic R, Horsley MK, Franey JJ and Bassett K (2016) Teaching in a digital age: How educators use technology to improve student learning. *Journal of Research on Technology in Education* 48(3): 194-211.

McMillan JH and Schumacher S (2001). *Research in Education: Evidence-Based Inquiry*. New York: Pearson Education Inc.

McNiff J and Whitehead J (2006) *Doing and Writing Action Research*. London, UK: Sage.

Means B and Olsen K (1994) The link between technology and authentic learning. *Educational Leadership* 51(7): 15-19.

Meena, W. (2004). Shifting from teaching to learning: Teachers educators' conceptions of curriculum change. In N. Mtana, E. Mhando, & G. Hojlund (Eds.), *Teaching and learning in primary education in Tanzania*. Dar es Salaam, Tanzania: Ministry of Education and Culture

Megowan-Romanowicz C (2010) Inside out: Action Research from the teacher-researcher perspective. *Journal of Science Teacher Education* 21: 993-1011.

Meierdirk C (2016) Is reflective practice an essential component of becoming a professional teacher? *Reflective Practice* 17(3): 1-10.

Mercier J (2012) From laboratory to authentic contexts: two studies of pedagogical reasoning across four levels of expertise. *World Journal of Education* 2(4): 2-19.

Merriam S and Tisdell E (2016) *Qualitative Research: A Guide to Design and Implementation*. San Francisco, CA, USA. John Wiley & Sons.

Mestre J (1989) Hispanic and Anglo students' misconceptions in Mathematics. Retrieved 24th of December 2020, from http://www.eric.ed.gov/PDFS/ED313192.pdf

Meyer I & Gent P (2016) *The status of ICT in education in South Africa and the way forward*.http://nect.org.za/publications/technical-reports/the-state-of-ict-in-education-in-south-africa/

Meyer H Pfiffner M and Walter C (2007) Versatile teaching.What do we know about the efficacyof methods? *Padogogik*,59(10) :44-48

Mikeska JN, Shattuck T, Holtzman S, McCaffrey DF, Duchesneau N, Qi Y and Stickler L (2017) Understanding science teaching effectiveness: Examining how science-specific and generic instructional practices relate to student achievement in secondary science classrooms. *International Journal of Science Education* 39(18): 2594-2623. DOI: 10.1080/09500693.2017.1390796

Miller E, Manz E, Russ R, Stroupe D and Berland L (2018) Addressing the epistemic elephant in the room: Epistemic agency and the next generation science standards. *Journal of Research in Science Teaching* 55:1053–1075.

Miller M (2007) Pedagogical content knowledge. In: Bodner G and Orgill M (eds) *Theoretical Frameworks for Research in Chemistry/Science*. Upper Saddle River, NJ, USA: Pearson-Prentice-Hall, pp. 86-105.

Mills G (2003) *Action Research: A Guide for the Teacher Researcher* (2nd ed.). Upper Saddle River, NJ, USA: Merrill/ Prentice Hall.

Minstrell J Anderson R and Li M (2011) Building on Learner Thinking: A Framework for Assessment in Instruction (Commissioned paper for the Committee on Highly Successful STEM Schools or Programs for K-12 STEM Education: Workshop, May 10/11, 2011)

Mishra P and Koehler MJ (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record* 108(6): 1017-1045. doi:10.1111/j.1467-9620.2006.00684.x

Mishra P and Koehler MJ (2008) What is technological pedagogical content knowledge (TPACK)? *Contemporary Issues in Technology and Teacher Education* 9(1): 60-70.

Mlachila M and Moeletsi T (2019) *Struggling to make the grade: A review of the causes and consequences of the weak outcomes of South Africa's education system*. IMF working paper

Mlitwa NS and Kesewaa K (2013) Integration of ICT into curricula in Western Cape schools: The activity theory perspectives. *The Journal of Community Infomatics* 9(4):1-16.

Moghaddam A (2007) Action research: A spiral inquiry for valid and useful knowledge. *Alberta Journal of Educational Research* 53(2): 228-239.

Mokiwa MO (2014) Exploring the teaching of physical science through inquiry. *International Journal of Educational Sciences* 7(1): 21-27.

Molenda M and Bichelmeyer B (2005) Issues and trends in instructional technology: Slow growth as economy recovers. In: Orey M, McClendon VJ and Branch RM (eds) *Educational Media and Technology Yearbook*. Englewood, CO, USA: Libraries Unlimited, pp. 3-28.

Moloi KC, Dzvimbo KP, Potgieter FJ, Wolhuter CC and van der Walt JL (2010) Learners' perceptions as to what contributes to their school success: A case study. *South African Journal of Education* 30: 475-490.

Moloi MQ and Chetty M (2010) *The SACMEQIII Project in South Africa. A study of the conditions of schooling and the quality of education. SACMEQ (Southern and Eastern Africa Consortium for Monitoring Educational Quality)*. Pretoria: Department of Basic Education

Moon J Passmore C Reiser BJ and Michaels S (2014) Beyond comparison of online versus face-to-face PD: Commentary in response to Fishman at al., "Comparing the impact of online and face-to-face professional development in the context of curriculum implementation". *Journal of Teacher Education*, 65(2):172-176

Mortimer E and Scott PH (2003) *Meaning Making in Secondary Science Classrooms*. Maidenhead, UK: Open University Press.

Moschkovich J (2012) Mathematics, the common core and language: Recommendations for mathematics instruction for ELs aligned with the common core. Available at: http://ell.stanford.edu/papers/ (accessed 17 November 2018).

Moss G, Jewitt C, Levaaic R, Armstrong V, Cardini A and Castle F (2007) *The interactive whiteboards, pedagogy and pupil performance evaluation: An evaluation of the Schools Whiteboard Expansion (SWE) project: London challenge. DfES*, Research Report 816. London, UK: Department for Education and Skills.

Mouza C, Karchmer-Klein R, Nandakumar R, Yilmaz Ozden SY and Hu L (2014). Investigating the impact of an integrated approach to the development of preservice teachers' technological pedagogical content knowledge (TPACK). *Computers & Education* 71: 206-221. doi:10.1016/j.compedu.2013.09.020

Mpungose CB (2017) *Exploring lecturers' reflections on the use of MOODLE to teach physical science modules at a South African university*. PhD thesis. University of KwaZulu-Natal, South Africa.

Msonde CE (2011) *Enhancing Teachers' Competencies on Learner-Centred Approaches through Learning Study in Tanzanian Schools*. Hong Kong: The University of Hong Kong.

Msonde SE and Msonde CE (2019) Re-Innovation of learner-centered pedagogy in Tanzania's secondary schools. *Journal of Education* 199(3): 142-154.

Mtika P and Gates P (2010) Developing learner-centred education among secondary trainee teachers in Malawi: The dilemma of appropriation and application. *International Journal of Educational Development* 30: 396-404.

Mtitu EA (2014) *Learner-centred teaching in Tanzania: Geography teachers' perceptions and experiences*. PhD Thesis. Victoria University, Melbourne, Australia.

Mudadigwa B and Msimanga A (2019) Exploring teacher pedagogical practices that help learners make connections during teaching of reactions in aqueous solutions at senior secondary level. *African Journal of Research in Mathematics, Science and Technology Education* DOI: 10.1080/18117295.2019.1688476

Mudau AV (2014) Micro underpinning for in-service philosophy: A case of the Vhembe district physical sciences teachers. *Mediterranean Journal of Social Sciences* 5(10): 404-408

Muennig PA (2006) *Healthier and Wealthier: Decreasing Health Care Costs by Increasing Educational Attainment*. Washington, DC: Alliance for Excellent Education. Available at: http://all4ed.org/wpcontent/uploads/HandW.pdf

Mugabo L (2015) Science teachers‟ understanding of inquiry-based science teaching (IBST): Case of Rwandan lower secondary school science teachers. *Rwandan Journal of Education* 3(1): 77-90.

Mulholland J and Wallace J (2003) Sharing strength and service: Restoring and the legitimation of research texts. *British Educational Research Journal* 29(1): 5-23.

Mulholland J and Wallace J (2005) Growing the tree of teacher knowledge: Ten years of learning to teach elementary science. *Journal of Research in Science Teaching* 42(7): 767-790.

Mundalamo F (2015) Teacher knowledge shaping the teaching of genetics: A case study of two underqualified teachers in Malawi. *African Journal of Research in Mathematics, Science and Technology Education* 19(1): 1-11.

Munikwa S (2016) *An analysis of Zimbabwean teachers' interpretation of the advanced level physics curriculum: Implications for practice*. PhD Thesis, University of South Africa.

Munns G (2007) A sense of wonder: Pedagogies to engage students who live in poverty. *International Journal of Inclusive Education* 11(6): 301-315.

Munsay N (2014) *What does an 'A' symbol in Physical Sciences represent about a learner's skills and knowledge in the subject? A study of the cognitive demand of the National Senior Certificate Physical Sciences examination question papers*. M. Ed dissertation, University of Kwazulu-Natal

Naiser EA Wright WE and Capraro RM (2004) Teaching fractions: Strategies used for teaching fractions to middle grades students. *Journal of Research in Childhood Education*,18(3): 193-198

National Center for Education Statistics. (2002). *The Condition of Education 2002. NCES 2002-025*. Washington, DC: U.S. Department of Education.

National Commission on Mathematics and Science Teaching for the 21st Century (2000) Available at: http://www2.ed.gov/inits/Math/glenn/index.html (accessed 2010 December).

National Education Infrastructure Management System [NEIMS] (2019) *School Infrastructure Report 2019*. Pretoria: Department of Basic Education.

National Planning Commission (2013) *National Development Plan Vision 2030*. Available at: http://www.nationalplanningcommission.org.za/Pages/default.aspx

National Research Council (1996) *National Science Education Standards*. Washington, DC: National Academy Press.

National Research Council (2000) *Taking Science to School: Learning and Teaching Science in Grades K-8*. Washington, DC: The National Academies Press.

National Research Council (2010) *Rising above the Gathering Storm, Revisited: Rapidly Approaching Category 5*. Washington, DC: National Academies Press.

National Research Council (2012) *A Framework for K-12 Science Education: Practices, Cross-Cutting Concepts and Core Ideas*. Washington, DC: Committee on a Conceptual Framework for New K-12 Science Education Standards, Board on Science Education, Division of Behavioural and Social Sciences and Education, The National Academies Press.

National Research Council (2013) *Monitoring Progress toward Successful K-12 STEM Education: A Nation Advancing?* Washington, DC: National Academies Press/Natural Sciences and Engineering Research Council of Canada.

Navy SL, Luft JA, Toerien R and Hewson PW (2018) Practices influenced by policy? An exploration of newly hired science teachers at sites in South Africa and the United States. *International Journal of Science Education* 40(8): 919-939.

Ndlovu M and Mji A (2012) Alignment between the South African mathematics assessment standards and the TIMSS assessment frameworks. *Pythagoras* 33(3): 63-71.

Ndlovu NS (2015) *The pedagogical integration of ICTs by seven South African township secondary school teachers*. PhD Thesis. University of Witwatersrand, South Africa.

Ndlovu NS and Lawrence D (2012) The quality of ICT use in South African classrooms. In: *Towards Carnegie III*, Cape Town, South Africa, 25 September, 2012.

Newton P and Burgess D (2008) Exploring types of educational action research: Implications for research validity. *International Journal of Qualitative Methods*,7(4),18-30.

Next Generation of Science Standards, Lead States (2013) *Next Generation Science Standards: For States, by States*. Washington DC: The Academies Press.

Nghifimule SN and Schafer M (2018) Analysing the role and use of visualisation objects in textbooks in Namibia. In: *26th Annual Conference of the Southern African Association for Research in Mathematics, Science and Technology Education (SAARMSTE)*. University of Botswana, Gaborone, Botswana, 18 January 2018.

Ni Shuilleabhain A (2014) Lesson study in a mathematics teacher community: Developing a problemsolving approach within Project Maths. In: *American Educational Research Association 2014 Conference*, Philadelphia, PA, USA, 24 October 2014.

Ní Shúilleabháin A (2015) Lesson study as a form of in-school professional development: Case studies in two post-primary schools. Thesis, University College, Dublin, Ireland.

Nilsson P (2009) Teaching for understanding: The complex nature of PCK in pre-service teacher education. *International Journal of Science Education* 30(10): 1281-1299.

Nkula K and Krauss EM (2014) The integration of ICTs in marginalised schools in South Africa: Considerations for understanding the perceptions on in-service teachers and the role of training. In: Steyn J. and Greunen D (eds) *ICTs for Inclusive Communities in Developing Societies: Proceedings of the 8th International Development Infomatics Association Conference*, Port Elizabeth, South Africa, 26 June 2014, pp.218-237.

Nompula Y (2012) An investigation of strategies for integrated learning experiences and instruction in the teaching of creative art subjects. *South African Journal of Education*, 32(2): 293-306.

Norman DA (2013) *The Design of Everyday Things*. New York: Basic Books.

Novak JD (1977) An alternative to Piagetian Psychology for science and mathematics education. *Science Education* 61(5-6): 453-477.

Nsengimana T, Habimana S and Mutarutinya V (2017) Mathematics and science teachers' understanding and practices of learner- centred education in nine secondary schools from three districts in Rwanda. *Rwandan Journal of Education* 4(1): 55-68.

Nxumalo-Dlamini NL and Gaigher E (2019) Teachers' use of computer-based simulations in teaching electrolysis: A case study in Eswatini. *African Journal of Research in Mathematics, Science and Technology Education* 23(3): 320-331, DOI: 10.1080/18117295.2019.1688475

Nyamupangedengu E (2016) *Teaching genetics to pre-service teachers: A teacher educator's approach to transformative practice through self study*. PhD thesis, University of Witwatersrand, South Africa.

Nyamupangedengu E (2017) Investigating factors that impact the success of students in a higher education classroom: A case study. *Journal of Education* 68(2): 113-130.

O'Toole N and Due C (2015) School engagement for academically at-risk students: A participatory research project. *Australian Education Researcher* 42(2):1-17.

Ocak C and Baran E (2019) Observing the indicators of technological pedagogical content knowledge in science classrooms: Video-based research. *Journal of Research on Technology in Education* 51(1): 43-62. DOI: 10.1080/15391523.2018.1550627

Ogunniyi M and Rollnick M (2015) Pre-service science teacher education in Africa: Prospects and challenges. *Journal of Science Teacher Education* 26(1): 65-79.

Ojo OA and Adu EO (2017) Transformation of teaching quality in secondary school education: Teachers' conception. *Perspectives in Education* 35(2): 60-72.

Okebukola PAO (1997) The state of science education in Nigeria. In: *ELLSA-British Council Primary Science Forum*, Kaduna, Nigeria, 23 March 1997.

Oldfather P (1993) What students say about motivating experiences in a whole language classroom. *The Reading Teacher* 46(8): 672-681.

Ollerenshaw J and Creswell J (2002) Narrative research: A comparison of two re-storying data analysis approaches. *Qualitative Inquiry* 8(3): 329-347.

Onyeachu JA (2010) Education for skill acquisition: A focus on adult and non-formal education in Nigeria. *Journal of Qualitative Education* 6(1):34-40.

Ooyo S (2012) Rethinking proficiency in the language of instruction (English) as a factor in the difficulty of school science. *The International Journal of Learning* 14(4): 231-238.

