Teachers' lived experiences of contextualised interventions, and its affordances for their professional development and for self-directed learning in physical sciences

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Dissertation accepted in fulfilment of the requirements for the degree ***Masters of Education*** *in* ***Natural Science Education*** at the North-West University.

Supervisor: Prof JJJ De Beer

Co-supervisor: Prof J Kriek

Graduation ceremony: December 2020

Student number: 28957210

DECLARATION

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work and that I have not previously submitted it, in its entirety or in part, at any university for a degree.

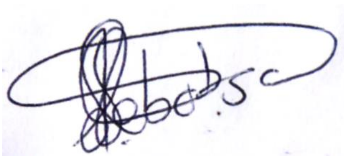
During this MEd journey, I have published two conference proceeding papers and one book chapter on this study. Sections in chapter 1 and 2 are aligned with these publications, but I do give due credit where applicable. These publications are:

1. Sebotsa, T., De Beer, J., & Kriek, J. (2019). 'Self-directed learning and teacher Professional development: An adapted Profile of Implementation'. *Proceedings of the IISES 8th Teaching and Education Conference*, Vienna, pp 338-360.
2. Sebotsa, T., De Beer, J., & Kriek, J. (2018). 'Considerations for teacher professional development: A case study on a community of practice'. Proceedings of the ISTE Science and Technology Education Conference, Kruger Park, October 2018, pp 268-276.
3. White, L., Bester, S., & Sebotsa, T. (2019). 'The use of puppetry as pedagogy to teach indigenous knowledge'. In: J. de Beer (ed), The decolonisation of the curriculum project: The affordances of indigenous knowledge for self-directed learning. AOSIS, Cape Town.

For a visual overview of the larger "Teachers without Borders project," the reader can watch the following YouTube videos:

https://www.youtube.com/watch?v=nlnHdWd6PEU&feature=youtu.be
https://www.youtube.com/watch?v=hrA3_MpsA2Q&t=118s

Signature



Date : 4 June 2020

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3. To the Fuchs Foundation, the NRF, and NWU, thank you for the generous financial support that made this study possible. It was a privilege that my study could have been part of the "Teachers Without Borders" flagship programme- thank you to Dr Riaan Els, CEO of the Fuchs Foundation. The "Teachers without Borders" project received NSTF-South32 "Science Oscars" accolades, namely being a Finalist in the 2019/2020 NSTF-SOUTH32 award in the category: Communication Award for outreach and creating awareness, see appendix S6.
4. To the Natural Sciences teachers who participated in this study, without your selflessness this study would not have materialised. Thank you from the bottom of my heart.
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12. To the Self-Directed Learning IK-community of practice (CoP), thank you for creating a safe space for development, and always being my soundboard and for sharing resources.

In case you missed it, here it is:

*‘I blame all of you. Writing this book has been an exercise in sustained suffering. The casual reader may, perhaps, exempt herself from excessive guilt, but for those of you who have played the larger role in prolonging my agonies with your encouragement and support, well…you know who you are, and you owe me’ (*Lin & Monga, 2017: *vii)*.

DEDICATION

Like Jaheim puts it in his song 'Everywhere I am':

"(Everywhere, everywhere I am)
(Just when) the walls are closing in on my world
(That's when) I see my favourite girl
(Clear as day inside my head) and it's obvious you're
(Everywhere, everywhere I am)
Was that you saying just keep on praying
You'll see the day when it will be worth the waiting
(Hey mama) I think I've received your message
Think how I'm receiving blessings."

Finally, I got my Master's degree Ma, and I dedicate this study to you. Thank you for instilling the thought of in versioning '*knowledge as an inheritance'* at an early age, and yes Ma, *thuto ke lefa leo o nfileng lona, kea leboha mme motswadi*.

I firstly like to thank my late mother, Lorraine "Noni" Orandah, Nomfundo Sebotsa. In the time of submission of this dissertation, it was your birthday my lady. A first-ever birthday that I was sure that I was not going to celebrate with you. Happy birthday Ma.

Thank you for being my light and peace in moments of confusions and frustrations, you will forever be loved. Send my regards to my brother Innocent "Mayoyo" Mlangengi, Yvonne Mlangeni and my son Oratilwe Innocent Sebotsa, you are all missed and loved. Paint haven with your love and smiles, until then we shall meet again in the next life.

Tswakae Sebotsa
4th June 2020

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CONFIRMATION OF EDITING

This letter serves to confirm that the following dissertation has been language and style edited:

Teachers' lived experiences of contextualised interventions, and its affordances for their professional development and for self-directed learning in physical sciences.

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Kind Regards
Xenia Kyriacou

1 June 2020

ABSTRACT

South Africa, with its cultural diversity, rich indigenous fauna and flora, cutting-edge science enterprises, and socio-economic inequalities, sets a unique table for a science teacher, who needs to ensure that diverse learners are adequately prepared for a complex 21st century. South Africa hosts some of the most advanced science and technology in the world, namely the square kilometre array (SKA) in the Carnarvon district. This area in the Northern Cape is also home to the oldest indigenous knowledge system in the world, that of the San. The picture provided at the end of this abstract, juxtaposes this contrast, namely 21st-century knowledge and skills, versus indigenous knowledge, and this creates a challenge for the South African science teacher, who needs to navigate the tensioned space between these two epistemologies.

Research studies of the last decade have shown that most science teachers are not sufficiently equipped for such epistemological border-crossing. The intervention which is described in this study attempted to assist Natural Sciences teachers to accomplish such epistemological border-crossing in the classroom. A community of practice (CoP) was established, and since the intervention was based on self-directed learning principles, learning activities that were provided in the CoP were conceptualised based on the teachers' actual needs. The leitmotif underpinning this research was therefore that teachers should take ownership of their own learning. Based on teachers' needs, a professional development programme was developed for 10 teacher participants from the greater Potchefstroom area, mostly teaching in 'township' schools in the suburbs of Ikageng and Promosa (mostly quantile 1 schools). These teachers engaged in diverse learning activities, e.g., a short learning programme on indigenous knowledge, a two-day immersion laboratory-work opportunity at the African Centre for DNA Barcoding at the University of Johannesburg (to develop a better understanding of the tenets of science), workshops on frugal (science-on-a-shoestring) science, where teachers explored how low-cost materials could be used to foster inquiry learning in an under-resourced classroom, a workshop on utilising ICTs (such as the PhET simulations) in the science classroom, and general workshops on pedagogies and learning strategies, e.g., problem-based and cooperative learning.

Teachers also commented on high stress levels, and a psychologist was employed to present a workshop to teachers on how to practically manage stress.

This mixed methods research utilised qualitative data-gathering methods such as individual interviews, focus group interviews, open-ended questionnaires, classroom observations, and studying artefacts (e.g., teacher professional development portfolios). The quantitative data included the Self-Directed Learning Instrument (SDLI) that was developed and validated by Cheng et al. (2010). Pre- and post-intervention data were collected, and I have utilised a revised Profile of Implementation to map each of the teachers' professional learning. This heuristic (the Profile of Implementation) consisted of five domains, namely (a) classroom interaction, (b) practical work and the nature of science, (c) science-in-society approaches (and the contextualisation of curriculum themes), (d) assessment practices, and (e) self-directed learning. Third-generation Cultural-Historical Activity Theory (CHAT) was used as a research lens, during a second level of data analysis. This lens provided insights into factors that either supported or impeded transfer to the post-intervention classroom.