Opfer VD, Kaufman JH and Thompson LE (2016) *Implementation of K-12 State Standards for Mathematics and English Language Arts and Literacy*. Santa Monica, CA, USA: Rand.

Opfer VD and Pedder D (2011) Conceptualizing teacher professional learning. *Review of Educational Research*.81(3):376–407.

Opie C (2002) Research approaches. In: Opie C (ed) *Doing Educational Research* Los Angeles, USA: Sage, pp. 73-90.

Orlando J (2014) Veteran teachers and technology: Change fatigue and knowledge insecurity influence practice. *Teachers and Teaching: Theory and Practice* 20(4): 1-15.

Orlando J and Sawyer W (2013) A fair go in education. In: Munns G, Sawyer W and Cole B (eds) *Exemplary Teachers of Students in Poverty*. London, UK: Routledge, pp. 113-130.

Osborne J and Dillion J (2008) *Science Education in Europe: Critical Reflections: A Report to the Nuffield Foundation*. London, UK: King's College. Available at:http://www.nuffieldfoundation.org/sites/default/files/SciEdinEurope_Report.Final.pdf(accessed 18 August 2014).

Ostterman KF (1990) Reflective practice. *Education and Urban Society* 22(2):133-153.

Ottesen E (2006) Learning to teach with technology: Authoring practised identities. *Technology, Pedagogy & Education* 15(3): 275-290.

Padayachee K (2017) A snapshot survey of ICT integration in South African schools. *South African Computer Journal*, 29(2):38-65

Pai A (2014) A picture worth a thousand words? Making a case for video case studies. *Journal of College Science Teaching* 43(4): 63-67.

Pailliotet AW (1995) I never saw that before: A deeper view of video analysis in teacher education. *The Teacher Educator* 31(2): 138-156.

Pajares MF (1992) Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research* 62(3): 307-332.

Pang M (2016) Pedagogical reasoning in EFL/ESL teaching: Revisiting the importance of teaching lesson planning in second language teacher education. *TESOL Quarterly* 50(1): 246-263.

Papert S (1980) *Mindstorms: Children, Computers, and Powerful Ideas*. New York: Basic Books.

Partnership for 21st Century Skill (2002) Learning for the 21st century. Available at: http://www.21stcenturyskill.org (accessed 16 February 2019).

Patton MQ (1990) *Qualitative Research and Evaluation Methods*. Newbury Park, CA, USA: Sage.

Patton MQ (2002) *Qualitative Research and Evaluation Methods* (3rd ed.). Thousand Oaks, CA, USA: Sage.

Pelgrum WJ and Law NW (2003) *ICT in Education around the World: Trends, Problems and Prospects*. Paris: UNESCO: International Institute for Educational Planning. Available at: http://unesdoc.unesco.org/images/0013/001362/136281e.pdf

Pella S (2015) Pedagogical reasoning and action: Affordances of practice-based teacher professional development. *Teacher Education Quarterly* 42(3): 81-101.

Pellegrino AM and Gerber BL (2015) Teacher reflection through video-recording analysis. *Georgia Educational Researcher* 9(1): Article 1.

Perkins D and Blythe T (1994) Putting understanding up front. *Educational Leadership* 51(5), 4-7.

Peters EE 2010 Shifting to a student-centered science classroom: An exploration of teacher and student changes in perceptions and practices. *Journal of Science Teacher Education* 21(3): 329-349.

Peters O (2003) Learning with new media in distance education. In Moore MG and Anderson WG (eds) Handbook of Distance Education. Mahwah, NJ, USA: Lawrence Erlbaum Associates, pp. 1083-1103.

Phillips DC (1994) Telling it straight: issues in assessing narrative research *Educational Psychologist* 29(1): 1321-1340.

Pleschova´ G and McAlpine L (2016) Helping teachers to focus on learning and reflect on their teaching: What role does teaching context play? *Studies in Educational Evaluation* 48(2):1-9.

Plummer JD and Ozcelik AT (2015) Pre-service teachers developing coherent inquiry investigations in elementary astronomy *Science Education*, 99(5): 234-249

Popejoy K (2006) *The impact of technology on the teaching and learning in elementary science classrooms*. PhD Thesis, University of the British Columbia, Canada.

Prensky M (2001) Digital natives, digital immigrants. *On the Horizon* 9(3): 1-6

Pretorius EJ (2015) Failure to launch: Matching language policy with literacy accomplishment in South African schools. *International Journal of the Sociology of Language* 2015(234): 47–76.

Pretorius EJ and Spaull N (2014) Exploring relationships between oral reading fluency and reading comprehension amongst English second language readers in South Africa. *Reading and Writing* 29(7): 1449-1471.

Prenzel M (2008) *PISA 2006 in Germany: Juvenile skills in the third international comparisons.* Munster: Waxman

Priestly M, Biesta G and Robinson S (2015) The role of beliefs in teacher agency. *Teachers & Teaching* 21(6): 624-640.

Purvis, A. J., Aspden, L. J., Bannister, P. W., & Helm, P. A. (2011) Assessment strategies to support higher level learning in blended delivery. *Innovations in Education and Teaching International*, 48(1), 91-100

Putnam RT and Borko H (1997) Teacher learning: Implications of new views of cognition. *International Handbook of Teachers and Teaching*. Dordrecht, Netherlands: Springer, pp. 1123-1296. https://x.doi.org/10.1007/978-94-011-4942-6_30

Putnam RT and Borko H (2000) What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher* 29(1) 4-15.

Qhobela M and Moru EK (2014) Understanding challenges physics teachers come across as they implement learner-centred approaches in Lesotho. *African Journal of Research on Mathematics, Science and Technology Education* 18(1): 63-74.

Quigley BL and Nyquist JD (1992) Using video technology to provide feedback to students in performance courses. *Communication Education* 41(3): 324-334.

Rabardel P (1995) *Les hommes et les technologies, approche cognitive des instruments contemporains*. Paris, France: Armand Colin.

Rabiee F (2004) Focus group interview and data analysis. In: *Proceedings of the Nutrition Society* 63: 655-660.

Ramnarain U and Hobden P (2015) Shifting South African learners towards greater autonomy in scientific investigations. *Journal of Curriculum Studies*,47(1) :94-121

Ramnarain U and van Niekerk C (2012) Student naïve conceptions in their explanations in grade 12 physics examination. *African Journal of Research in Mathematics Science and Technology Education* 16(1): 112-125.

Ramsden P (1992*) Learning to Teach in Higher Education*. New York: Routledge.

Ramsey J (1993) Developing conceptual storylines with the learning cycle. *Journal of Elementary Science Education*, 5 (2):1-20.

Razfar A (2011) Ideological challenges in classroom discourse: A sociocritical perspective of English learning in an urban school. *Critical Inquiry in Language Studies* 8(4): 344-377.

Readence J, Bean T and Baldwin S (2004) *Content Area Literacy: An Integrated Approach* (8th ed.). Dubuque, IA, USA: Kendall-Hunt.

Reddy, C., & le Grange, L. (2017). Assessment and curriculum. In L. Ramrathan, L. Le Grange, & P. Higgs (Eds.), Education Studies: for Initial Teacher Development (pp. 159-173). Cape Town: Juta & Company (Pty) LTD.

Reiser BJ, Michaels S, Moon J, Bell T, Dyer E, Edwards KD, …Park A (2017) Scaling up three-dimensional science learning through teacher-led study groups across a state. *Journal of Teacher Education* 68(3): 280-298.

Remillard JT (2005) Examining key concepts in research on teachers' use of mathematics curricula. *Review of Educational Research* 75(2): 211-246.

Remillardv JT and Bryans MB (2004) Teachers' orientations toward mathematics curriculum materials: Implications for teacher learning. *Journal for Research in Mathematics Education* 35(5): 352-388. doi: 10.2307/30034820

Resnick L, Asterhan C and Clarke S (2015) *Socializing Intelligence through Academic Talk and Dialogue*. Washington, DC: American Education Research Association.

Rhem J (1995) Deep/surface approaches to learning: An introduction. *The National Teaching & Learning Forum* 5(1): 1-5.

Rich PJ and Hannafin M (2009) Video annotation tools: Technologies to scaffold, structure and transform teacher reflection. *Journal of Teacher Education* 60(1): 52-67.

Richards JC (2014) Teacher thinking and foreign language teaching. *MEXTESOL Journal* 38(1): 7-13.

Risimati HP (2007) *Whole school evaluation in rural primary schools in Limpopo province,* PhD thesis, University of South Africa.

Roberson AD Scherr RE and Hammer D (2015) *Responsive teaching in science and mathematics*. New York: Routledge

Rodgers C (2002) Defining reflection: Another look at John Dewey and reflective thinking. *Teachers College Record* 104(4): 842-866.

Rogers L and Twiddle J (2012) The challenge of developing innovative science teachers with ICT. *School Science Review* 34(7): 119-128.

Rogers RR (2001) Reflection in higher education: A concept analysis. *Innovative Higher Education* 26(1): 37-57.

Rolfe V (2012) Open educational resources: Staff attitudes and awareness. *Research in Learning Technology* 20(1): 7-19.

Rollnick M, Bennett J, Rhemtula M, Dharsey N and Ndlovu T (2008) The place of subject matter knowledge in pedagogical content knowledge: A case study of South African teachers teaching the amount of substance and chemical equilibrium. *International Journal of Science Education* 30(10): 1365-1387.

Romano EM (2004) Teacher reflections on ‘bumpy moments’ in teaching: A self-study. *Teachers and Teaching* 10(6):663–681.

Romiszowski AJ (1988) *The Selection and Use of Instructional Media.* New York: Nichols Publishing.

Rosaen CL Lundeberg M Terpstra M, Cooper M Fu J and Niu R (2010) Seeing through a different lens: What do interns learn when they make video cases of their own teaching? *The Teacher Educator* 45(1): 1-22.

Roth KJ Garnier H Chen C Lemmens M Schwille K and Wickler NI (2011) Videobased lesson analysis: Effective science PD for teacher and student learning. *Journal of Research in Science Teaching*, 48(2):117-148.

Ruhrig J and Höttecke D (2015) Components of science teachers' professional competence and their orientational frameworks when dealing with uncertain evidence in science teaching. *International Journal of Science & Mathematics Education* 13(4): 447-465.

Ryu M and Sikorski T-R (2019) Tracking a learner's verbal participation in science over time: Analysis of talk features within a social context. *Science Education* 2019(103): 561-589.

Sabates R Westbrook J and Hernandez-Fernanez J (2012) The 1997 universal primary education in Tanzania: A historical base for quantitative inquiry. *International Journal of Research and Method* 35(1): 55 - 70.

Sadler AV and Tai RH (2000) A study of the association of autonomy and achievement in performance. *Science Educator* 16(1): 22-28.

Sagor R (1992) *How to Conduct Collaborative Action Research*. Alexandria, VA, USA: Association for Supervision and Curriculum Development.

Salavati S (2016) *Use of digital technologies in education: The complexity of teachers everyday practice*. PhD thesis, Linnaeus University, Växjö, Sweden.

Saleh S (2012) The effectiveness of brain-based teaching approach in dealing with the problems of students' conceptual understanding and learning motivation towards physics. *Educational Studies* 38(1): 19-29.

Samaras AP (2011) *Self-Study Teacher Research: Improving Your Practice through Collaborative Inquiry*. Thousand Oaks, CA, USA: Sage.

Sanchez J and Salinas A (2009) Digital inclusion in Chile: Internet in rural schools. *International Journal of Educational Development* 29: 573-582.

Santagata R and Guarino J (2011) Using video to teach future teachers to learn from teaching. *ZDM Mathematics Education* 43: 133-145.

Sawada D and Piburn, M (2002) Measuring reform practices in science and mathematics classrooms: The reformed teaching observation protocol. *School Science and Mathematics Journal* 102 (October): 245–253.

Schneider RM, Krajcik J and Blumenfeld P (2005) Enacting reform-based science materials: The range of teacher enactments in reform classrooms. *Journal of Research in Science Teaching* 42(3): 283-312.

Schulze S and Steyn T (2007) Stressors in the professional lives of South African secondary school educators. *South African Journal of Education* 27:691-707.

Schwab JJ (1970) Education and the structure of the disciplines. In: Westbury I and Wilkof N (eds) *Joseph J. Schwab: Science, Curriculum, and Liberal Education—Selected Essays* Chicago: University of Chicago Press, pp. 229-272.

Schwab K (2012) *The Global Competitiveness Report 2012−2013*. Geneva, Switzerland: World Economic Forum. Available at: http://www3.weforum.org/docs/WEF_GlobalCompetitivenessReport_2012-13.pdf

Schwarz C, Gunckel KI, Smith EL, Covitt B and Bae MJ (2008) Helping elementary preservice teachers learn to use curriculum materials for effective science teaching. *Science Education* 93: 346-377.

Schweisfurth M (2011) Learner-centred education in developing country contexts: From solution to problem? *International Journal of Educational Development* 31(5): 425-432.

Schweisfurth M (2013) Learner-centred education in international perspective. *Journal of International and Comparative Education* 2(1): 1-8.

Schön D (1983) *The Reflective Practitioner*. San Franscisco, CA, USA: Jossey-Bass.

Scott P, Mortimer E and Ametller J (2011) Pedagogical link-making: A fundamental aspect of teaching and learning scientific conceptual knowledge. *Studies in Science Education* 47(1): 3-36. https://doi.org/10.1080/03057267.2011.549619

Seale J and Cooper M (2010) E-learning and accessibility: An exploration of the potential of generic pedagogical tools. *Computers & Education* 54(4): 1107-1116.

Sethusha MJ (2015) An exploration of the challenges facing underperforming schools in the Vhembe district, Limpopo Province, South Africa. *Journal of Educational Studies* 14(1): 51-73.

Sfard A (2006) *Moving between discourses: From learning-as acquisition to learning-as participation*. Michigan State University, US

Shavelson RJ Ruiz-Primo MA and Wiley EW (2005) Windows into the mind. *Higher Education*, 49(3): 413-430.

Shavelson RJ and Stern P (1981) Reading teachers' judgements, plans and decision making. *The Reading Teacher* 37(3): 280-286.

Sherin MG and Van Es EA (2005) Using video to support teachers' ability to notice classroom interactions. *Journal of Technology and Teacher Education* 13(3): 475-491.

Shubha S and Meera BN (2015) Impact of visual representation on the conceptual understanding of abstract Physics concept-electric flux. *American Scientific Publishers, Advanced Science, Engineering and Medicine*,7(3):533-537.

Shuell, T. J (1996) Teaching and learning in a classroom context. In Berliner DCand Calfee RC (eds) *Handbook of Educational Psychology* New York: Simon& Schuster Macmillan, pp. 726-764.

Shulman JH (2004) How and what teachers learn: a shifting perspective. *Journal of Curriculum Studies* 36(2): 257-271.

Shulman LS (1986) Those who understand: Knowledge growth in teaching. *Educational Researcher* 15(2): 4-14. doi:10.3102/0013189X015002004

Shulman LS (1987) Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review* 57(1): 1-23. doi:10.17763/haer.57.1j463w79r56455411

Sickel JL (2019) The great media debate and TPACK: A multidisciplinary examination of the role of technology in teaching and learning. *Journal of Research on Technology in Education* 51(2): 152-165, DOI: 10.1080/15391523.2018.1564895

Siddiqui U and Khatoon T (2013) Teaching physical science: Should we implement teacher-centered CAI or student-centered CAI at secondary school level in India? *European Scientific Journal* 9(10): 136-149.

Sikorski T-R and Hammer D (2017) Looking for coherence in science curriculum. *Science Education*101: 929–943. https://doi.org/10.1002/sce.21299

Silk Y, Silver D, Amerian S, Nishimura, C and Boscardin CK (2009) *Using classroom artifacts to measure the efficacy of a professional development*. CRESST Report 761, UK.

Singal N Mahama Salifu E Iddrisu K Casely-Hayford L and Lundebye H (2015) The impact of education in shaping lives: Reflections of young people with disabilities in Ghana. *International Journal of Inclusive Education*, 19(9):908–925.

Sipilä K (2014) Educational use of information and communications technology: Teachers' perspective. *Technology, Pedagogy and Education* 23(2): 225-241. DOI: 10.1080/1475939X.2013.813407

Smart V (2016) *Technological pedagogical reasoning. The development of teachers pedagogical reasoning with technology over multiple stage careers*. PhD Thesis. Griffith University, South East Queensland, Australia.

Smart V, Sim C and Finger G (2015) Are teachers lost in thought with technology? Moving from pedagogical reasoning to technological pedagogical reasoning. In: Proceedings of Society for Information Technology International Conference 2015, Las Vegas, NV, USA. http://www.editlib.org/p/48620/

Smetana LK and Bell RL (2013) Which setting to choose: Comparison of whole-class vs small-group computer simulation use. Journal of Science Education & Technology 23: 481-495.

Smith HJ, Higgins S, Wall, K and Miller J (2005) Interactive white boards: Boon or bandwagon? A critical review of the literature. *Journal of Computer Assisted Learning*, 21(4): 91-101.

Smith-Senger E (1999) Reflective reform in mathematics: the recursive nature of teacher change. *Educational Studies in Mathematics,* 37 (3):199–221.

Smithenry DW (2010) Integrating guided inquiry into a traditional chemistry curricular framework. *International Journal of Science Education* 32(13): 1689-1714.

Smylie MA (1989) Teachers' views of the effectiveness of sources of learning to teach. *The Elementary School Journal* 89(5): 543–558.

Smyth R (2004) Exploring the usefulness of a conceptual framework as a research tool: A researcher's reflection. *Issues in Educational Research* 14(3): 1-10.

Solheim K, Ertesvåg SK and Berg GD (2018) How teachers can improve their classroom interaction with students: New findings from teachers themselves. *Journal of Educational Change* 19:511-538. doi.org/10.1007/s10833-018-9333-4

Spaull N (2013). *A preliminary analysis of SACMEQ III South Africa. Stellenbosch: Department of Economics, University of Stellenbosch*. Available at:

http://www3.weforum.org/docs/WEF_GlobalCompetitivenessReport_2012-13.pdf

Spector JM, Merrill MD, van Merrienboer J and Driscoll MP (eds) (2008) *Handbook of Research on Educational Communications and Technology*. New York: Lawrence Erlbaum.

Spencer J (2003) Learning and teaching in the clinical environment. *BMJ* 326:591

Spillane J (2006) *Distributed Leadership*. San Francisco, CA, USA: Jossey-Bass.

Srisawasdi N and Panjaburee P (2015) Exploring effectiveness of Simulation-based inquiry learning in science with integration of formative assessment. *Journal of Computers in Education* 2:323-352.

Star JR and Strickland S.K (2008) Learning to observe: Using video to improve preservice mathematics teachers' ability to notice. *Journal of Mathematics Teacher Education* 11(2), 107-125. doi:10.1007/s10857-007-9063-7

Starkey L (2010) Teachers' pedagogical reasoning and action in the digital age. *Teachers and Teaching* 16(2): 233-244.

Stecher BM and Barron S (2001) Unintended consequences of test-based accountability when testing in "milepost" grades. *Educational Assessment* 7(4): 259-281.

Stenhouse L (1981) What counts as research? *British Journal of Educational Studies* 29(2) :103-114

Stephens AL (2012) *Student recognition of visual affordances: Supporting use of physics simulations in whole class and small group settings*. Doctoral Dissertation, University of Massachusetts, Amhurst, MA, USA.

Stieff M, Scopelitis S, Lira ME and Desutter D (2016) Improving representational competence with concrete models. *Science Education* 100(2): 344-363.

Stohlmann M Moore TJ and Roehrig GH (2012) Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research,* 2(1):28–34.

Stott A (2013) South African physical sciences teachers' understanding of force and the relationship to teacher qualification, experience and their school's quintile. *African Journal of Research in Mathematics, Science and Technology Education* 17(1-2): 173-183.

Stott AE (2018) Are instructivist pedagogies more appropriate for learning the sciences in South African low-quintile schools than western literature suggests? *Journal of Education* 71. Available at: http://journals.ukzn.ac.za/index.php/joe

Stroupe D (2014) Examining classroom science practice communities: How teachers and students negotiate epistemic agency and learn science-as-practice. *Science Education* 98(3): 487-516.

Stroupe, D (2017) Ambitious Teachers' Design and Use of Classrooms as a Place of Science. *Science Education,* 111(3):458–485

Svensson M and Johansen G (2017) Teacher's didactical moves in the technology classroom. *International Journal of Technology Design Education*. https://doi.org/10.1007/s10798-017-9432-1

Symth J and Fasoli L (2007) Climbing over the rocks in the road to student engagement and learning in a challenging high school in Australia. *Educational Research* 49(2): 273-295.

Taber KS (2000) Should physics teaching be a research-based activity? *Physics Education* 35(3): 163-168.

Tabulawa R (1997) Pedagogical classroom practice and the social context: The case of Botswana. *International Journal of Educational Development* 17(2): 189-204.

Tafoya E, Sunal D and Knecht P (1980) Assessing inquiry potential: A tool for curriculum decision makers. *School Science & Mathematics Journal* 80(1): 43-48.

Tallvid M (2014) Understanding teachers' reluctance to the pedagogical use of ICT in the 1:1 classroom. *Education and Information Technologies*, 21:503-519.

Tarling I and N'gambi D (2016) Teachers pedagogical change framework: a diagnostic tool for changing teachers uses of emerging technologies. *British Journal of Educational Technology* 47(3): 554-572.

Taylor N (2008) What wrong with South African schools? Available at: http://www.jet.org.za/events/conferences (accessed May 2020).

Teddlie C and Tashakkori A (2009) Foundations of Mixed Methods Research integrating quantitative and qualitative approaches in the Social and Behavioral Sciences. Thousand Oaks, CA, SAGE Publications, Inc.

Tesfaye CL and White S (2012) Challenges high school teachers face. American Institute of Physics. Available from http://www.aip.org/statistics (accessed January 2020)

Thanh PTH (2010) Implementing a student-centred learning approach at Vietnamese higher education institutions: Barriers under layers of casual layered analysis. *Journal of Future Studies*,15(1):21-38

The Inquiry Synthesis Project (2004) Center for Science Education, Education Development Center, Inc. Technical report 2 Conceptualizing Inquiry Science Instruction. Education Development Center, Inc. Available at: http://www.cse.edc.org/work/research /technicalReport2.asp (accessed 10 June 2015).

Thierry K, Harper-Merrett T, Traorè D, Mbangwana M and Tourè K (2009). The PanAfrican research agenda on the pedagogical integration of ICTs. In: *The 3rd OECD World Forum on "Statistics, Knowledge, and Policy"*. Busan, South Korea: OECD World Forum, 27-30 October 2009.

Thompson N and Pascal J (2012). Developing critically reflective practice. *Reflective Practice: International and Multidisciplinary Perspectives,* 13: 311–325.

Tondeur J, Roblin NP, van Braak J, Voogt, J and Prestridge S (2017) Preparing beginning teachers for technology integration in education: Ready for take-off. *Technology, Pedagogy and Education* 26(2): 157-177.

Torrance H and Pryor J (1998) *Investigating formative assessment: Teaching and learning in the classroom*. Buckingham: Open University Press

Trouche L (2005) Managing the complexity of human/machine interactions in computerized learning environments: Guiding students' command process through instrumental orchestrations. *International Journal of Computers for Mathematical Learning* 9(3): 281-307.

Trumbull D (2012) Following a student into her science classroom to better understand the tensions of science education. In: Bullock S and Russell T (eds) *Self-Studies of Science Teacher Education Practices*. Dordrecht, Netherlands: Springer, pp. 139-156.

Trundle K and Bell R (2010) The use of computer simulation to promote conceptual change: A quasi-experimental study. Computers & Education 54(5):1078-1088.

Tschannen-Moran M and Woolfolk Hoy A (2007) The differential antecedents of self-efficacy beliefs of novice and experienced teachers. *Teaching and Teacher Education*, 23:944-956.

Tsybulsky D (2019) Students meet authentic science: the valence and foci of experiences reported by high-school biology students regarding their participation in a science outreach programme. *International Journal of Science Education* 41(5): 567-585. DOI: 10.1080/09500693.2019.1570380

United Nations Educational Scientific & Cultural Organisation(UNESCO) (2010) *Current Challenges in Basic Science Education.* Paris, France: Author.

Utterberg M, Lundin J and Lindström B (2017) Conditions influencing mathematics teachers' uptake of digital tools–A systematic literature review. In Resta P and Smith S (eds) Proceedings of *Society for Information Technology & Teacher Education International Conference*, (pp.2016-2029). Austin, TX, United States: Association for the Advancement of Computing in Education (AACE). accessed on:2020 May 24.

Valenzuela A (1999) *Subtractive schooling: Issues of caring in education of US-Mexican youth*. New York, NY: State University of New York Press

Van der Berg S, Spaull N, Wills G, Gustafsson M and Kotzé, J (2016) *Identifying Binding Constraints in Education*. Stellenbosch, South Africa: Department of Economics, University of Stellenbosch.

Van de Grift WJ (2014) Measuring teaching quality in several European countries. Teachers and Teaching 25(3): 295-311.

Van Driel J and Verloop N (1998) Pedagogical content knowledge: a unifying element in the knowledge base of teachers. *Pedagogische Studiën*,75 :225-237

van Manen M (1991) *The Tact of Teaching*. New York: SUNY Press.

van Manen M (2014) *Phenomenology of Practice: Meaning-Giving Methods in Phenomenological Research and Writing*. Walnut Creek, CA, USA: Left Coast Press.

Van Rooyen H and De Beer J (2010) The missing link in science education: Dealing with ethics in the science classroom. In van Rooyen H and & de Beer J (eds) *Teaching Science*. Braamfontein, South Africa: Macmillan, pp. 93-112.

Velazquez-Marcano A, Williamson VM, Ashkenazi G, Tasker R and Williamson KC (2004) The use of video demonstration and particulate animation in general chemistry. *Journal of Science Education & Technology* 13(3): 315-323.

Vermeulen J (2019) The massive matric dropout problem in South Africa. Available at: http://mybroadband.co.za/news/government/290868 (accessed 26 March 2020).

Volk SK (2009) Action research as a sustainable endeavour for teachers: Does initial training lead to further action? *Action Research* 8(3): 315-332.

Voogt J and Pareja-Robin N (2012) Teaching and learning in the 21st century: A comparative analysis of international frameworks. *Journal of Curriculum Studies* 44(3): 299-321.

Wajnryb, R (1992) *Classroom Observation Tasks: A Resource Book for Language Teachers and Trainers.* Cambridge, UK: Cambridge University Press.

Walker M (1988) Thoughts on the potential of action research in South African schools. *Cambridge Journal of Education* 18(2): 147-154.

Wallace CS and Priestley MR (2017) Secondary science teachers as curriculum makers: Mapping and designing Scotland's new curriculum for excellence. *Journal of Research in Science Teaching* 54(3): 324-349.

Wallace J (2003) *Learning about Teacher Learning: Reflections of a Science Educator*. London, UK: Routledge Falmer.

Wang H, Moore TJ, Roehrig GH and Park MS (2014) STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research* 1(2), 1-13.

Warren K, Duffy J and Walsh M (2001) Classroom interactions: Gender of teacher, gender of student and classroom subject. *Sex Roles* 45: 579-593.

Watkins A (2006) So what exactly do teacher-researchers think about doing research? *Support for Learning* 21(1): 12-18.

Webb L (2015) The use of cartoons as a tool to support teacher ownership of mathematics curriculum change. *African Journal of Research in Mathematics, Science and Technology Education* 19(1): 57-69.

Webb M (2002) Pedagogical reasoning: Issues and solutions for the teaching and learning of ICT in secondary schools. *Education and Information Technologies* 7(3): 237-255. http://dx.doi.org/10.1023/A:1020811614282

Webb M (2005) Affordances of ICT in science learning: Implications for an integrated pedagogy. *International Journal of Science Education* 26(6): 705-735.

Webb M (2012) Pedagogy with ICTs in transition. *Education and Information Technologies*. Doi: 10.1007/s10639-012-9216-x

Wellington JJ (1985) *Children, Computers and the Curriculum: An Introduction to Information Technology and Education*. London, UK, Harper and Row.

Weimer M (2012) Five characteristics of learner-centred teaching. Available at https://www.teachingprofessor.com/topics/teaching-strategies/active-learning/five-characteristics-of-learnercentred-teaching/. Accessed 7 December 2020.

Wenner JA and Kittleson J (2018) Focussed video reflections in concert with practice-based structures to support elementary teacher candidates in learning to teach science. *Journal of Science Teacher Education* 29(8): 741-759.

Wertsch JV (1998) *Mind as Action*. Oxford, UK: Oxford University Press.

White BY and Frederiksen, JR (2013) Inquiry, modelling and metacognition: Making science accessible to all students. *Cognition & Instruction* 16(1): 3-18.

Wilkerson-Jerde MH and Wilensky UJ (2015) Patterns, probabilities and people: Making sense of quantitative change in complex systems. *Journal of Learning Sciences* 24(2): 204-251.

Wiliam, D., & Thompson, M. (2008). Integrating assessment with instruction: What will it take to make it work? In C. A. Dwyer (Ed.), *The future of assessment: Shaping teaching and learning* (pp. 53-82). Mahwah, NJ: Erlbaum.

Williams M (1989) A developmental view of classroom observations. *ELT Journal* 43(2): 34-48.

Williams PJ, Nguyen N and Mangan J (2017) Using technology to support science inquiry learning. *Journal of Science and Technology Education* 7(1): 26-57.

Wilson S, Shulman L and Richert A (eds) (1987). *150 Different Ways of Knowing: Representations of Knowledge in Teaching*. Sussex, UK: Holt, Rinehart, & Winston.

Windschitl M (2003) Using simulations in the middle school: Does assertiveness of dyad partners influence conceptual change? *International Journal of Science Education*, 23(1): 17-32.

Windschitl M Thompson J and Braaten M (2018) *Ambitious science teaching*. Cambridge, MA: Harvard Education Press.

World Bank Report 2016 *Government expenditure on education, total (% of GDP)*. Accessed from data.worldbank.org/indicator/SE.XPD.TOTL.GD.ZS

Ye L and Cheng L (2018) Fill the classroom with life: Deepening the reform of Chinese primary and secondary classroom teaching. *Journal of Curriculum Studies* 50(3): 352-363.