The seven themes that emerged from this research were:

1. The intervention helped teachers to develop more nuanced understandings of the nature of science, yet little evidence of transfer and acknowledgement of the tenets of science (transformed teaching) were observed in the post-intervention classroom.
2. The intervention assisted teachers to develop more nuanced understandings of the nature of indigenous knowledge, yet little evidence of transfer of such indigenous knowledge (transformed teaching) was observed in the post-intervention classroom.
3. Despite the fact that teachers showed greater sensitivity towards contextualising curriculum themes through indigenous knowledge, the majority of them have challenges to implement contextualised problem-based learning (PBL) in the Natural Sciences classroom.
4. Evidence exists of nascent self-directed learning, but this does not yet direct transformed teaching practices or the development of teacher agency in overcoming systemic barriers.

5. Despite teachers' enthusiasm about frugal science and PhET simulations, very little transfer took place in the classroom, and little evidence of the use of science-on-a-shoestring approaches or ICT approaches was observed.
6. Despite experiencing the 'world of a scientist' at the ACDB at UJ, none of the teachers portrayed such tenets of science in the post-intervention classroom, probably because of their lack of knowledge and skills of laboratory protocols.
7. A longitudinal professional development programme, fostering a supportive community of practice, could enhance teacher learning but should involve all stakeholders during the planning phase.

Acknowledgement: This photograph is published with the permission and courtesy of Dr Anton Binneman, the National Research Foundation, and the South African Radio Astronomy Observatory (SARAO).

KEYWORDS: Teacher professional development; science education; tenets of science; tenets of indigenous knowledge; self-directed learning; inquiry learning; cultural historical activity theory; mixed methods research; social constructivism; zone of proximal teacher development; community of practice; profile of implementation.

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LIST OF ACRONYMS

4IR	4th Industrial Revolution
ACDB	African Centre for DNA Barcoding
CAPS	Curriculum and Assessment Policy Statement
CHAT	Third-Generation Cultural-Historical Activity Theory
CNEP	Christian National Education Policy
CoP	Community of Practice
DBR	Design-Based Research
EDU-REC	Ethics Committee at North-West University
EKI	Ethnobotanical Knowledge Index
ESDC	Embodied, Situated and Distributed Cognition
ICTs	Information and Communication Technologies
IK	Indigenous Knowledge
IST	In-Service Training
ISTE	International Society for Technology in Education
NAC	Native Affairs Commission
NEF	New Education Fellowship
NOIK	Nature of Indigenous Knowledge
NOS	Nature of Science
NRF	National Research Foundation
PCK	Pedagogical Content Knowledge
PCR	Polymerase Chain Reaction
PEPP	People's Education for People's Power
PhET	Physics Education Technology
PIRLS	Progress in International Reading Literacy Study
PISA	Programme for International Student Assessment
RTOP	Reformed Teaching Observation Protocol
SACMEQ	Southern and East African Consortium for Monitoring Educational Quality
SADTU	South African Democratic Teacher Union
SDL	Self-Directed Learning
SDLI	Self-Directed Learning Instrument

SLP	Short-Learning Programme
STS	Science Technology Society
TIMMS	Trends in Mathematics and Science Study
TPDI	Teacher Professional Development Interventions
VNOIK	Views of the Nature of Indigenous Knowledge
VNOS	Views of the Nature of Science
VUDEC	Vista University Distance Education Campus
WEF	World Economic Forum
ZPD	Zone of Proximal Development
ZPTD	Zone of Proximal Teacher Development

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CHAPTER 1: OVERVIEW OF THE STUDY

Can the phoenix rise from the ashes?
The significance of science teacher professional development

1.1 INTRODUCTION

South African Natural Sciences learners continue to perform poorly in international benchmark tests such as the Trends in Mathematics and Science Study (TIMSS) (Sebotsa et al., 2018:268[1]; De Beer, 2016; TIMSS, 2015; Kriek & Grayson, 2009) and in the Southern and East African Consortium for Monitoring Educational Quality (SACMEQ) (Spaull, 2013). The Progress in International Reading Literacy Study (PIRLS) report provides a similar assessment on the poor state of education in South Africa (Monyooe, 2017). In the 2015 TIMSS study, South Africa was listed as number 38 out of 39 countries, with Botswana being the lowest (Reddy et al., 2016). The Programme for International Student Assessment (PISA) of 2011 ranked the South African schooling system fourth last in the world, namely 97th out of 100 countries (Monyooe, 2017). Who would dispute that science education in South Africa is a national priority? While that is the case, Spaull (2013) indicates that learners are not making the grade and are performing dismally in mathematics and science.

Research highlights three dominant reasons for this unfortunate state of affairs. For example, under-qualified teachers (CDE, 2011); teachers with superficial subject knowledge and/or insufficient pedagogical content knowledge (PCK) (Kriek & Grayson, 2009; Lyons & Quinn, 2010; Kunter, Frezel, Naggy, Baumert & Pekrun, 2011; Motwa, 2011); and teachers exchanging learner-centred inquiry learning approaches for transmission-mode teaching due to systemic pressures, despite their own pedagogical orientations (Ramnarain & Schuster, 2014). De Wet (2016:144) raised several concerns that many South African 'teachers have below-basic levels of content knowledge, with high proportions of teachers being unable to answer questions aimed at their learners'.

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[1] Sections in chapter 1 and 2 are aligned with some of my publications, but I do give due credit where applicable. These publications are:

1. Sebotsa, T., De Beer, J., & Kriek, J. (2019). 'Self-directed learning and teacher Professional development: An adapted Profile of Implementation'. *Proceedings of the IISES 8th Teaching and Education Conference*, Vienna, pp 338-360.
2. Sebotsa, T., De Beer, J., & Kriek, J. (2018). 'Considerations for teacher professional development: A case study on a community of practice'. Proceedings of the ISTE Science and Technology Education Conference, Kruger Park, October 2018, pp 268-276.
3. White, L., Bester, S., & Sebotsa, T. (2019). 'The use of puppetry as pedagogy to teach indigenous knowledge'. In: J. de Beer (ed), The decolonisation of the curriculum project: The affordances of indigenous knowledge for self-directed learning. AOSIS, Cape Town.

Yükse and Sezer (2017) state that, in addition to teachers' lack of PCK, two other factors negatively influence learner performance in TIMSS. The factors mentioned by the authors are the curriculum and a lack of adequate teaching and learning resources.
Several other authors also list lack of resources, such as information and communication technologies (ICTs) (Mullis, Martin, Foy & Arora, 2012), as a reason for the poor performance. In the McKinsey study (2007), it was highlighted that no schooling system can rise above the limits imposed by the quality of its teachers (Sebotsa et al., 2019). Moreover, Van Rooyen and De Beer et al. (2006) are of the opinion that teachers lack agency, and are not able to improvise using shoestring (frugal science) experiments in under-resourced classrooms (Sebotsa et al., 2019). Much research in science education has focused on interventions aimed at improving the state of science education in South Africa. However, most of these interventions, according to Schlager and Fusco (2003), have put the 'cart before the horse'. It is unfortunate that, most often, facilitators presenting teacher professional development interventions (TPDIs) structure such interventions based on their own perceptions of teachers' needs (Pretorius, 2015; Antoniou, 2017; Sebotsa, De Beer & Kriek, 2018). This approach does not address the real needs of the teachers and, usually, the focus is on developing teachers' content knowledge (Pretorius, 2015; Antoniou, 2017; Sebotsa, De Beer & Kriek, 2018).