Yeh YF, Hsu YS, Wu HK and Chien SP (2017) Exploring the structure of TPACK with video embedded and discipline-focused assessments. *Computers & Education* 104: 49-64. doi:10.1016/ j.compedu.2016.10.006

Yeh YF Lin TC Hsu YS Wu HK and Hwang FK (2015) Science teachers' proficiency levels and patterns of TPACK in a practical context. *Journal of Science Education and Technology* 12:2-13.doi 10.1007/s10956-014-9523-7

Youngs P and Bird T (2010) Using embedded assessments to promote pedagogical reasoning among secondary teaching candidates. *Teaching & Teacher Education* 26(2): 185-198.

Zacharia J (2007) Comparing and combining real and virtual experimentation: An effort to enhance students' conceptual understanding of electric circuits. *Journal of Computer Assisted Learning* 23(2): 120-132.

Zbiek RM (2001) Influences on mathematics teachers' transitional journeys in teaching with CAS. *The International Journal of Computer Algebra in Mathematics Education* 9(2): 129-147.

Zeichner MK and Noffke SE (2001) Practitioner research. In: Richardson V (ed) *Handbook of Research on Teaching* (4th edition). Washington, DC: American Educational Research Association, pp. 293-330.

Zenda R (2017) Essential teaching methods to enhance learner academic achievement in physical sciences in rural secondary schools: A South African case study. *Information and Learning Science* 118(3/4): 170-184. https://doi.org/10.1108/ILS-03-2017-0014

Zeyer A, Certin-Dindar A, Zain AN, Juriševič M, Devetak I and Odermatt F (2013) Systemazing A cross-cultural constant for motivation to learn science. *Journal of Research in Science Teaching* 50(9):1047-1067.

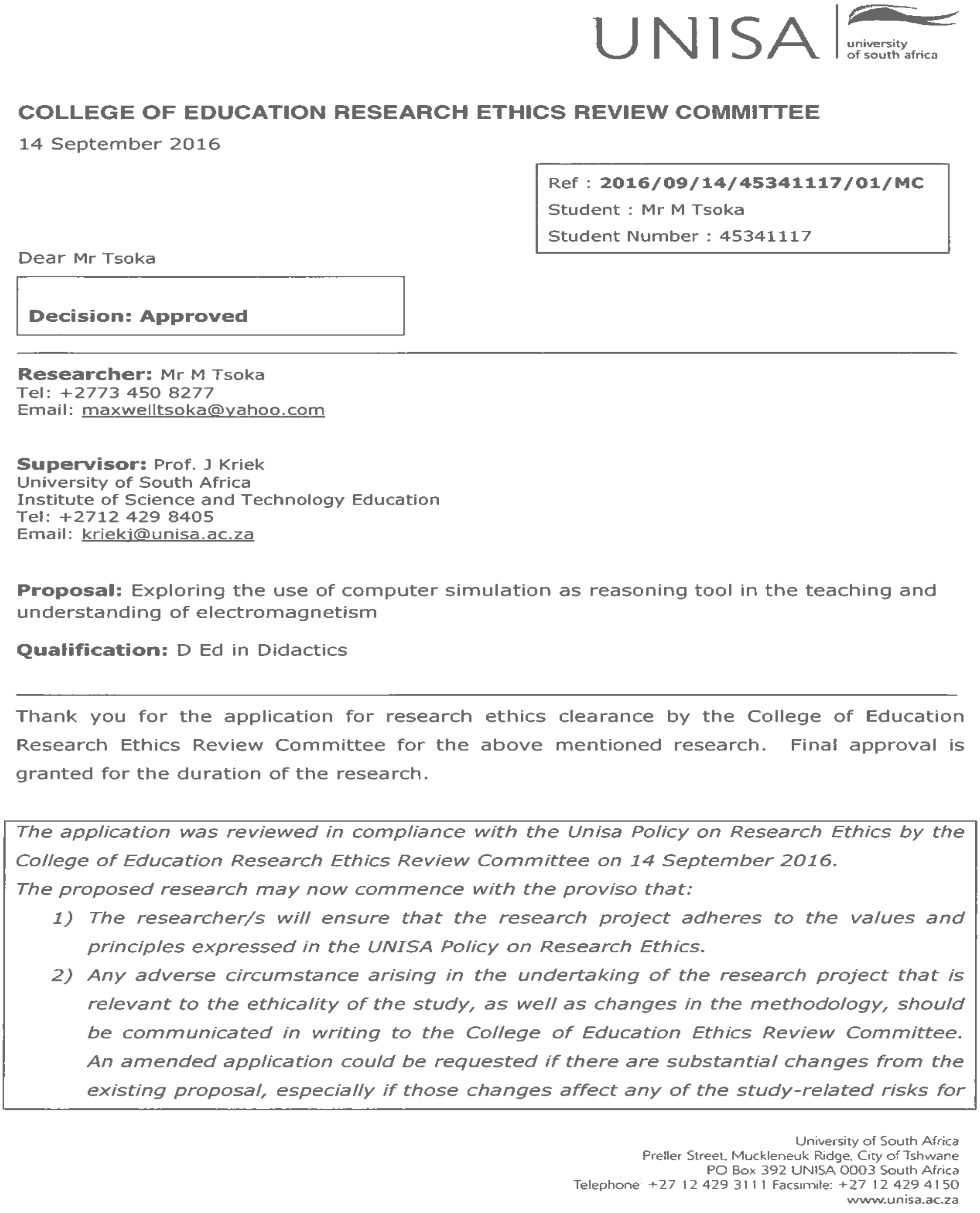
Zhao Y, Pugh K, Sheldon S and Byers JL (2002) Conditions for classroom technology innovation. *Teachers College Record* 104(3): 482-515.

Zimmerman G (2015) *The design and validation of an instrument to measure the Topic Specific Pedagogical Content Knowledge of physical sciences teachers in electric circuits*. Thesis. Witswaterand University, Johannesburg, South Africa

Zyngier D (2007) Listening to teachers-listening to students: Substantive conversations about resistance, empowerment and engagement. *Teachers & Teaching: Theory and Practice* 13: 327-347.

Appendices

Appendix 1A Ethical clearance



UNISA university of south africa

COLLEGE OF EDUCATION RESEARCH ETHICS REVIEW COMMITTEE

14 September 2016

Ref : **2016/09/14/45341117/01/MC**
Student : Mr M Tsoka
Student Number : 45341117

Dear Mr Tsoka

Decision: Approved

Researcher: Mr M Tsoka
Tel: +2773 450 8277
Email: maxwelltsoka@yahoo.com

Supervisor: Prof. J Kriek
University of South Africa
Institute of Science and Technology Education
Tel: +2712 429 8405
Email: kriekj@unisa.ac.za

Proposal: Exploring the use of computer simulation as reasoning tool in the teaching and understanding of electromagnetism

Qualification: D Ed in Didactics

Thank you for the application for research ethics clearance by the College of Education Research Ethics Review Committee for the above mentioned research. Final approval is granted for the duration of the research.

The application was reviewed in compliance with the Unisa Policy on Research Ethics by the College of Education Research Ethics Review Committee on 14 September 2016.

The proposed research may now commence with the proviso that:

1) *The researcher/s will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.*
2) *Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should be communicated in writing to the College of Education Ethics Review Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those changes affect any of the study-related risks for*

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

the research participants.

3) *The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study.*

Note:

The reference number **2016/09/14/45341117/01/MC** *should be clearly indicated on all forms of communication [e.g. Webmail, E-mail messages, letters] with the intended research participants, as well as with the College of Education RERC.*

Kind regards,

MClaassens

Dr M Claassens
CHAIRPERSON: CEDU RERC
mcdtc@netactive.co.za

Prof VI McKay
EXECUTIVE DEAN

Appendix 1B Consent letters

Attention: The Principal
Patrick Ramaano Secondary School

Dear Sir,

RE: APPLICATION FOR PERMISSION TO USE LEARNERS AND SCHOOL

I hereby apply for permission to use school facilities and involve grade 11 learners from your school to conduct a research project based on science education.

I am conducting research for a Doctor of Education Degree at the University of South Africa (UNISA). My research topic is *"Exploring the use of computer simulations as reasoning tool in the teaching and learning of electromagnetism"*.

The study aims to examine the effect of using computer simulations as heuristics on the learning process . The process will involve writing a pre-post test, and focus group discussions with grade 11 learners about their learning experiences in learning *electromagnetism*. I would like to assure you that no classes will be disrupted, a condition given from the Limpopo Department of Education. Learners who do not wish to take part in the study and those whose parents do not want them to be part of the study will be excluded from these sessions. An alternative arrangement will be sought from these learners and their parents to ensure that I teach them this topic at their convenient time. All information collected will be coded so that participants and the school cannot be identified in any report about this research.

A letter requesting permission to conduct research at your school was sent to the Limpopo Department of Education Offices in Thohoyandou. The response will be forwarded to the school as soon as permission to conduct research is granted.

This research is conducted under the supervision of Prof Jeanne Kriek at the Institute of Science and Technology Education at UNISA. Any questions regarding this research can be directed to me or my supervisor through the following contacts.

Prof Jeanne Kriek,
Institute of Science & Technology Education,
UNISA.
Tel: 012-337 6017
Email:kriekj@unisa.ac.za

Mr. Tsoka M,
Student no: 4534-111-7
Mobile: 073 450 8277
Email: maxwelltsoka@yahoo.com

Letters to the parents and Consent form

Dear Parent,
I hereby ask for permission to allow your child to take part in a research project that I will be conducting at the secondary school during the third term of the school calendar. I am conducting research for a Doctor of Education Degree at the University of South Africa (UNISA). My research topic is *"Exploring the use of computer simulations as reasoning tool in the teaching and learning of electromagnetism"*.

The process will involve writing a pre-post test, lesson observation and focus group discussions with grade 11 learners about their learning experiences in learning *electromagnetism*. The assessment task will take about 45 minutes. I also intend to involve some of the learners in focus group discussion for about one hour. Learners who do not wish to take part in the study and those whose parents do not want them to be part of the study will be excluded from these sessions. However, alternative arrangements will be sought from these learners and their parents to ensure that I teach them this topic at their convenient time.

All information collected will be kept confidential and no names of participants will be identified in any report of this research. Learners are free to withdraw at any stage of the study. Allowing your child to be part of the study will benefit him/her in that I intend using generative instructional methods to teach the topic. These lessons will be conducted during school hours as this topic forms part of the Grade 11 new curriculum.

Attached is a consent form to be completed by the parents responding whether or not they would like their children to be part of this research project.

Thanking you in advance.

Yours faithfully,

....
Tsoka M

....

RETURN SLIP

CONSENT FORM

I, ___________________________ parent/guardian of the learner _______________________ in grade 11 hereby grant/do not grant permission for my child to be part of the Physical Sciences research project that will be conducted at school during the third term of the school calendar. I understand that his/her participation is voluntary and that he/she may withdraw at anytime if he/she no longer wishes to be part of the study.

Signature of Parent: _____________________ Date: ________________

Attention: The District Senior Manager.
Vhembe District: Department of Education
Private Bag X2250
Sibasa
0970

From: Mr M Tsoka,
P. O. Box 350
Dzanani ,0955

Dear Sir/Madam,

Re: Request for permission to conduct a research in Nzhelele west circuit

I, Maxwell Tsoka, hereby requesting for a permission to conduct a research study in Nzhelele West circuit.
This information will be solely used for conducting a research for the Doctor of Education (Didactics) degree at the University of South Africa (UNISA). My research topic is *"Exploring the use of computer simulations as reasoning tool in the teaching and learning of electromagnetism"*. I am requesting permission to use facilities and involve Grade 11 learners at Patrick Ramaano Secondary School.

This research is conducted under the supervision of Prof Jeanne Kriek at the Institute of Science and Technology Education at UNISA. Any questions regarding this research can be directed to me or my supervisor through the following contacts.

Prof Jeanne Kriek,
Institute of Science & Technology Education,
UNISA.
Tel: 012-337 6017
Email:kriekj@unisa.ac.za

Mr. Tsoka M,
Student no: 4534-111-7
Mobile: 073 450 8277
Email: maxwelltsoka@yahoo.com

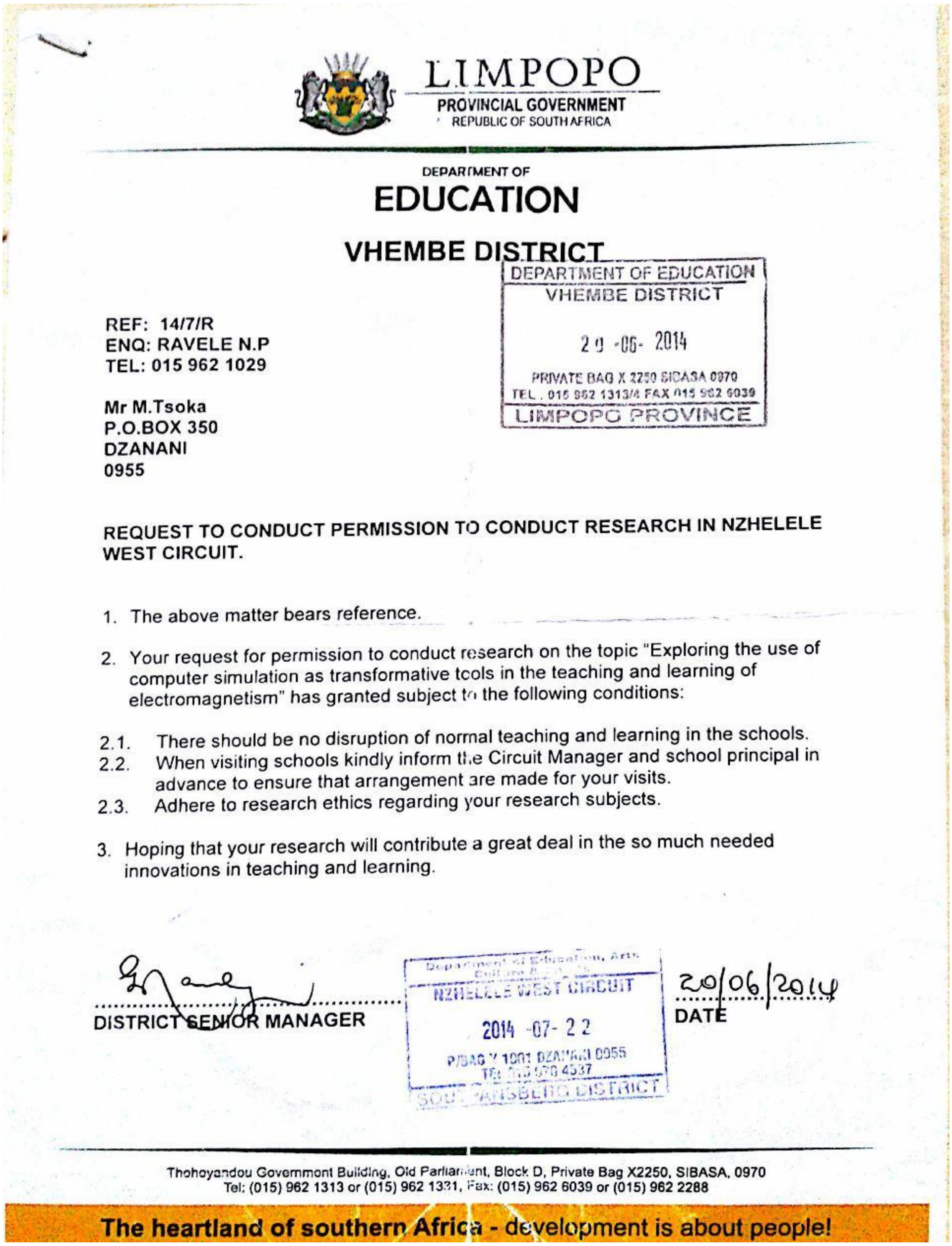
Thank you in advance in anticipation of favourable response.

Yours Sincerely

…………………………………

Tsoka Maxwell

Appendix 1C Letter of approval from the Department of Education



LIMPOPO
PROVINCIAL GOVERNMENT
REPUBLIC OF SOUTH AFRICA

DEPARTMENT OF
EDUCATION

VHEMBE DISTRICT

DEPARTMENT OF EDUCATION
VHEMBE DISTRICT
20 -06- 2014
PRIVATE BAG X 2250 SIBASA 0970
TEL. 015 962 1313/4 FAX 015 962 6039
LIMPOPO PROVINCE

REF: 14/7/R
ENQ: RAVELE N.P
TEL: 015 962 1029

Mr M.Tsoka
P.O.BOX 350
DZANANI
0955

REQUEST TO CONDUCT PERMISSION TO CONDUCT RESEARCH IN NZHELELE WEST CIRCUIT.

1. The above matter bears reference.
2. Your request for permission to conduct research on the topic "Exploring the use of computer simulation as transformative tools in the teaching and learning of electromagnetism" has granted subject to the following conditions:

2.1. There should be no disruption of normal teaching and learning in the schools.
2.2. When visiting schools kindly inform the Circuit Manager and school principal in advance to ensure that arrangement are made for your visits.
2.3. Adhere to research ethics regarding your research subjects.

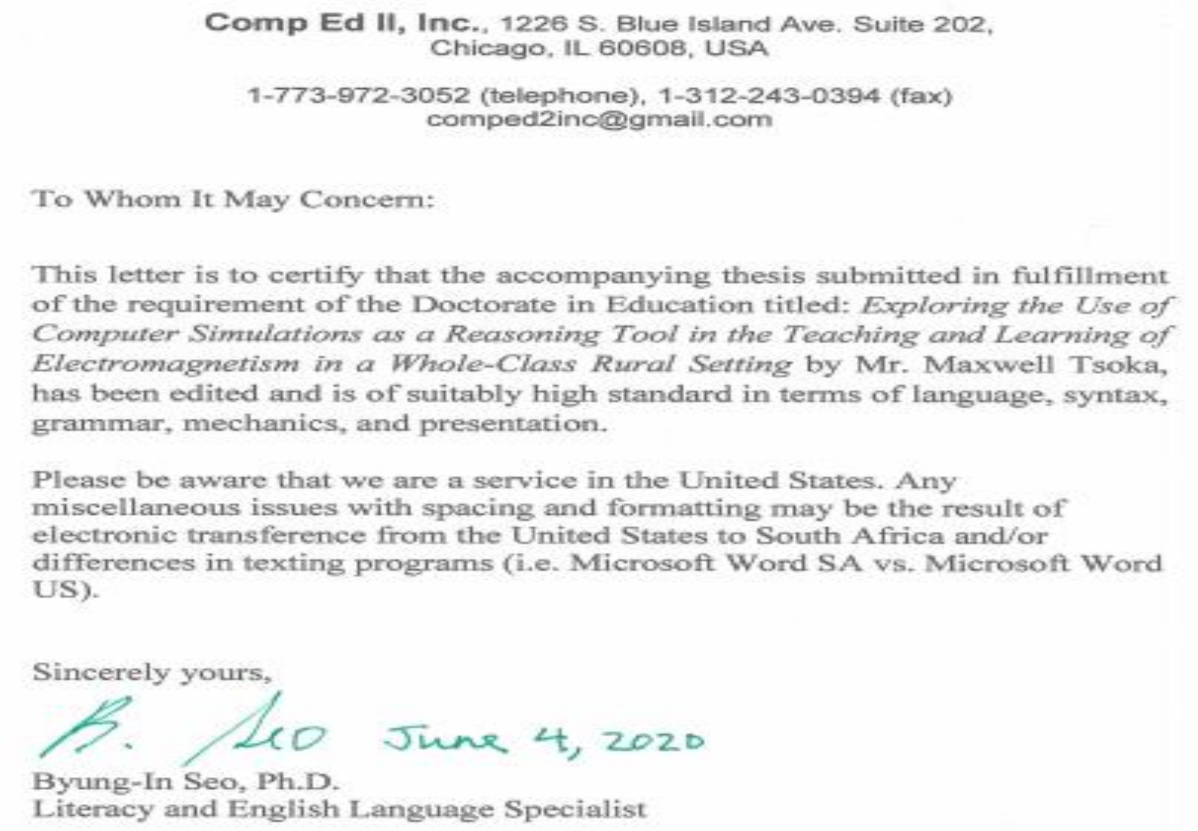
3. Hoping that your research will contribute a great deal in the so much needed innovations in teaching and learning.

DISTRICT SENIOR MANAGER

Department of Education, Arts, Culture & [illegible]
NZHELELE WEST CIRCUIT
2014 -07- 22
P/BAG X 1001 DZANANI 0955
TEL: 015 970 4537
SOUTPANSBERG DISTRICT

20/06/2014
DATE

Appendix 1D English language edit certificate



Comp Ed II, Inc., 1226 S. Blue Island Ave. Suite 202,
Chicago, IL 60608, USA

1-773-972-3052 (telephone), 1-312-243-0394 (fax)
comped2inc@gmail.com

To Whom It May Concern:

This letter is to certify that the accompanying thesis submitted in fulfillment of the requirement of the Doctorate in Education titled: *Exploring the Use of Computer Simulations as a Reasoning Tool in the Teaching and Learning of Electromagnetism in a Whole-Class Rural Setting* by Mr. Maxwell Tsoka, has been edited and is of suitably high standard in terms of language, syntax, grammar, mechanics, and presentation.

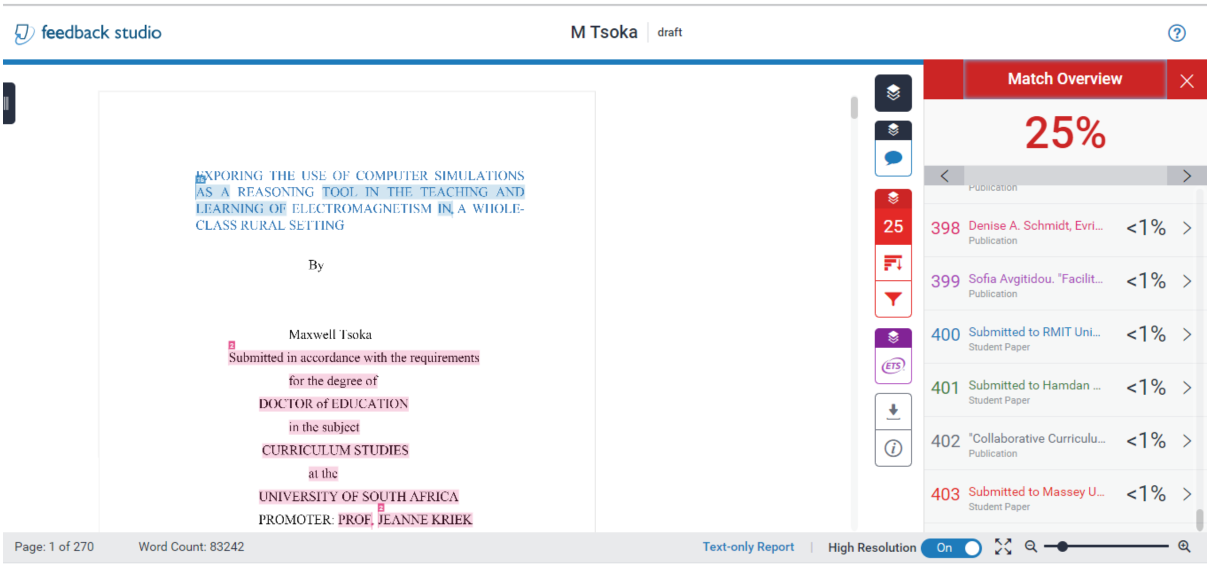
Please be aware that we are a service in the United States. Any miscellaneous issues with spacing and formatting may be the result of electronic transference from the United States to South Africa and/or differences in texting programs (i.e. Microsoft Word SA vs. Microsoft Word US).

Sincerely yours,

B. Seo June 4, 2020

Byung-In Seo, Ph.D.
Literacy and English Language Specialist

Appendix 1 E Turnitin Report



EXPORING THE USE OF COMPUTER SIMULATIONS AS A REASONING TOOL IN THE TEACHING AND LEARNING OF ELECTROMAGNETISM IN, A WHOLE-CLASS RURAL SETTING

By

Maxwell Tsoka
Submitted in accordance with the requirements
for the degree of
DOCTOR of EDUCATION
in the subject
CURRICULUM STUDIES
at the
UNIVERSITY OF SOUTH AFRICA
PROMOTER: PROF. JEANNE KRIEK

25%

398	Denise A. Schmidt, Evri... Publication	<1%
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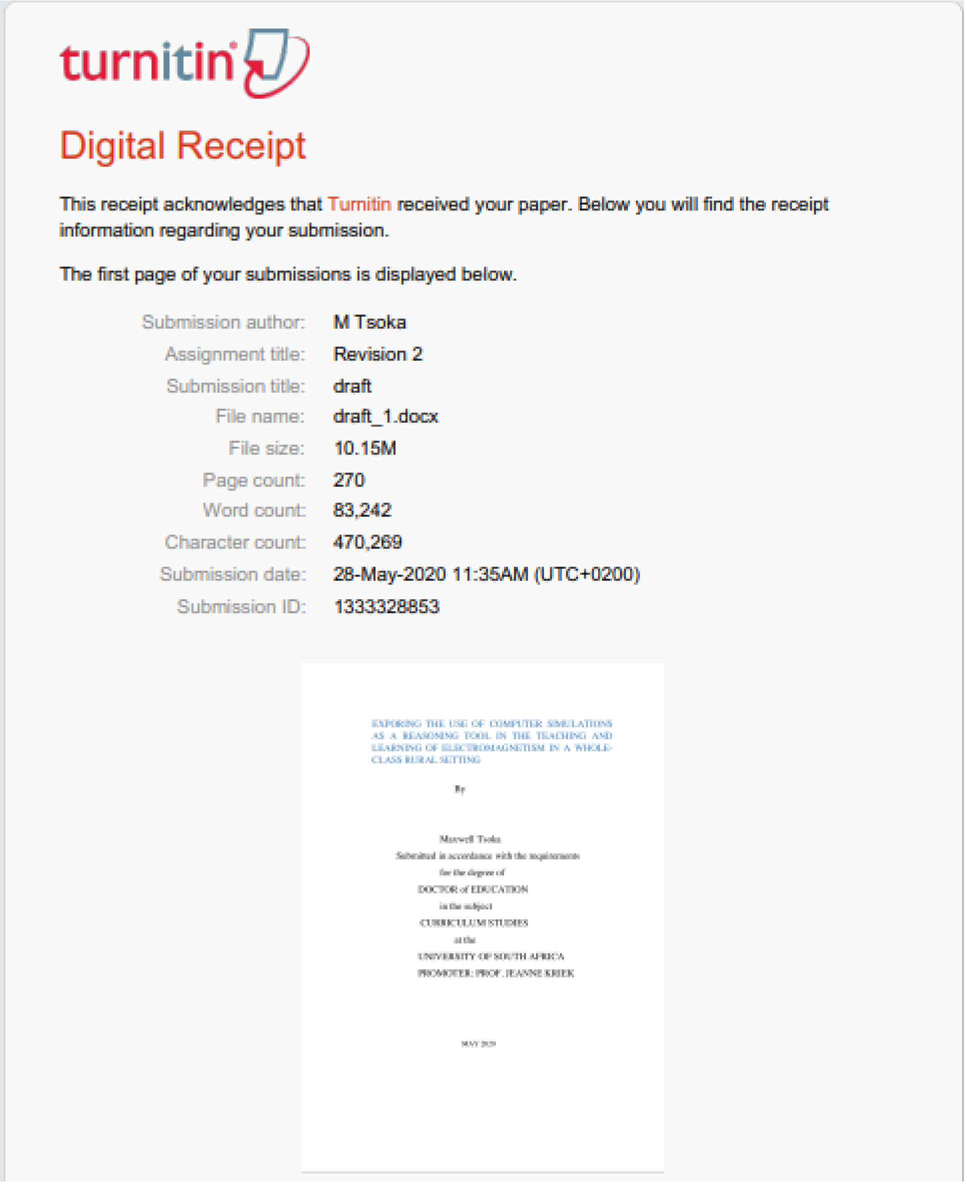

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Submission ID:	1333328853

EXPORING THE USE OF COMPUTER SIMULATIONS AS A REASONING TOOL IN THE TEACHING AND LEARNING OF ELECTROMAGNETISM IN A WHOLE-CLASS RURAL SETTING