Commonly, teachers struggle with more than curriculum challenges and poor pedagogical content knowledge. Many teachers need guidance on (a) maintaining healthy discipline, (b) classroom and personal wellbeing (i.e., stress management), (c) learners and their needs, and (d) teacher professional development needs, such as focussing on the affective domain in the science classroom (Antoniou, 2017; Sebotsa, De Beer & Kriek, 2018). Consequently, the interventions in this study adopt a more holistic approach to teacher professional development. The 'gap' that this study addresses is clearly articulated in the Centre for Development and Enterprise report (2011), namely, that once-off teacher professional development workshops are not very effective, and that more longitudinal and systemic approaches are needed in teacher professional development.

This study, therefore, set out to assist a group of teachers in the larger Potchefstroom district with their professional development, and planned the workshops according to teachers' real needs. A major focus of the programme, in an era where the 'decolonisation of the curriculum' debate is receiving a lot of attention, was to address indigenous knowledge in

the science curriculum. The affective domain was highlighted by assisting teachers to include indigenous knowledge in their Natural Sciences teaching.
This was achieved by using Curriculum and Assessment Policy Statement (CAPS) themes to better contextualise the curriculum for culturally diverse learners; and to stimulate learners' interest in the content.

This study forms part of a larger National Research Foundation (NRF) and Fuchs Foundation research project, 'Teachers without Borders', in which teachers are trained in ways to infuse indigenous knowledge into the CAPS curriculum. It was the imperative of this study to engage teachers in relevant holistic tailored-made interventions and workshops by providing the teachers with knowledge and skills for innovative teaching strategies known to be fruitful in promoting self-directed learning (SDL). Self-directed learning, I argue in this dissertation, is a *sine qua non* for teacher professional development programmes.

1.2 THE CURRENT STATE OF THE SCIENCE CURRICULUM IN SOUTH AFRICA

There have been many curriculum reforms in South Africa since the dawn of democracy in 1994. This has resulted in much experimentation with the science curriculum. Therefore, the curriculum has not achieved the stability it seeks. A new form of protest has been sweeping South Africa as from 2015, in which students expressed dissatisfaction with the curriculum, which is often viewed as biased and foreign (Le Grange, 2016). Movements such as *#ScienceMustFall* (Jansen, 2017), *#RhodesMustFall* and *#FeesMustFall* campaigns, have received much attention as students across the country demand 'decolonisation' and 'transformation' in institutions of higher education in South Africa. This has led to severe damages to infrastructure, and the disruption of education. Campaigns like this are long overdue and should be seen in the light of the previous political regime that marginalised indigenous knowledge (IK) and its people (for example, the Suppression of Witchcraft Act of 1957 criminalised traditional medicinal practices).

Le Grange (2016; 2019) is of the view that the unrest stems from the need to decolonise the South African curriculum. He further suggests an approach to explore ways of developing and designing locally and regionally relevant curricula. Wingfield (2017) explains that decolonization does not mean that Western knowledge should not be taught, but that it should be supplemented by indigenous knowledge, and that the value of IK should be acknowledged.

The aim is, therefore, for globally relevant knowledge with local application. De Beer (2019) refers to 'glocalisation', and quotes Patel and Lynch (2013:223) who emphasise the need for 'pedagogical framing of local and global community connectedness in relation to social responsibility, justice and sustainability'. Jansen (2017:13) recently articulated the yearning for a curriculum 'anchored in the African experience, but richly engaged with and related to other knowledges of the South', which recognises the complexities and interrelatedness of different sets of knowledge, as well as how such knowledge has changed over time.

I concur with authors such as Abah, Mashebe and Denuga (2015:672) who state that 'while Western science offers a broader appreciation of context beyond the local level, indigenous knowledge offers a depth of experience in a local, culture-specific context'. The researcher argues for an epistemological border-crossing in which indigenous knowledge (IK) is seen as equal to Western science, and where the science curriculum is locally contextualised (Sebotsa et al., 2018; De Beer, 2012, 2016, 2019; Wingfield, 2017). One way of including local context can be by infusing IK into the science curriculum.

This study argues for the value of including indigenous knowledge in order to provide a more nuanced and contextualised curriculum, as compared to a political stance that intends to eradicate Western viewpoints. This, I argue, holds affordances for removing the political 'sting' from the decolonising debate. In addition, this study has its epistemological home within the research unit Self-Directed Learning (SDL) of the NWU, and particularly in the SDL sub-area Indigenous Knowledge. Teachers were supported in contextualising science by infusing indigenous knowledge (IK), and the intervention scaffolded teacher professional development in order to facilitate such border-crossing in the science classroom. The focus was on teacher pedagogical content knowledge (PCK) development and also on addressing teachers' real needs, over and above their PCK needs.

This longitudinal and systemic intervention scaffolded teacher professional development within a community of practice (CoP), which I affectionately called the 'A-Team'. During the intervention, science teachers were expected to enhance their own self-directed learning skills, in navigating the Vygotskyan (1978) zone of proximal development (ZPD). The intervention workshops provided a 'pedagogical laboratory' (Ramsaroop & Gravett, 2018), where teachers were able to experiment with new strategies and techniques.

However, these authors indicate that 'cognitive apprenticeship' is also needed, and both the facilitators (acting as keystone species) and the other teachers within this community of practice, provided this.

The zoologist Robert Paine coined the term 'keystone species' in an ecological context. The term refers to a species who has a disproportionally large influence on its natural habitat. In this study keystone species refer to expertise by 'more knowledgeable others', who during the interventions, provided scaffolding to the "A-Team" teachers. These individuals had a large sphere of influence.

1.3 THE CONTEXT OF THE STUDY

Rogan and Grayson (2003) recommend that, in the course of the implementation of a curriculum or phenomenon (the phenomenon in this instance, was engaging the Natural Sciences teachers in meaningful learning and professional development experiences), three aspects need to be kept in mind:

- ***Implementation should consist of a series of small steps (and is, thus, a long-term process).*** In this instance, the Natural Science teachers participated in a number of tailored interventions and workshops at the North-West University, Potchefstroom campus (as well as an intervention at the University of Johannesburg). Rogan (2006:441) introduced the term 'zone of feasible innovation' (ZFI), which he defines as 'a collection of teaching strategies that go beyond current practice, but are feasible given the prevailing environment of the school in terms of its ability to foster and sustain innovation'. The ZFI implies that strategies mentioned in the definition are attained in small manageable steps, as was done in this study.

- ***The context of the school (teachers, learners and environment) should be taken into account*.** This study was conducted in Potchefstroom with a clear focus on assisting historically disadvantaged schools in Ikageng and Promosa (suburbs in the greater J.B. Marks Municipality). The schools chosen for this study are situated in the locations mentioned, where most schools fall within the national poverty ranking quintiles for public schools. All the schools chosen for this study were non-paying schools in quintile 1, which is the most disadvantaged quintile. According to the SACMEQ III report of 2012, the no-fee policy was argued and implemented based on opening access to schooling to a large sector of learners who otherwise, due to poverty, would not be able to access education. This, in summary, portrays the background of the schools I chose for this study.

- ***The level of the teachers' pedagogical knowledge and experience should be considered.***

Petersen and De Beer (2012) state that many teachers in South Africa do not possess the basic pedagogical content knowledge needed to implement the curriculum. When conceptualising the intervention, our hypothesis was that many of the teachers would have under-developed PCK, and we used the intervention to administer instruments to test this hypothesis. Rogan and Grayson’s (2003) suggest that the teachers’ experience and level of pedagogical knowledge should be considered when planning professional development interventions. All three conditions stated by Rogan and Grayson (2003) were, therefore, met in this study.

Within the vicinity of Ikageng and Promosa lies the North-West University (Potchefstroom campus). The university's purpose is to excel in innovative teaching and learning and cutting-edge research, thereby benefiting society through knowledge. One of the aims of this study was to recognise context and to provide the necessary support to the community, and to support the goal of the university in assisting the community with innovative teaching methods. One of the successful models of the university is their commitment to, and the focus on, community engagement. The university achieve this community engagement by including the community in teaching and learning, research that is aligned to community needs, and developing a culture of self-directed learning.

This study provided teachers with tailor-made interventions which provided the Natural Sciences teachers with more nuanced science understanding and teaching strategies. From the literature, it is clear that teachers struggle to integrate indigenous knowledge into the science curriculum (Antoniou, 2017; Akerele, 2016; De Beer, 2016; and Cronje, 2015). Since this is the case, the researcher provided Natural Sciences teachers with a short learning programme (SLP) that assisted the them with strategies for the inclusion of indigenous knowledge into the Natural Sciences curriculum) (SLP, 2016).

The short learning programme that the Natural Sciences teachers completed was a 16-credit qualification at NQF level 6. The A-Team teachers are shown standing in Figure 1.1. The three kneeling members in the front row are (from left to right): Prof Jeanne Kriek (co-supervisor); Mr Tswakae Sebotsa (researcher); and Prof Josef De Beer (study leader). Acording to ethical protocol the researcher received written agreement with the participants to reveal their faces.

Figure 1.1: The A-Team teachers at the North-West University with the researcher, the study leader and the co-supervisor (their photograph is reproduced with their written consent).
Photographer: Neal Petersen. All participants provided consent that the photographs may be published.

1.4 THE GAP ADDRESSED BY THIS STUDY

Research literature identifies three perpetual concerns in South African science education. The complexity of teaching science in South Africa necessitates on-going teacher professional development. Divergent classrooms, reforms in curriculums, under-qualified teachers, ineffective training, large classes, and lack of resources, all contribute to this complexity (Antonio, 2017; Pretorius, 2015). This study is, therefore, multifaceted with two prominent themes focused on:

- How teacher professional development can be better positioned to scaffold Natural Sciences teachers across the zone of proximal teacher development (ZPTD) within six bounded systems, i.e., six schools within a supportive community of practice (CoP).

- How teachers experienced systemic and longitudinal tailor-made interventions and needs-driven professional development programmes.

It is important to distinguish this study from recent similar studies in order to delineate the gap addressed by this study. Pretorius (2015) and White (2012), who engaged in similar research, focused on professional development within university-based interventions and within clusters, respectively.
These scholars did not pose the same research questions as this study. Antoniou (2017) focused on teacher professional development within a school-based CoP in an urban school in Johannesburg, Gauteng Province. Ramnarain and Shuster (2014) emphasise that township schools have a more ‘active direct orientation’, i.e., chalk-and-talk approaches. Suburban schools often exhibit a guided-inquiry orientation, i.e., an inquiry-based learning approach. One can thus argue that the students in township schools are more often passive recipients of teachers' knowledge and their voices are ‘silenced’ by the mode of teaching. The context of this study, namely teachers working in township schools, while being part of a community of practice, has the potential of providing different perspectives on teacher professional development interventions. The context of the schools, and the use of six classrooms (six bounded systems) within the CoP, set this study apart and contribute to its value.

The study is vital, due to the state of science education in South Africa. De Beer (2016) asks whether the phoenix can rise from the ashes. Like the legendary bird of Greek mythology, science education in South Africa can be seen as dying in flames. How can science education be regenerated, like the phoenix? A key to this question lies in teacher education. To address this question, I explored holistic teacher professional development, as well as how to make the curriculum more relevant to learners through better contextualisation. The teachers’ professional development entailed involvement in a two-day short learning programme (SLP) on the affordances of indigenous knowledge, as well as numerous other interventions (e.g., a two-day workshop at the African Centre for DNA Barcoding at the University of Johannesburg), which will be explained in Chapter 3. Kinsella and Pitman (2012) noted that teacher education in South Africa does not bridge the theory-practice gap, implying that teacher education is overly theoretical to the extent that it marginalises practice and the transfer of new knowledge and skills to the ‘coalface’ of teaching in the classroom. During the SLP teachers were assisted with approaches that could be used in the Natural

Sciences classroom to address this ‘ivory tower’ effect (the theory-practice divide). During the SLP teachers were involved in the following strands that formed the itinerary of the programme:

- Laboratory activities such as the Kirby-Bauer technique for testing anti-microbial activity; and indigenous knowledge ‘labs’ such as soap making.
- Problem- and project-based learning using the post-harvest physiology of cut flowers. In this activity, the teachers had to find ways to increase the shelf life of cut flowers. Another project- and problem-based activity dealt with optics. Teachers had to design an inquiry-learning activity to teach refraction.
- Science-on-a-shoestring approach, or what Jackson, De Beer and White (2020) call ‘frugal science’. Teachers explored how a paper-based microscope could facilitate problem-based learning in the Natural Sciences classroom.
- Ethnobotanical survey, where teachers were provided with techniques on how to determine local plant use, and the application value of indigenous knowledge, using the matrix method, the ethnobotanical knowledge index (EKI), and the species popularity index (De Beer & Van Wyk, 2011).
- Cooperative learning was linked to self-directed learning, and teachers engaged in the essential elements of cooperative learning, as suggested by Johnson and Johnson (1999). This perspective provided guidance to teachers on how to use the jigsaw method and De Bono's thinking hats.
- Engaging teachers as *Homo ludens (*the playing human) (Huizinga, 1957). With the shift from STEM to STEAM (the A representing the arts) education, puppetry was used as an approach to include as the Art in STEM education.
- Teachers were navigated on how to design meaningful learning and assessment, paying particular attention to lesson planning, Bloom's Taxonomy and reflection.
- Before the SLP the A-Team teachers were involved in a number of tailored workshops, excursions and interventions based on their identified professional development needs.