By

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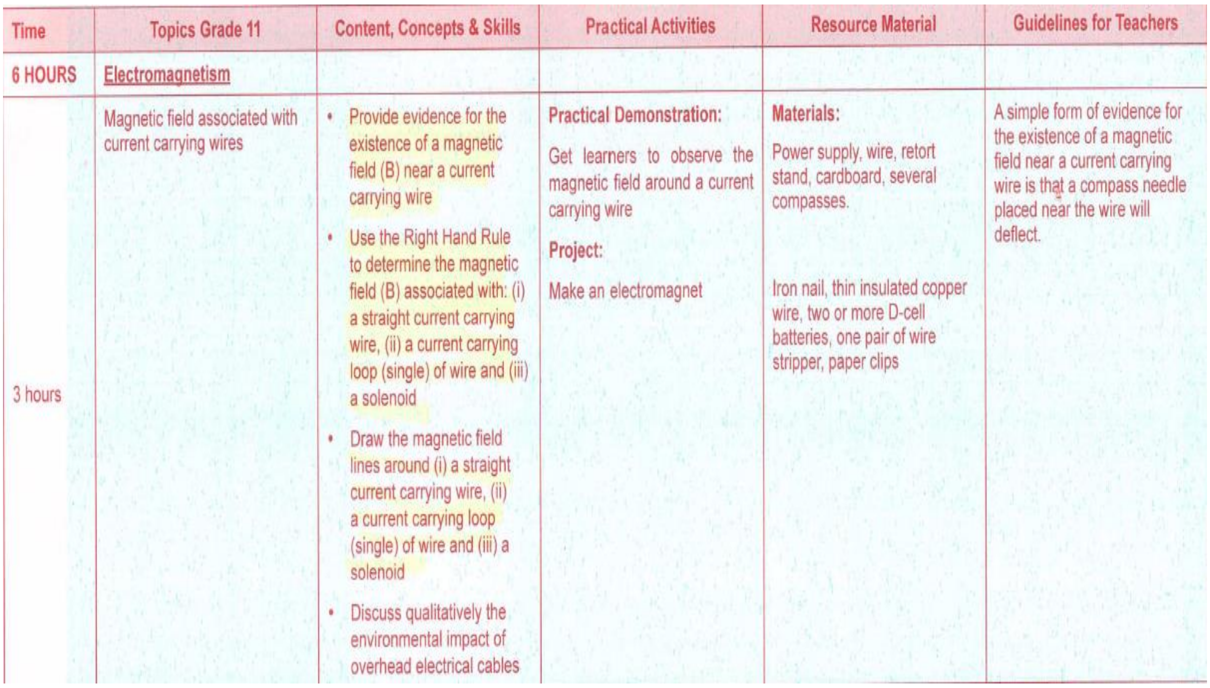
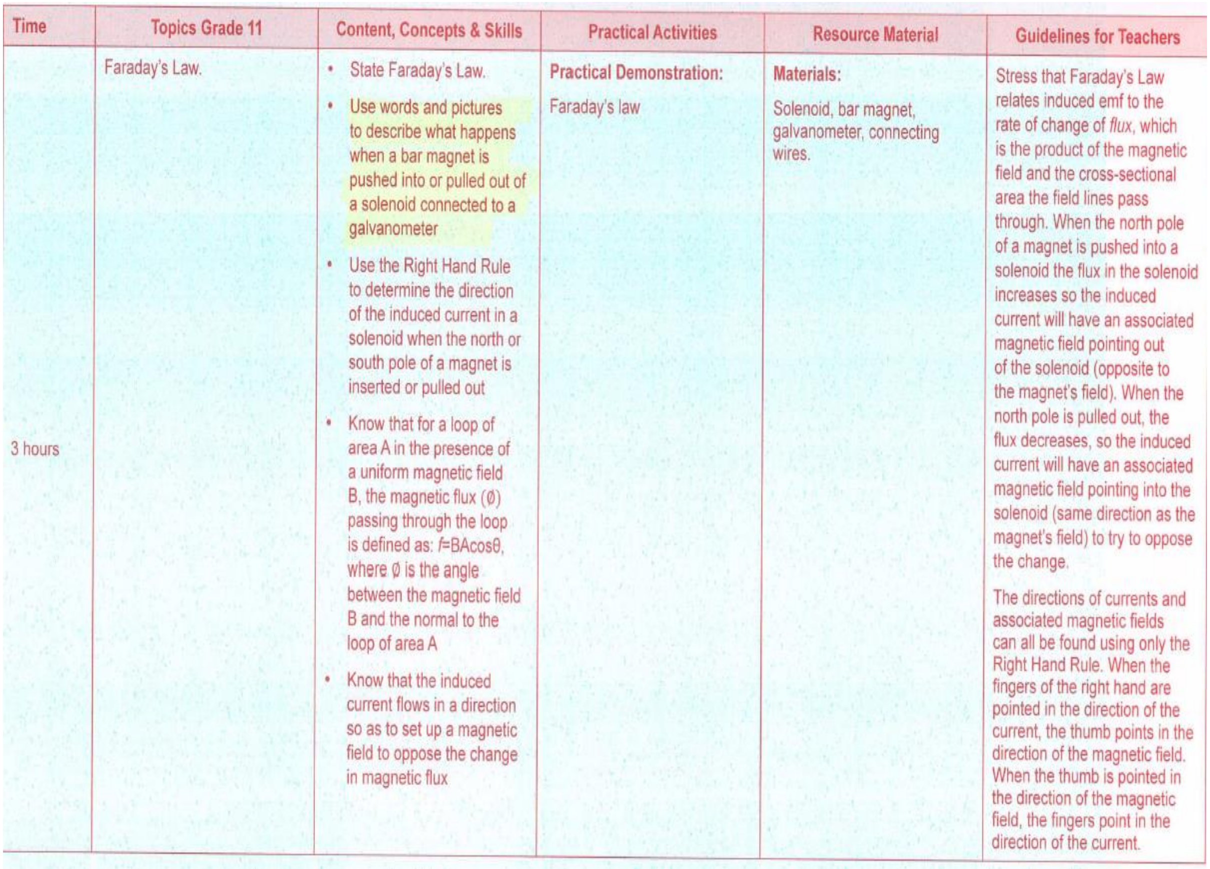
PROMOTER: PROF. JEANNE KRIEK

MAY 2020

Appendix 2 Curriculum statement



Time	Topics Grade 11	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
6 HOURS	**Electromagnetism**				
3 hours	Magnetic field associated with current carrying wires	• Provide evidence for the existence of a magnetic field (B) near a current carrying wire • Use the Right Hand Rule to determine the magnetic field (B) associated with: (i) a straight current carrying wire, (ii) a current carrying loop (single) of wire and (iii) a solenoid • Draw the magnetic field lines around (i) a straight current carrying wire, (ii) a current carrying loop (single) of wire and (iii) a solenoid • Discuss qualitatively the environmental impact of overhead electrical cables	**Practical Demonstration:** Get learners to observe the magnetic field around a current carrying wire **Project:** Make an electromagnet	**Materials:** Power supply, wire, retort stand, cardboard, several compasses. Iron nail, thin insulated copper wire, two or more D-cell batteries, one pair of wire stripper, paper clips	A simple form of evidence for the existence of a magnetic field near a current carrying wire is that a compass needle placed near the wire will deflect.



Time	Topics Grade 11	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
3 hours	Faraday's Law.	• State Faraday's Law. • Use words and pictures to describe what happens when a bar magnet is pushed into or pulled out of a solenoid connected to a galvanometer • Use the Right Hand Rule to determine the direction of the induced current in a solenoid when the north or south pole of a magnet is inserted or pulled out • Know that for a loop of area A in the presence of a uniform magnetic field B, the magnetic flux (Ø) passing through the loop is defined as: $f=BA\cos\theta$, where Ø is the angle between the magnetic field B and the normal to the loop of area A • Know that the induced current flows in a direction so as to set up a magnetic field to oppose the change in magnetic flux	**Practical Demonstration:** Faraday's law	**Materials:** Solenoid, bar magnet, galvanometer, connecting wires.	Stress that Faraday's Law relates induced emf to the rate of change of *flux*, which is the product of the magnetic field and the cross-sectional area the field lines pass through. When the north pole of a magnet is pushed into a solenoid the flux in the solenoid increases so the induced current will have an associated magnetic field pointing out of the solenoid (opposite to the magnet's field). When the north pole is pulled out, the flux decreases, so the induced current will have an associated magnetic field pointing into the solenoid (same direction as the magnet's field) to try to oppose the change. The directions of currents and associated magnetic fields can all be found using only the Right Hand Rule. When the fingers of the right hand are pointed in the direction of the current, the thumb points in the direction of the magnetic field. When the thumb is pointed in the direction of the magnetic field, the fingers point in the direction of the current.

Appendix 3 Pace setter

2019 PACE SETTER GRADE 11

PHYSICAL SCIENCES

TERM ONE (12 Weeks): 7 JAN 2018 – 28 MARCH 2018							
Calendar Week Number	**Knowledge Area**		**Topics**	**Time-frame (CAPS Teaching)**	**Date**		**Comments**
					Started	**Completed**	
3	Schools Re-Open on 15 January 2018 and Teaching Starts 17 January 2018						
3 – 9	Mechanics		Vectors in Two Dimensions (4 hours)				
		*	Resultant of perpendicular vectors	2 hrs			
		*	Resolution of a vectors into its parallel and perpendicular components	2 hrs			
			Newton's Laws and Applications of Newton's Laws (23 hours)				
		*	Different kinds of forces: normal force, frictional force, applied (pull, push), tension (strings or cables)	5 hrs			
		*	Force diagrams, free body diagrams	3 hrs			
		*	Newton's first, second and third laws	11 hrs			
		*	Newton's Law of Universal Gravitation	4 hrs			
10 – 13	**Matter and Materials**		Atomic Combinations: Molecular Structure (6 hours)				
		*	A chemical bond (seen as the net electrostatic force two atoms, sharing electrons, exert on each other)	2 hrs			
		*	Molecular shape as predicted using the Valence Shell Electron Pair Repulsion (VSEPR) Theory	2 hrs			
		*	Electronegativity of atoms to explain the polarity of bonds	1 hr			

		*	Bond energy and bond length	1 hr			
		Intermolecular Forces (10 hours)					
		*	Intermolecular and interatomic forces (chemical bonds); physical states and density explained in terms of these forces; particle kinetic energy and temperature	6 hrs			
		*	The density of water (Macroscopic properties of the three phases of water related to their sub-microscopic structure)	4 hrs			

Formal Assessment to include Experiment 1 + Formal Test 1

Informal Assessment to be on a daily basis and to include tests after each topic and experiments (refer to Program of assessment)

Formal Test 1 Date: 19 March 2018 / Practical Test 1 Date: 05 March 2018)

13 – 15	**School holidays: 29 March 2018 – 09 April 2018**

TERM TWO (11 Weeks): 10 APRIL 2018 – 22 JUNE 2018

Calendar Week number	**Knowledge Area**	**Topics**		**Time-frame (Teaching)**	**Date**		**Comments**
					Started	**Completed**	
16 – 19	Waves, Sound & Light	Geometrical Optics (10 hours)					
		*	Refraction	3 hrs			
		*	Snell's Law	4 hrs			
		*	Critical angles and total internal reflection	3 hrs			
		3D and 2D Wavefronts (3 hours)					
		*	Diffraction	3 hrs			
19 – 20	M at	Ideal Gases and Thermal Properties (8 hours)					

		*	Motion of particles; kinetic theory of gases	1 hr			
		*	Ideal gas law	6 hrs			
		*	Temperature and heating; pressure	1 hr			
21 – 23	Chemical Change	Quantitative Aspects of Chemical Change (12 hours)					
		*	Molar volume of gases; concentration of solutions	3 hrs			
		*	More complex stoichiometric calculations	6 hrs			
		*	Volume relationships in gaseous reactions	3 hrs			
24 – 26	**MID-YEAR EXAMINATION (± 3 Weeks)** **Practical Test 2 : 25 May 2018** **Paper 1: 08 June 2018 AND Paper 2: 11 June 2018**						
Formal Assessment to include Experiment 2 + Mid-year Exam (refer to Programme of Assessment) **Informal Assessment to be on a daily basis and to include tests after each topic and experiments (refer to Programme of Assessment)**							
26 – 28	**School holidays: 23 June 2018 – 16 July 2018**						
TERM THREE (10 Weeks): 17 JULY 2018 – 28 SEPT 2018							
Calendar Week number	**Knowledge Area**	**Topics**		**Time-frame (Teaching)**	**Date**		**Comments**
					started	**completed**	
29 – 34	Electricity and Magnetism	Electrostatics (6 hours)					
		*	Coulomb's law	3 hrs			
		*	Electric field	3 hrs			
		Electromagnetism (6 hours)					
		*	Magnetic field associated with current carrying wires	3 hrs			

		*	Faraday’s law	3 hrs			
		Electric Circuits (8 hours)					
		*	Ohm’s law	4 hrs			
		*	Power; energy	4 hrs			
35 – 39	Chemical Change	Energy and Chemical Change (4 hours)					
		*	Energy changes in reactions related to bond energy change	2 hrs			
		*	Exothermic and endothermic reactions	1 hr			
		*	Activation energy	1 hr			
		Types of Reactions (6 hours)					
		*	Acid-base reactions	6 hrs			

Formal Assessment to include a Research Project + Control Test 2

Informal Assessment to be on a daily basis and to include tests after each topic and experiments (refer to Programme of Assessment)

Formal Test 2 Date: 17 September 2018 / Research Task Submission Date: 03 March 2018

40	

TERM FOUR (9 Weeks): 09 OCT 2018 – 14 DEC 2018

Calendar Week number	Knowledge Area	Topics		Time-frame (Teaching)	Date		Comments
					started	completed	
41 – 42	Chemical Change	Types of Reactions (6 hours)					
		*	Redox reactions	5 hrs			
		*	Oxidation number of atoms in molecules to explain their relative “richness” in electrons	1 hrs			
43 – 45	Chemical Systems	Exploiting the Lithosphere or Earth’s Crust (8 hours)					
		*	Mining and mineral processing: gold; iron; phosphate	8 hrs			

Appendix 4A Lesson plan for lesson one

Lesson Plan 1

Topic: Magnetic field around current-carrying conductor

Objectives

1. Learners should construct a simple model of magnetic field around a current-carrying conductor
2. Learners should use the field model to explain the action of an electromagnet

Assumed knowledge

Learners are familiar with magnets, current, voltage/emf

Teaching plan

Introduction

Demonstration

Group/Class discussion

Conclusion

Stage	Teaching- Learning Activity	Skills intended to be developed
Warm-up activity (10 mins)	To introduce learners to the concept of magnetic field, the educator will take a large iron nail with many turns of wires and connected to a cell. The educator will ask the learners what happens when the iron nail is brought near iron fillings/paper clips. Learners record their observations. The educator disconnects the wire from the cell and try to pick up the iron fillings/paper clips. The learners should explain their answers The educator asks learners to describe factors affecting the strength of a temporary magnet	Making and recording observations Communicating evidence Formulating and using models to explain the attraction of the iron filling by the nail Predicting/Hypothesising

Main Activity (30 mins)	The educator shows the computer simulations (PHET, TEAL) of magnetic fields around a straight conductor, loop and solenoid. The learners are to observe the spatial arrangement of the fields and respond to questions like: What is the nature of the field?; Is it a uniform or non-uniform field? What is responsible for creating the field? What is the relationship between the interacting variables? What purpose is served by winding the conductor into many loops? What is the effect of changing the direction of the current on the magnetic field Learners to use the 'right hand thumb rule' to determine the direction of the magnetic field	Making and recording Observations Visual thinking Communicating Identifying and controlling variables Predicting Formulating models
Group work (15 mins)	Learners are presented with a worksheet 1 to complete	The activity was not completed and bad on the activity
Conclusion (5mins)	Educator projects a summary of the lesson using power point and learners take notes	

Appendix 4B Lesson plan for lesson two

Topic: Electromagnetic Induction

Objectives

3. Learners should be able to use the field model to explain electromagnetic induction

4. State the variables that affect the magnitude of the induced emf

Assumed knowledge

Learners are familiar with magnetic fields

	Teaching-Learning Activity	Skills intended to be developed	Comments/Reflections
Warm-up activity (15mins)	The educator introduces the topic by giving the learners the following task: You are given the following materials and required to draw a circuit that will cause the bulb to light Explain the physics behind the working of the bulb	Problem solving Hypothesising Identifying and controlling variables Formulating models	The activity was a bit challenging to learners and provided evidence of the mental models that learners hold to this topic. Many learners were convinced that it was necessary to have a cell/battery in order to light the bulb hence in many diagrams they represented the magnet as the source of electricity in the same

			way that a cell/battery operates. The activity took about 30 minutes instead of the planned 15 minutes
Main activity (30 mins)	The educator demonstrates using the PHET simulations electromagnetic induction. Learners respond to questions like: What happens to the bulb as the magnet is moved relative to the solenoid? What happens when the magnet is held stationary inside the solenoid? What happens when the magnet is moved away from the solenoid? Can you explain the observations?	Observations Communicating evidence Visual thinking Identifying and controlling variables Hypothesising Formulating models	This activity was intriguing. The learners did not believe what they were seeing. A number suggested that they will only believe if they see it with their own eyes. However learners were engaged in the activity
Group discussion (10 mins)	Learners are to work in groups of five as they complete Worksheet 2	The activity was badly done. It was given as homework for learners to go and finish at home	
Conclusion (5mins)	Educator project a summary of the lesson on the screen using PowerPoint		