Pretorius (2015) showed that many teachers have naïve understandings of the nature of science, and she argues for opportunities in which teachers are exposed to authentic science laboratory work, mentored by real scientists. To this end, teachers in my study engaged in authentic science laboratory work at the African Centre for DNA Barcoding

(ACDB) at the University of Johannesburg, in November 2018. DNA barcoding is a method used to identify species by using DNA sequences from a small fragment of the genome, a process known as polymerase chain reaction (PCR) (Lahaye et al., 2008). This experience engaged the A-Team teachers to work as scientists would in an authentic laboratory space, guided by post-graduate researchers of the ACDB.
This was an attempt to address the affective domain, increase awareness of the impact of science in society, and to provide teachers with a more nuanced understanding of the nature and tenets of the natural sciences, and laboratory protocol. Teachers were also introduced to 'frugal science' (Ahuja, 2014) or 'science-on-a-shoestring' approaches, and interactive computer PhET-simulations, all with the intention of accelerating their agency as science teachers.

There have been a number of South African studies that have focused either on science-on-a-shoestring approaches or the use of ICT's, but in this particular study, I looked at the affordances of a combination of these approaches. To the researcher's knowledge, the combining of shoestring science and ICT within a contextualised, indigenous knowledge perspective, has not been studied before and constitutes one of the contributions of this study. The researcher further investigated the participating teachers' experiences of all the interventions mentioned above, and how this could enhance their own self-directed learning – provided an additional aspect to the research.

Warford (2011:255) indicates that teachers often 'discard the academy for what they perceive as the real world of teaching'. Often professional development programmes are not successful, and new knowledge and skills are often 'washed out' (Zeichner & Tabachnick, 1981:7) when teachers return to the classroom. This intervention was longitudinal and systemic, and the focus was on scaffolding teacher learning over a sustained period (an intervention over time), providing what Ramsaroop and Gravett (2018) call 'cognitive apprenticeship'.

A good volume of research has been done on the integration of indigenous knowledge into the Life Sciences curriculum (De Beer, 2016; Cronje, 2015; De Beer & Ramnarain, 2012; Akerele, 2016). This contrasts with the Natural and Physical Sciences, where little work has been done. For instance, this study addressed indigenous knowledge in the field of visible light (a CAPS theme in Natural Sciences); beer making (fermentation); and soap making (the process of saponification). The CAPS content requires teachers to teach the properties of acids, bases and neutrals, as well as fermentation. It is hoped that soap making, and traditional beer making, will provide teachers with the affective domain and ways of contextualising Natural Sciences themes in their classroom.

1.5 THEORETICAL AND CONCEPTUAL FRAMEWORK

In this section, I provide an overview of literature reviewed, which I will structure according to the theoretical and conceptual framework of the study. It is discussed in more detail in Chapter 2.

1.5.1 Theoretical framework

This study is embedded in social constructivism, as explained by Vygotsky (1978), and guided by this theoretical framework. Third-generation Cultural-Historical Activity Theory (CHAT) as conceptualised by Engeström (1987) was used as a research lens. CHAT is rooted in social constructivism. I used Warford's (2011) application of the well-known Vygotskyan (1978) construct of the zone of proximal development (ZPD), namely, the zone of proximal teacher development (ZPTD). The work of Warford aided me to structure the professional development of the science teachers across this zone of proximal teacher development. This was achieved by focusing on the four constructs of ZPTD stages, namely, self-assistance, expert other assistance, internalisation (automatisation) and recursion (de-automatisation), as explained by Warford. De Beer and Mentz (2018) link the stages in Warford’s ZPTD with those in Knowles's definition of self-directed learning. During the intervention, teachers were encouraged to identify personal learning goals, identify resources to scaffold their learning, and monitor their own learning. These insights helped me to expand and revise Rogan and Grayson’s (2004), Rogan and Aldous’s (2005), and Petersen and De Beer's (2016) framework of implementation by including the SDL construct to the framework.

1.5.2 Conceptual framework

The conceptual framework in this study was derived from research on problems associated with poor learners’ performance in science education such as (1) teacher’s under-developed PCK, (2) lack of resources such as laboratory apparatus and ICTs, and (3) the (often decontextualised) curriculum. In the literature review, these aspects are discussed as they apply to the conceptual framework (or, in Engeström's language, ‘intermediate theories’) of this study. The conceptual framework includes embodied, situated and distributed cognition (ESDC); teacher pedagogical content knowledge (PCK); teacher agency; learning through a pedagogy of play (*Homo ludens*) (Huizinga, 1957); PhET simulations (interactive computer simulations); affordances of indigenous knowledge in the Natural Sciences; problem- and project-based learning; teacher professional development and self-directed learning (SDL). All these concepts contributed to designing the interventions and the workshops within a community of practice.

The above ‘intermediate theories’ were used as filters, while Cultural-Historical Activity Theory (CHAT) was used as a research lens. The CHAT lens allowed the researcher to examine each activity system (constituted by the filters mentioned above). The research lens helps to capture teachers’ journeys from their actual development to their potential development during and after interventions.

1.5.3 Teacher professional development

Teacher professional development should be seen as essential for improving classroom instruction and student achievement in the science classroom (Pehmer et al., 2015; 2000; Ball & Cohen, 1999). Teacher professional development includes different learning activities, such as: in-service training; professional interventions; and workshops and courses that support learning.

The consideration of ‘teacher as a learner’ requires lifelong learning, and this perspective shed light on the importance of teacher professional development. During the teacher development programmes, teachers engaged with activities aimed at scaffolding. These activities have considerable significance for teacher practice. The benefits of teacher professional development are as follows:

(a) It improves teachers' content knowledge;
(b) It provides opportunities for active learning; and
(c) It addresses teacher's needs (Antoniou, 2017; Pretorius, 2015).

1.5.4 Contextualised interventions

According to the Merriam-Webster Dictionary (2011) ‘to “contextualise” is to put a study in context, where context refers to the circumstances that form the setting for an event, statement, or idea, and in terms of which it can be fully understood’. Contextualised instruction can be described as ‘a process of knowledge integration which uses the ideas that students hold prior to instruction as the building blocks to an active process of linking, connecting, distinguishing, organising and structuring understanding of scientific phenomena’ (Ngman-Wara, 2015:340). Other authors give similar definitions, for example, Davis & Linn (2000) and Linn & His (2000).

Kasanda et al. (2005) and Johnson (2002) suggest that contextualised teaching should consider connecting content knowledge to meaningful situations that are appropriate to learners’ lives. These scholars state that contextualised teaching dictates that the teacher should package the curriculum content in a way that it connects to the daily lives of students, and make learning meaningful.

In this study, the contextualisation was achieved by, amongst others, showing teachers how learning opportunities could be created that would teach learners the relevance of science in their everyday lives (the science-technology-society or STS approach). This took place in the form of a series of interventions informed by teachers’ stated professional development needs; and designed to facilitate a change in classroom practise.

1.5.5 Teacher pedagogical content knowledge

To teach science effectively, teachers need to have more than good content knowledge, as commonly believed. Teaching science also requires sensitivity to context and expertise in adapting method of delivery and relevance of content. Such ability is what Shulman (1996, 1987) calls pedagogical content knowledge (PCK). The term refers to a teacher's subject matter knowledge and the skills to teach those concepts to a particular group of learners so that they understand the content. Since Shulman (1987) and many other scholars regard PCK as one of the cornerstones of teacher knowledge, it is vital to understand its origins.

A visual representation is provided below in Figure 1.2. Since teachers’ PCK is often under-developed, teachers often resort to transmission-mode teaching and learning, such as chalk-and-talk approaches (De Beer & Ramnarain, 2012). The latter scholars refer to chalk and talk as an approach that precludes self-directed, inquiry-based learning and problem-based learning in the science classroom. The intent of this teacher professional development was to scaffold teachers' pedagogical content knowledge development.

This intersection between content knowledge and pedagogical knowledge that makes up pedagogical content knowledge (PCK) is visually represented in Figure 1.2

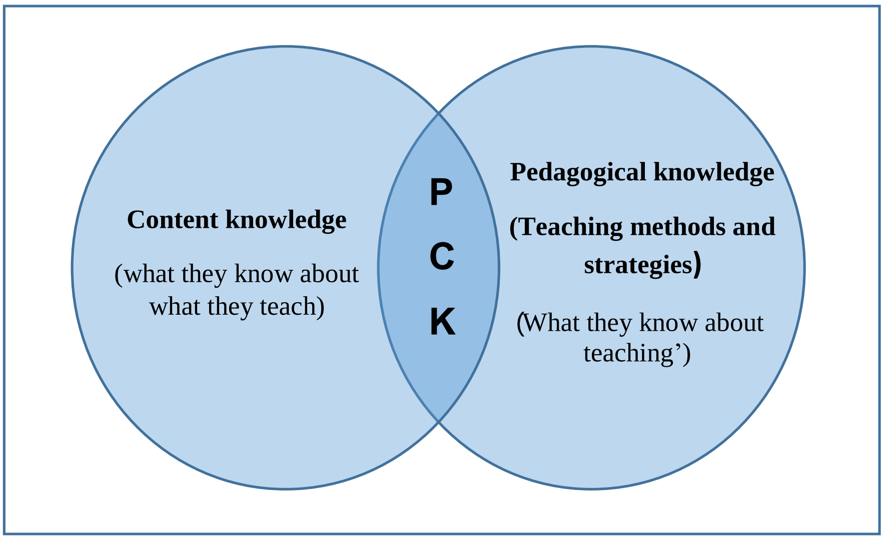


Figure 1.2: Simple representation of pedagogical content knowledge (adapted from Pretorius, 2015)

PCK is topic-specific and, in this intervention, we used the topics of visible light and optics, as well as DNA technology. A focus was also on the nature of science (NOS) and the nature of indigenous knowledge (NOIK).

1.5.6 The curriculum and the affordances of indigenous knowledge

De Beer and Petersen (2015) argue for a more Afrocentric curriculum that centralises indigenous knowledge (IK) in science education. Cronje (2015) has shown that there are many shared tenets, despite several differences between the nature of indigenous knowledge and the nature of science. Jautse, Thambe and De Beer (2016:42) show that IK and science are both empirical (although indigenous knowledge also has a metaphysical component), both are tentative (and subject to change), both are inferential, both are creative, and both are socially and culturally based. This approach could facilitate science teaching that acknowledges students' knowledge and cultural-based ways of thinking, which will potentially make science more meaningful to learners (Cronje, 2015).

White, Bester and Sebotsa (2019) argue that indigenous knowledge can be infused into the Science curriculum. As Cronje et al. (2015) indicate Western knowledge systems and IK systems need not necessarily be in conflict. The space where IK and Western ways of knowing connect and overlap can be understood as a cultural interface (Nakata, 2002). 'This can be a contested space, but can also be a space where different ways of knowing work together synergistically' (Bester & Sebotsa, 2019:251).

By infusing relevant indigenous knowledge (IK) into the curriculum themes, we might make science more thought-provoking, interesting and more relevant for learners, which might improve their performance (De Beer, 2016). One reason for the poor performance in science, which is often overlooked, is that the affective domain of human thinking is often neglected in science education (De Beer, 2016). From an embodied, situated and distributed cognition (ESDC) perspective, learning cannot take place in isolation (White, Bester & Sebotsa, 2019; Hardy-Vallee & Payette, 2008).

According to Maxwell and Chahine (2013:67), 'effective learning takes place in an atmosphere of a learner's existing knowledge, background and environment'. These authors argue that indigenous knowledge holds affordances to make the science curriculum more relevant and accessible. Dubinsky, Roehrig and Varma (2013) show us that experiences with an emotional stamp are more likely to be committed to long-term memory (Sebotsa et al., 2019:253).

1.5.7 Teacher agency

According to Eacute and Esteve (2000:197) 'the change from a system designed to educate an elite, to one of mass education, not only increased the numbers of teachers and learners, but it also created perplexing problems related to quality of education. How to achieve high standards of education in these circumstances is a challenge that needs much creative thought and determination from teachers. Teachers are required to be creative to meet the demands of teaching in the 21st century when educational reforms are formulated in a new era marked by disenchantment (Eacute & Esteve, 2000). Two decades ago, these scholars claimed that the teaching profession was getting more challenging; and it presented teachers with new challenges in preparing the learners for futuristic thinking and 'deeper levels of reality' (Quinn 2012:47). This, I claim, has resulted in disruptive transformations that have caused many tensions at the 'coalface' of teaching. When teachers are required to reposition their professional identity, they need to become agents of change (Cochran-Smith, 2005). Archer's (2007) view of agency in the modern age is based on human reflexivity, which asks for a deliberate commitment and knowledgeability.

The interpretation by Archer (2007) of human reflexivity stems from the idea that teachers need to be agents of change and to re-evaluate their teaching practice which requires *commitment* particularly in era punctuated by many curriculum reforms, which asks for *knowledgeability*. It is common for teachers to adhere to the latter in an era of 'quality education for all', which is a buzz phrase in the South African schooling system. Therefore, in order for teachers to be agents of change they need to participate in transformative learning. In this study, a transformative learning environment was created, and different learning strategies were explored. The teachers were required to design spectrometers using science-on-a-shoestring approaches to address challenges of teaching in under-resourced classrooms. The teachers used material such as lids, scissors, old compact disks, etc., to build the product and to envisage how the product will support inquiry-based learning. Secondly, the use of PhET simulations to promote inquiry-based teaching was deemed appropriate in an era of 4th industrialisation.

The view above was linked with Mezirow's interpretation of agency and is consistent with the idea of effecting change (Mezirow, 1977, 1981). Mezirow (1977:157) maintains that 'people's perspectives on reality are transformed as a result of reflection upon disjunctive or "disorienting" experiences; when a meaning perspective can no longer comfortably deal with anomalies in the next situation, a transformation can occur. Such transformation amounts to a paradigm shift.' It was the purpose of this study to influence teacher agency and assist the teachers in making this paradigm shift, and in affording them with the prospect of turning challenges into workable solutions, and to develop the necessary skills to do so.

1.5.8 The pedagogy of play

According to Wood (2004), pedagogy of play can be described as how professionals integrate playful approaches in their teaching and learning while considering all the pedagogical decisions, strategies and techniques to support learning. There has been substantial research on play in early childhood development (Wood, 2008), in contrast to a lack of substantial research in the general education and training GET and further education and training (FET) band on teaching through play. This despite the fact that play has been linked to the six areas of learning and the cognitive domains, for instance positive outcomes in the cognitive, social and psychomotor and emotional domain (Wood, 2008).