Appendix 5 RTOP

RTOP: Reformed Teaching Observation Protocol

Teacher Candidate: TSOKA M
Observer: MUSONZA H.K.
Grade Level: 11 Date of Observation: 2017

Lesson Plan & Implementation

	Never Occurred			Very Descriptive	
1.) Instructional strategies and activities respected students' prior knowledge and the preconceptions inherent therein.	0	1	2	3	[✓ 4]
2.) The lesson was designed to engage students as members of a learning community.	0	1	2	3	[✓ 4]
3.) In this lesson, student exploration preceded formal presentation.	0	1	2	[✓ 3]	4
4.) This lesson encouraged students to seek and value alternative modes of investigation or of problem solving	0	1	2	[✓ 3]	4
5.) The focus and direction of the lesson was often determined by ideas originating with students.	0	1	2	[✓ 3]	4

Content

		Never Occurred			Very Descriptive	
Propositional	6.) The lesson involved fundamental concepts of the subject.	0	1	2	3	[✓ 4]
	7.) The lesson promoted strongly coherent conceptual understanding.	0	1	2	[✓ 3]	4
	8.) The teacher had a solid grasp of the subject matter content inherent in the lesson.	0	1	2	3	[✓ 4]

	9.) Elements of abstraction (i.e., symbolic representations, theory building) were encouraged where it was important to do so.	0	1	2	[✓ 3]	4
	10.) Connections with other content disciplines and/ or real world phenomena were explored and valued.	0	1	2	[✓ 3]	4
Procedural Knowledge	11.) Students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.	0	1	[✓ 2]	3	4
	12.) Students made predictions, estimations and/or hypotheses and devised means for testing them.	0	1	[✓ 2]	3	4
	13.) Students were actively engaged in thought-provoking activity that often involved the critical assessment of procedures.	0	1	2	[✓ 3]	4
	14.) Students were reflective about their learning.	0	1	2	[✓ 3]	4
	15.) Intellectual rigor, constructive criticism, and the challenging of ideas were valued.	0	1	2	[✓ 3]	4

Classroom Culture

		Never Occurred			Very Descriptive	
Communicative Indicators	16.) Students were involved in the communication of their ideas to others using a variety of means and media.	0	1	2	3	[✓ 4]
	17.) The teacher's questions triggered divergent modes of thinking.	0	1	2	3	[✓ 4]
	18.) There was a high proportion of student talk and a significant amount of it occurred between and among students.	0	1	2	3	[✓ 4]
	19.) Student questions and comments often					

	determined the focus and direction of classroom discourse.		0	1	2	3	[✓ 4]
	20.) There was a climate of respect for what others had to say.		0	1	2	3	[✓ 4]
Student/ Teacher Relationships	21.) Active participation of students was encouraged and valued.		0	1	2	3	[✓ 4]
	22.) Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence.		0	1	2	[✓ 3]	4
	23.) In general the teacher was patient with students.		0	1	2	3	[✓ 4]
	24. The teacher acted as a resource person, working to support and enhance student investigations.		0	1	2	3	[✓ 4]
	25.) The metaphor "teacher as listener" was very characteristic of this classroom.		0	1	2	3	[✓ 4]

Feedback

Groups at the end could have been more organized to improve interaction and more effective communication.

Terms

Loop ,Solenoid, Right hand rule Fig 4i for straight wire, Right hand rule for solenoid,Tesla

Objective

To study the magnetic fields set up by a current through a straight wire, a flat coil and a solenoid

1. The field lines around a straight wire are ____________. Figures 4g and 4h show the directions of magnetic field patterns. The dot or cross symbols represent the current directions.
2. Note that the B-field is the _____________ (strongest/weakest) close to the wire. Therefore, the field lines are closer near the wire.
3. The directions of current and B-field can be worked out with the ____________________________________for straight wire

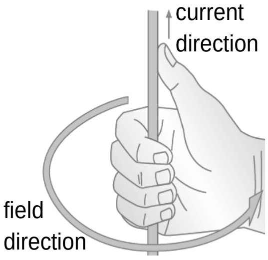


Fig 4i

> If the right hand grips the wire so that the thumb points the same way as the _____________, the fingers curl in the same way as the ____________________.

4. The B-field around a wire has the following properties:

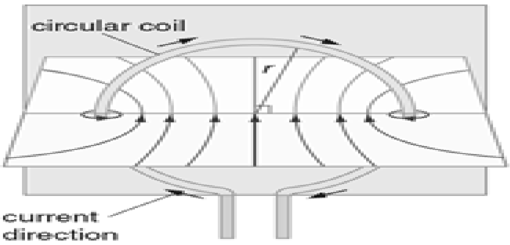
i The field lines are _______________ around the wire.

ii The B-field is the _______________ close to the wire.

iii Increasing the current makes the B-field _______________.

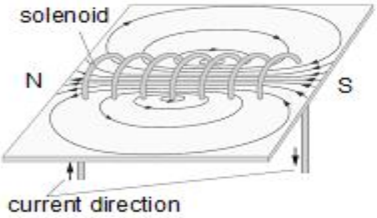
iv Reversing the current reverses the direction of the field lines, but the field pattern ____________________________.

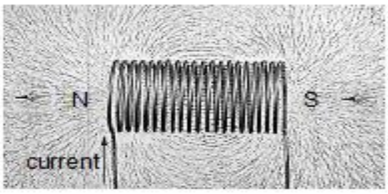
5. The field lines at the centre of a flat circular coil are _____________ and at right angles to the plane of the coil. Outside the coil, they run in ______________



6. i inside the solenoid, field lines are ____________ and ___________________ ⇒ uniform field

ii outside the solenoid, the pattern is similar to that of a bar magnet.





7. The poles of the solenoid can be worked out using the ____________________ for solenoid (Fig 4m).

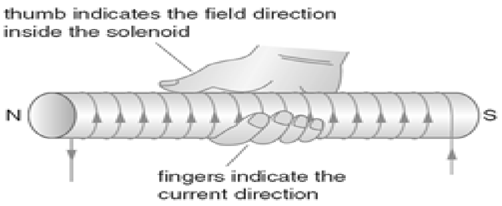


Fig 4m

If the right hand grips the solenoid so that the fingers curl in the same way as the_______________, the thumb points the same way as the ___________________ inside the solenoid.

8. The B-field of the solenoid can be increased by
   i ____________ the current,
   ii ____________ the no. of turns in the solenoid (for the same length of solenoid),
   iii inserting a __________________ through the solenoid.

9. If we make an object behave like a magnet, the object is called __________________. If we make an object no longer behave like a magnet, we say that it is __________________.

Appendix 7 GROUP WORK

APPLICATION OF ELECTROMAGNETS

Study the pictures below

Figure 0.1. An electromagnet used to lift a container from a goods train

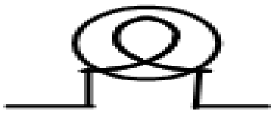
- An electromagnet being used to pick up scrap

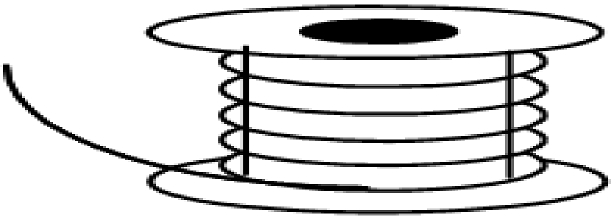
Figure 0.2

Can you explain how the electromagnets works in both diagrams? Can you draw an electrical schematic circuit diagram showing the electromagnet, electrical power supply and wiring necessary for this to work. Also include a switch so the crane operator can turn the magnet on and off.

Appendix 8 WARM UP ACTIVITY

You are given the following materials: coil of wire (solenoid), magnet and bulb and connecting wires. Is it possible to make the bulb light? If yes can you make a diagram of the circuit that will light the bulb? Give an explanation of your diagram


Bulb

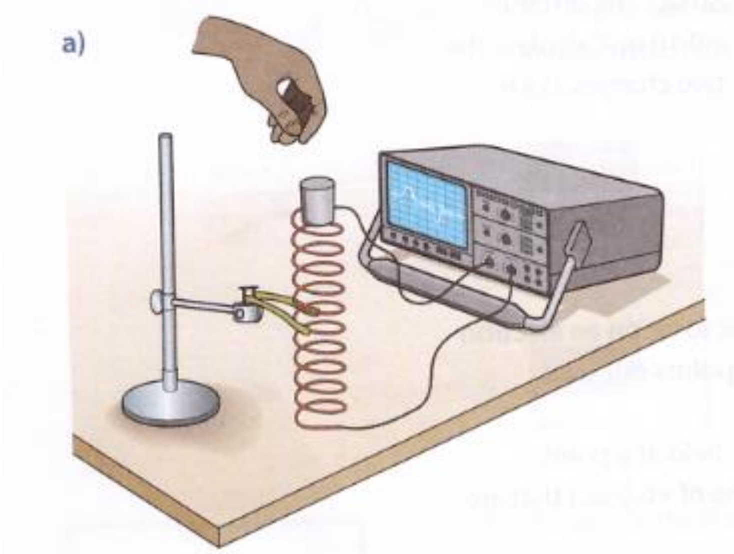

Coil of wire

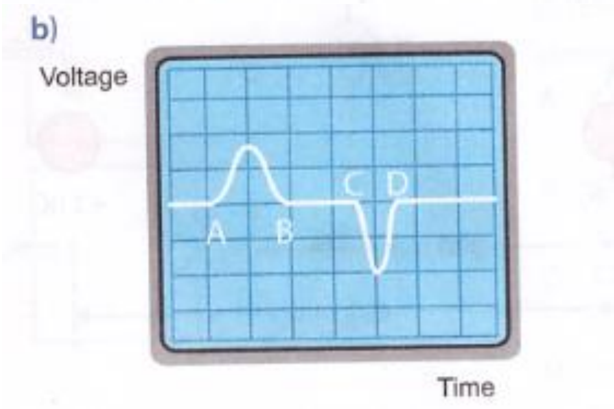
Magnet

Appendix 9 **WORKSHEET 2**

Attempt the following questions

A magnet is dropped and falls vertically through the solenoid. An oscilloscope (CRO) connected to the solenoid shows the emf induced in the solenoid. The oscilloscope traces shows how the emf that is induced in the coil varies as the magnet accelerates downwards.





(1) Explain why an emf is induced in the coil as the magnet enters it (section AB of the trace) /3

(2) Explain why no emf is induced while the magnet is entirely inside the coil (section BC) /2

(3) Explain why section CD shows a negative trace /2

(4) Explain difference in the relative magnitudes of the two peaks /3

(5) Explain why CD represents a shorter time interval than AB? /3

Appendix 10

REVIEW OF LESSON NUMBER 1

DEMONSTRATION: The demonstration was very good and helped draw learners' attention. The teacher let the learners observe and came up with their own ideas about the lesson without much of leading them. The demonstration made the learners participate.

LESSON:

5. **INTERACTION WITH LEARNERS:** The interaction was very good and led to better understanding of concepts. The learners really constructed the knowledge and it will not be easy to forget whatever was learnt in that particular lesson. Most of the talking was done by learners and the teacher provided guidance. The teacher constantly referred to the observations made by the learners.
6. **THE USE OF TECHNOLOGY:** The use the projector helped draw learners' attention. They were focused on the subject matter throughout the lesson. The summary provided in through the power point presentation was good. It serves on time. The teacher focuses on explaining concepts rather than writing on the board.

CONCLUSION: The conclusion was drawn and linked very well with learners' observations and contributions. Important points were noted and expanded on the board.

Appendix 11

An example of a transcribed focus group discussion number 1

Interviewer : Ok can you please tell me about the experiences of lesson we had from now

Interviewee : ok this was a wonderful experience, it taught me a lot but most of things that it taught me I used to observe them, people doing them, and as I was a kid we used to do some of the things but I didn't know that what I was doing was science. I just knew that if I am playing with a magnet, it just a magnet, if I bring it to maybe a coil or something, it had a repulsive force I just thought that maybe it is something which is a miracle because I didn't know more about science, but this lesson has taught me that, this magnet being put towards a north pole or a north pole being towards a north pole there is a repulsion force and north pole and south pole there is attraction force. I have learnt a lot, and the things that I wanted this thing to be done in a way, we don't have more of the equipment that we needed to perform all those experiments, but as my teacher tried to elaborate on them on his computer and things like that… It will be much fun or much more of experimental if we have observed it by our eyes, because whatever you observe by your eyes never goes and whatever you touch and do by yourself, you can never forget that. So if we have all those equipment on that experiment I could have done better but even now even though we didn't have the opportunity to do all the things by ourselves, he tried his best so that we can understand and I understood a lot about electro-magnetism and I have seen that it is a very interesting topic, it needs someone who is so dedicated towards his studies.

Interviewee2 : As the previous speaker has already discussed about attraction and what, I won't repeat. I too I have learnt a lot about electro-magnetism, I didn't believe that electricity can be generated in many things except water, wind which they are normal, everyone know that. About electricity being induced by generator it was my first time I heard about such thing, but maybe I have already used it in some cases without knowing it, but our teacher here tried to make us understand, but I urge with him one day he brings something that have a got a small generator, the bulb and he start winding, riding this thing like a bicycle because it got gears then it start to produce current and I see a bulb lightening. I start to believe that is not all the time that electricity can be generated by battery or just electricity from Eskom, this lesson was very good, because we were observing something we don't know, I don't know much about this lesson up to here. I think It was very good and we are still going to learn more and I can now calculate everything about electricity, at home I can stop them when they are using much electricity because we now know how to calculate the cost of electricity, yah! I have learnt a lot.

Interviewer : Oh you have learnt a lot. Talk about lesson. What exactly made you to understand? That's what I want you to talk about, feel free this is not exam where maybe you are going o be punished, this is suppose to be fun. Feel free. Say whatever you want

Interviewee2: Ah ok this lesson taught us a lot, we never knew that magnet can induce current and that current can be induced by magnetism, so it really taught us a lot. Now we know that maybe if we want a magnet, and we don't have a magnet we use current to induce magnet. Now we know that generator has a magnet, we never knew all this. Yah that day when you came with those things of yours, the generator and the bulb, then you start using it then it taught us that we can use a generator to induce magnetism and to induce electricity.

Interviewer: Talk about simulations. Let’s talk about those simulations.

Interviewee2: Ok mmh! At first when you brought those things I didn’t understand what was going on. I think It took me something like a week to realise that when a magnet is moving towards a coil current appears, so those simulation. I think they were accurate.

Intervieweee3: I think the lesson was the best

Interviewer : Why do say was the best?

Interviewee3 : Because the best will always be the best.

Interviewer : No! Do you think you understand the lesson?

Interviewees : Yes

Interviewer : What I want you to tell me is that what made you to understand the lesson?