Podolefsky, Rehn and Perkins (2013) have implemented PhET interactive computer simulations in middle school classrooms and found that 'open play' can allow increased student agency and simultaneously provide a platform for student-centred pedagogy. In this study, the intervention provided the affordances of play by allowing the teachers to engage and play with the PhET simulations and science-on-a-shoestring resources; and to allowed creativity during the intervention using inquiry-learning approaches.

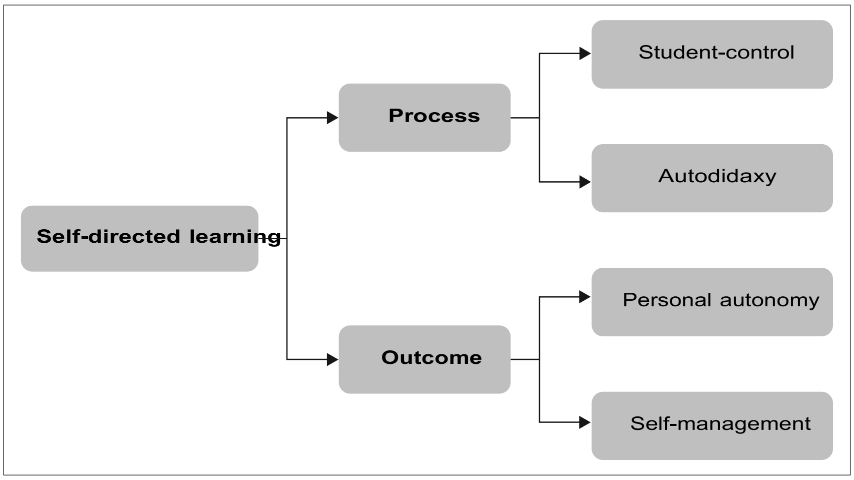
Pedagogies of play (i.e., games, drama and music) might hold affordances that other pedagogies might not, and may assist teachers in the teaching-learning situation to improve access to concepts, relationships and procedures in abstract school science, making it more meaningful and accessible to learners (Brits, De Beer & Mabotja, 2016; Rusling, 2009). This narrative engages teachers as *Homo ludens* or the 'playing human' (Huizinga, 1957), and affords teachers the opportunity to make the curriculum more relevant and interesting in the digital age.

1.5.9 PhET interactive simulations

The PhET (Physics Education Technology) project makes innovative simulations available for teaching and learning physics (and other sciences) and makes them freely available on the PhET website (http://phet.colorado.edu) (Perkins et al., 2006). According to Perkins et al. (2006:18) these simulations provide learners with opportunities to learn 'through exploration in an interactive, game-like environment'. Thompson et al. (1996) consider simulations as a model used to represent scientific phenomena. The model is used to replicate an abstract idea into a basic version of a scientific process, which is built upon a mathematical model aimed to emulate reality (Radinschi et al., 2017). The PhET simulations holds affordances to provide learners with practical skills and the nature of science in schools that are under- resourced, like many South African schools.

1.5.10 Self-directed learning

It is hoped that this study will enhance self-directed learning (SDL) among the participating teachers, but eventually also among their school learners. Knowles (1975:19) defines SDL as follows: 'In its broadest meaning self-directed learning describes a process by which individuals take the initiative, with or without the assistance of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating outcomes'. Johnson & Johnson (1999:2) again describe SDL as 'a situation in which (a) the individual is able to define his or her own goals, (b) the goals are related to his or her central needs or values, (c) the individual is able to define the paths (i.e., procedures, strategies, resources) taken to achieve the goals, and (d) the achievement of these goals represents a realistic level of aspiration for the individual, that is, not too high or too low, but enough to be challenging'. These are some of the SDL principles that guided the design and implementation of inquiry using a spectrometer as discussed above. A representation of the SDL model is given in Figure 1.3.



Source:Recreated from Candy (1991:22).

Figure 1.3: Simple representation the SDL model (adapted from Candy (1991:22).)

During the intervention, the teachers identified their own professional development needs and the facilitators supported the teachers in their self-directed learning. The image in Figure 1.4 shows teachers developing their own resources for a Natural Sciences classroom.

Figure 1.4: The A-Team constructing spectrometers guided by the characteristics of SDL according to Johnson and Johnson (1999:2), and demonstrating teacher agency

Photographer: Tswakae Sebotsa. All participants provided consent that the photographs may be published.

1.5.11 Project-based learning as a form of problem-based learning

Smith and Kristie (2017:34) define project-based learning (PBL) as 'a teaching-learning method by which students increase knowledge, skills (practical skills, communication skills, skills to work effectively in a group) and values by working for a period of time to investigate and respond to an authentic, engaging and complex question, problem, or challenge'.

Barrows (2002) argues further that PBL is a student-centred approach in which students need to determine their own learning needs, what they need to learn, define the gaps in their knowledge base, and plan and reflect how to acquire the missing knowledge.

Torp and Sage (2002) described PBL as focused experiential learning organised around the investigation and resolution of messy, real-world problems. They describe students as engaged problem solvers, seeking to identify the root problem and the conditions needed for a good solution and, in the process, becoming self-directed learners. PBL is an effective and enjoyable way to learn – and to develop deeper learning competencies required for success in learning and in life (https://www.bie.org/about/what_pbl).

In this study, teachers attended a short learning programme on the infusion of indigenous knowledge into the science curriculum. Teachers submitted a project-based portfolio.

The project required the teachers to solve problems related to the infusion of IK in the classroom by testing the following knowledge and skills:

- Teachers were required to focus on experiential learning organised around the investigation and resolution of messy, real-world problems.
- Teachers had to be problem solvers.
- Teachers had to showcase their practical skills, communication skills, and skills to work effectively in a group.
- Teachers were required to showcase their ability to engage in a complex question, problem, or challenge to solve a context-based problem.

1.6 AIMS OF THE RESEARCH AND RESEARCH QUESTIONS

1.6.1 The research questions that guided the study

The following primary research question guided the research:

Primary research question

What are Senior Phase Natural Sciences teachers' lived experiences of participating in a longitudinal and systemic professional development intervention, aimed at addressing their specific professional development needs?

Given the complexity of this study, the following secondary research questions were formulated as follows:

Secondary research questions

- What is the role of a professional development programme in assisting Natural Sciences teachers to develop more nuanced views of the tenets of science?
- What is the role of a professional development programme in assisting Natural Sciences teachers to develop more nuanced views of the tenets of indigenous knowledge?
- What are teachers' experiences of implementing contextualised problem-based learning (PBL) in the Natural Sciences classroom?
- What transfer of newly acquired knowledge and skills took place in the classroom, after the series of professional development interventions?

- How do teachers' views of their own self-directed learning change during the intervention?
- What are teachers' experiences of using science-on-a-shoestring (frugal science) approaches in the classroom?
- What difficulties do teachers experience in using PhET-simulations (ICT's) in the classroom?
- How do teachers contextualise lessons after the intervention?
- What are the experiences of the Natural Sciences' teachers after engaging in authentic investigations in a real science laboratory at the African Centre for DNA Barcoding?
- What insights does an auto-ethnography offer when evaluating the intervention?