Interviewee : At first I didn’t understand the topic until you came with those things and then you have to show us what happens when the magnet is moved towards the coil, that current flow then I understand better the lesson than I used to. When we did that practical the lesson mmh, I get interested in what happens in most cases when electricity is generated in many not just in the lesson but you took us also the other way such as hydro-electricity that happens.

Interviewee1 : I think at first when you brought those simulations, I didn’t believe them I was just like these are the simulations that were made by scientists. There is no such thing, the one that I didn’t believe most was that one, and there was a magnet which was being brought close to the coil and bulb started lightening, and I was like how come there is no battery there is nothing. How could such thing happening but as you kept on like telling us, magnet can induced current which that there is a possibility of bulb lightening. Yah I enjoyed the lesson a lot because you also made it possible to bring thing that we can observe what you were saying through those simulations. Most of us didn’t believe that the simulation were true but as you brought that thing you were winding then the light started to glow that’s where I started to believe that those simulations were correct.

Interviewer : Ok, tell me if there is a difference in your learning in a class where there are no simulations and in a class where there are simulations. Does it affect your learning?

Interviewee : There is a big difference

Interviewer : Why do you say there is a big difference?

Interviewee : Eh difference is there because when you just teach theory when you don’t teach it practically some students, most of us we won’t understand because will just read and cram for just us to pass, but if you can make it practically then we can analyse that it is true we go and apply it in real life because like inducing the magnet from the current if you have lost a needle in the soil you can just go if you have a phone battery and a wire then you can induce the magnet, then you started looking for your needle , then the needle it get attracted to the magnet, then it will help you in real life. If it is not practically I think it will be difficult for people to pass or for people to understand.

Interviewer : You are saying that you can understand more if you see the things that you will be doing than for me to just come and say we going to talk about this.

Interviewee : Yes

Interviewer : Maybe in one or two words or three words, how would you describe this lesson that we did.

Interviewee : Fun, experimental, enjoyable and it is full of variety of things that we didn't believe, like it makes those who don't believe science to believe science. Yah that's where science comes from

Interviewee2 : Exciting, challenging and fun

Interviewer : Ok from those activities that we did, like the one that I did, after that task I gave you to do in a group and that other one I gave you before the lesson. Did you learn anything from those tasks? Was is it difficult?

Interviewee : Yah it was difficult, I remember that one of car, it works on scrapyards that magnet in car in scrapyard, like I didn't get it, I was lost, I was like what is happening, how can this be happening but as you explained it, I get to know that there was a current there flowing that's why the was magnitude that moves cars from one position to another

Interviewer : What will be your view, if all your subjects could be put these computers if there is a chance.

Interviewee : If all subjects it will be possible to be taught using computers, I think we could perform well, because what they teach now is theory we don't understand. We just say it's school work we just have to cram that and focus on that so that we can pass. But I think if they use computer to teach practically we can pass.

Interviewer : You can pass?

Interviewee 1 : Yes we can pass because computer is technology and nowadays this world is full of technology and if they were to use computers in every lesson we can manage to improve our results

Interviewee3 : Eh one thing is that if computers were used at school, I think these people who are leaving schools there will be a minimum number of them , no child will have that arrogance of leaving school because school will be fun, very fun, because everything you are being taught you gonna see it, when they are say this and that, if you add this and that you get this and you gonna see them and being done and being taught things you cannot see is like a dream, you just have to use it for the sake of you passing, that's why most learners drop out of school, because school subjects becomes boring because you have to learn more things, more things and theoretical things without getting that practical version. We just focus on books without understanding what is taught, like without seeing this, what is this, when is this being saying to be like this, how does it look like and I think that is the most way it can help learners at school, and another thing here is that if they are using computers, we can just take a video when a teacher is teaching so that when are at home when you didn't understand well, you can just play a video and see so that you can remember what you have forgotten. So using computer at school it will be of an advantage. A very good advantage because computers …

Interviewee : It will really help us because us learners we don't want to be taught but we want to see things by our eyes, so it will help us a lot because we love things such as technology. Using computers it will be really fascinating. It is really boring just sitting in class, listening to the teacher just teaching from the book and we like to see things for ourselves.

An except of a transcript of focus group discussion number 2

Interviewer : What I want you to tell me is the experience of the lesson. How did you see the lesson?

Interviewee : Lesson yo vha ya vhudi eh! Ndo vhona zwi khwine ngauri muthu u thoma u vha interested uri like kharali hu khou pfi experimental, like hezwila zwa galvanometer, I tshi deflecta ...magnet uri I vha I khou dzheniswa hani, ri vha ri sa khou sokou fuziwa nga maipfi fhedzi ri vha ri khou vhona. Zwi ita uri na rine ri pfe ri tshi zwi funa.

Interviewer : Tell me exactly what is the thing that helped you to understand the lesson

Interviewee : Zwithu zwone zwine zwi dzula zwi practical. Hu na zwinwe zwithu zwe nda zwi wana zwine zwa vha zwa vho ri nga heniela lesson zwo ngitisa uri ndi swike ndi this sedza mudagasi wa hayani u ne nda khou u shumisa u tshi bav hangei nthuni, hangei hu ne wa khou bva hoe, u bva u AC u tshi swika kha transformer wa step-down wav ha DC. Ndi this shumisa hayani u vha u DC. Then, na kha tshibogisi nda swika nda tsheka dzi voltmeter dze ne dzila, nda wana uri zwo nwala nga heneila ndila. So, zwo ngita uri ndi kone u talukanya uri ndi vha ndi khou shumisa mudagasi mufhio.

Interviewee2 : Ndo guda uri magnetic field kana eh current a I flow fhedzi kha magnet, fhedzi kha battery dzedzi na kha conducting wires.

Interviewee3 : Ndo guda uri hu na other ways ya u ita electricity besides u shumisa battery, and it can be a solution na mini mini.

Interviewer : Did you understand the topic of magnetism? You did right?

Interviewees : Yes

Interviewer : What made you to understand the topic?

Interviewee : For us to understand the topic was because of the practicals that we did.

Interviewer : By seeing them

Interviewee : Yes by seeing them, then it was easy for us to follow through and the example you made.

Interviewer : Basically what you are saying is that what helped it was seeing the things neh.

Interviewee : Yes by being taught we understand but by seeing them we understand much better

Interviewer : Then what do you think will be the experience if they were lack computer simulation

Interviewee1 : It will be hard because you will not understand, we will just cram go there in the exam and submit what we been taught

Interviewee2 : I believe it was better because we able to prove, about the laws which we are being taught about electricity by ourselves rather than for us to be told that they are true if they were done. Then, we will be able to do it by ourselves and we can be sure that this is true.

Interviewer : This means that you can confirm what you are taught and what you are seeing there agree. Ok now what do you think will be the experience of learning if computer were used in all the subjects. Do you think is necessary to use computer for your learning?

Interviewee3 : Yes

Interviewer : How?

Interviewee3 : Zwi do increase na pass rate

Interviewer : How do you think is going to increase the pass rate?

Interviewee3 : Ngauri vhana vha do vha vha khou kona u vhona zwithu zwine vha vha vha khou funziwa zwone, and vha si tsha tou cram. Vha do vha vha tshi vho tou understand.

Interviewee2 : Zwine nne nda vhona zwone ndi zwauri if hu khou shumiswa computer then it will be easy for us uri nwana a ng a kona u creata definition yawe because u khou kona u talutshedza uri hu khou itea mini, mara if ri khou sokou funziwa nga mulomo ri tou kombetshedzea ur ri tou cram ngeno ri sa khou understand.

Interviewer : Basically you are saying when you are using computer you are able to make sense about what you are being taught

Interviewee2 : Yes

Interviewer : So, maybe in one or two words what you can say about this lesson that we had

Interviewee2 : Interesting

Interviewer : What makes you think it they were interesting?

Interviewee2 : By seeing them, so it's different from just seeing tools from books and also projectors to see what happens and also inspired

Interviewer : Let's say one day you are going to be a teacher, how would you use those things? Where you going to use the same thing or you are not going to use them?

Interviewee1 : I will use them because it helped us a lot, because we can say learners what are you seeing right now, and they can try to explain because they are able to think. Then if you don't have that things then you have to teach and we have to take things as it is, but if we are doing practical's I can say I'm seeing and this.

Appendix 12

An example of a reflective journal

Lesson 1 – magnetic fields around current-carrying conductors

Date: August 2015

Time: 60 minutes

The goal of the lesson was to have learners construct a picture of the nature of the magnet field around a current carrying conductor. The lesson was for 60 minutes. The warm up activity captured the attention of the learners and even the observer. It seemed a very simple demonstration but presented challenges to learners. The learners attributed the attraction of the iron fillings to current. They were not able to recognise the effect of the magnetic field around the conductor as the cause of the attraction of the iron fillings. In trying to define magnetic field, learners were only referring to the magnet as the only one which has a magnetic field. However when demonstrating the magnetic field around a current-carrying conductor, learners were able to describe the field as consisting of concentric circles. I was able to elicit a response which l had not anticipated from the learners. One learner said that the field was not uniform since the circles were not equally spaced with the field lines near the conductor very close together while those far from the conductor were farther apart. He even suggested that the field was therefore stronger near the conductor while weak far away from the conductor. All the learners agreed with this description. Furthermore the simulation representations really worked to show learners that electric charges (electrons) are responsible for the magnetic field. I felt that the computer simulations l used to demonstrate the field around a solenoid was a bit difficult to understand because it was moving fast. The animation were not like the other two where learners could see the magnetic field lines clearly. What l did in stopping the simulations helped learners, somehow to see how the field around each loop in the solenoid combine to form a bigger field. This computer simulation gave me the opportunity to relate the combining of magnetic field around loops to the 'principle of superposition', a concept they had done in grade 10.This enabled me to explain the magnetic field around a solenoid as resulting from the addition of individual magnetic fields around loops. I had not planned for teaching this content as it is not included in the curriculum. I wanted however to show the learners the unity between concepts in physics. I felt l should have given learners the opportunity to manipulate the computer simulations themselves and allow them to explain the phenomenon to other learners. From the elicited responses it was clear to me that learners can explain the phenomenon amongst themselves. I am excited about the comment made by the person who was observing who noted that the learners seemed to be engaged and enjoying the lesson and even in their discussions in pairs. However he noted that l should have allowed learners to be involved in bigger groups like in fours or fives and not only in pairs. This l think might help because in the task that l gave them learners seemed to struggle to answer it in pairs and then l suggested that they should go and do it as homework. In my next lesson with the other class l plan to allow the learners the opportunity to manipulate the computer simulations and also allow learners to explain the phenomenon to other learners amongst themselves. I also intend to involve learners in larger groups.

What l have learnt?

Learners are not used to this approach of learning.

Reflective journal (Magnetic fields of current-carrying conductors)

Date: 03 August 2017 (1 hour)

The comment by video recording person sums up the whole lesson. He said that the learners seem to enjoy learning physical science. When l asked why he said so, he said that their attentiveness and participation was different to the way they would normally do in mathematics. In mathematics he said '*zvifhatuwo zwovha zvo sinyarara'*(their faces will be sad).

The demonstration, though very simple, was able to invite a 'wow its magic' from the learners with some calling it magic. I guess they were surprised by the simple phenomenon. What l liked about the demonstration is that the materials used in the demonstration were all familiar to learners. The learners were able to describe their observation- the attraction of the iron fillings by the iron nail when the cell was connected and the falling of the iron fillings when the cell was disconnected. On what was responsible for causing the attraction, learners suggested that it due to magnetism while another said it was due to the current flowing from the cell. However they could not pick out the idea of magnetic field. This became my introduction to the topic of magnetic field.

The online simulations I used were from www.cdaclabs.id.I was using my mobile internet device to download the simulations.(The school needs to help us in this regard). One was meant to show the magnetic field around a straight wire while the other one was for the magnetic field around a solenoid. The one for the magnetic field around the solenoid failed to download- l guess it was because of weak internet connection. So l had to find an alternative simulation to show the magnetic field around the solenoid. The learners were providing good responses when l asked them to describe the nature of the magnetic field around a straight wire. This was very encouraging. Their participation showed that they were really engaged and followed what was happening. One learner said that the field lines were anticlockwise. When l changed the direction of the current, the field lines were no longer going anti-clockwise. This gave me the opportunity to introduce the idea of the right hand rule to determine the direction of the magnetic field. There is something l noticed about the simulation on the magnetic field around a straight wire. Learners from their observation described the magnetic field around the straight wire as being uniform. The simulation present their field lines as equidistant from each other. This gave learners a false view of the nature of the magnetic field. However the simulation was beneficial in hypothesis testing. The learners were able to say that when the current is increased, the magnetic field becomes stronger. When l asked what would be seen to indicate a stronger field, the learners said the number of the field lines will increase which we were able to prove with the simulation.

In my next lesson l am going to use two suites of computer simulations to demonstrate the nature of the magnetic field around a straight conductor. The other one is for showing the nature of the magnetic field while the other one is for hypothesis testing the relationship between current (I) and field (B).

What have I learnt?

Learners do enjoy learning with computer simulations, it removes boredom.

Reflective journal

Lesson on magnetic fields around current-carrying conductors

Date: August 2017

The warm up activity was very interesting, it evoked diverse feelings in the learners. It was captivating to learners as they could not understand how or why the iron fillings were being attracted to the iron nail when there was no connection with the cell. The learners felt it was magic, hence they all shouted 'it's magic'. This was a good opportunity to show the applicability and relevance of science. This was a good experience and good introduction to the lesson. The learners were able to recognise that the attraction was as a result of magnetism (which I guess was their prior learning). However they could not identify the magnetic field as responsible for the attraction of the iron fillings. I did appreciate the ability to make the correct observation done by the learners. The computer simulations was another tool that excited the learners. They had not come across such tools before and they appreciated my effort to teach using the tool. What l particularly liked about the tool is the opportunity of question asking. This is different when teaching with the textbook. When teaching with computer simulations you are able to ask questions to address the content and also to enhance their understanding of the concept. For example, what is the nature of the magnetic field around the current-carrying conductor? Why do you think the field lines are close together near the conductor while further apart when far from the conductor? What do you think can be done to increase the strength of the magnetic field? This is different to ask them when they are not seeing the phenomena. Thus the use of computer simulations allowed me to elicit the idea of learners and their thinking about the phenomenon. I did not dictate notes to the learners but we used their ideas when they were jotting important ideas. I find this to be appropriate as we need to guide these learners instead of spoon-feeding those notes. I am excited about the use of computer simulations, learners are given the opportunity to speak out their ideas. Computer simulations creates what l can call a 'zone of actions'- the teacher asking questions, learners observing and responding, constructing explanations, correcting misconceptions. Everyone is involved. In that way learners do not become passive passengers but active participants in constructing knowledge. As a teacher you are given the opportunity to move around the class and not direct from the front. You have an opportunity to interact with the learners. There is need to remove this idea from the learners' mind that the teacher should always be talking and their task is to listen and copy down notes. Learners should take responsibility for their learning.

Appendix 13

Assessment for understanding framework

Task 1: Have we achieved our objectives

1. What was the most meaningful thing you learned in this lesson?

2. What questions do you have from what we have done?

Task 2: Lesson summary

Summarise in your own words the key points of what we have done in form of a concept map

Task 3: Key-words list

Can you write what you think could be the key-words of this lesson/topic.

Task 4: Grey area

Can you write down any aspect(s) which is/are not clear to you resulting from this lesson/topic?