1.7 Aims of the study

The main aim of the research was to investigate Natural Sciences teachers' lived experiences of developing contextualised learning opportunities in their classrooms, after a professional development intervention.

The following sub-aims guided this study:

- To determine the views that teachers held of the nature of science, before and after the intervention.
- To determine the views that teachers held of the nature of indigenous knowledge, before and after the intervention.
- To document teachers' experiences of implementing contextualised PBL in the Natural Sciences classroom.
- To research how teachers use PBL in their classrooms and what transfer took place in the classroom, after the professional development intervention.
- To determine teachers' views of their own self-directed learning prior to, and after, the intervention.
- To record teachers' experiences of using science-on-a-shoestring approaches in teaching optics in the classroom.
- To document difficulties that teachers experienced in using ICT's (PhET-simulations) in the science classroom.
- To record how teachers contextualised lessons after the intervention.

- To document teachers’ experiences of engaging in authentic investigations in a real science laboratory at the African Centre for DNA Barcoding.
- To document the significance of an auto-ethnography in adding value to the intervention.

1.7 RESEARCH DESIGN

This study used an exploratory sequential design mixed-method research approach to triangulate data (Creswell & Plano Clark, 2007) and to provide a thick data description (Geertz, 1973). The exploratory mixed-method design approach favoured a dominant qualitative component, and included elements of qualitative case studies, phenomenology (capturing teachers’ lived experiences), and design-based research. The quantitative data was collected through a self-directed learning instrument (Cheng et al., 2010), as well as the Likert-scale component of the Reformed Teaching Observation Protocol (RTOP). However, due to the small sample, descriptive statistical analysis was only performed on the data from the SDLI instrument. The qualitative data was collected through individual, personal interviews, a focus group interview, lesson observations, and a number of qualitative instruments (such as VNOS and VNOIK); as well as teacher portfolios (with lesson plans), and a researcher auto-ethnography, all of which provided a ‘thick description’ (Geertz, 1973).

Merriam and Tisdell (2016:37) describe a case study as ‘an in-depth description and analysis of a bounded system’. In this study, six classrooms acted as ‘bounded systems’ or, in the parlance of CHAT, ‘activity systems’. In each of these systems (teachers' classrooms), the teachers' lived experiences of using PBL (to infuse IK into the Natural Sciences curriculum); the Jigsaw method (cooperative learning); science-on-a-shoestring approaches; PhET simulations; DNA barcoding investigations; optics experiments; managing personal wellbeing; and the SLP activities were captured.

The study therefore has elements of a phenomenological inquiry. Merriam and Tisdell (2016:26) describe phenomenology as ‘the way of access to the world as we experience it pre-reflectively…pre-reflective experience is the ordinary experience we live in’. Unlike ‘pure’ phenomenological studies, this study drew on pre-determined theoretical and conceptual frameworks (such as CHAT). Since third-generation Cultural-Historical Activity Theory (CHAT) as conceptualised by Engeström (1987) was used as a research lens, and

Vygotsky's social constructivism as a theoretical framework, this study cannot claim to be a pure phenomenological study. However, capturing teachers' lived experiences of the intervention infused the study with a phenomenological slant.

The study also has elements of design-based research (DBR). Plomp and Nieveen (2010:13) describe DBR as '...the systematic study of designing, developing and evaluating educational interventions as solutions for complex problems in educational practice, which also aims at advancing our knowledge about the characteristics of these interventions and the processes of designing and developing them'. In my final chapter, I distilled design principles that could guide the next cycle of workshops or short learning programmes as part of professional development within a community of practice.

1.7.1 Population and sampling

The population sampled was the teachers in Ikageng and Promosa schools in Potchefstroom, North-West Province, who are teaching Senior Phase Natural Sciences, as the research is aimed specifically at Natural Sciences teachers. A purposive sampling method, as proposed by Creswell (2013), was used to select the 10 teachers who participated in the study. These teachers all indicated their enthusiasm to participate in the longitudinal intervention. Unfortunately, out of the 10 participants, only six participants submitted all the information needed to compile the profiles.

Because of the ethical guidelines, the researcher only reports on those aspects of the profiles that provide an in-depth understanding of the six activity systems. Due to the comprehensive data collection, six profiles and six activity systems lead to data saturation, and what Geertz (1973) calls a 'thick description' of the phenomenon. The researcher only selected teachers who were teaching grade 7–9 Natural Sciences, as this criterion qualified the participants for sampling purposes.

1.7.2 Research methods, instruments and data collection

Both quantitative and qualitative data was gathered by making use of pre- and post-intervention questionnaires for teachers, as well as interviews, classroom observations, and the analysis of artefacts. Insights from my own auto-ethnography were also used. In this section, I provide the reader with an overview of the research methods, instruments used and data collection strategies. Detail discussion is provided in Chapter 3 in the methodology section; and the data is presented in Chapter 4 in the data analysis section.

1.7.2.1 Views-of-the-nature-of-science (VNOS) questionnaire

In this study, the views-of-the-nature-of-science (VNOS) questionnaire (Abd-El-Khalick, Bell & Lederman, 1998) was used. This questionnaire helped the researcher to determine the views that teachers hold of the nature of science, before and after the intervention.

1.7.2.2 Views-of-the-nature-of-indigenous-knowledge (VNOIK) instrument

The researcher used Cronje's (2015) views-of-the-nature-of-indigenous-knowledge (VNOIK) instrument. This instrument assisted the researcher to determine the views that teachers held on the nature of indigenous knowledge, both before and after the intervention.

1.7.2.3 Qualitative, open-ended questionnaire

A qualitative questionnaire was developed to determine how teachers view their participation in the intervention (workshops and the SLP), and their participation in the community of practice.

1.7.2.4 Questionnaire to determine teachers' professional development needs

In order to determine the real needs of teachers, they were asked to complete a questionnaire. The tailor-made programme then addressed these specific needs.

1.7.2.5 Pre- and post-test on content knowledge

In order to evaluate the teachers' content knowledge, and the success of the intervention, the teachers completed pre- and post-tests on the topic of optics from the grade 7-9 Natural Sciences curriculum.

1.7.2.6 Individual interviews with participating teachers

Each participant was interviewed. The interview consisted of a pre- and post-interview (exit interview). The interviews captured a series of themes ranging from the teachers' lived experiences of the intervention to the value of a community of practice. The main aim of the interviews was to probe for deeper information from the participants.

1.7.2.7 Focus-group interview

On the way back from an exhilarating laboratory work session hosted by the African Centre for DNA Barcoding at the University of Johannesburg, teachers were interviewed on their experiences of the intervention. A two-hour detailed focus-group interview was conducted with the teachers.

1.7.2.8 Classroom observations (Reformed Teaching Observation Protocol)

During the lesson observation, the researcher used the RTOP (Reformed Teaching Observation Protocol) instrument (Sawada et al.,2002). The instrument was used to evaluate the current teaching practice of the teacher (pre-observation) and if there was any change in the teachers' pedagogical orientation after the intervention (post-intervention).

1.7.2.9 The stimulated recall method

With their permission, teachers' lessons were video-recorded during the last round of classroom and lesson observations. The video was then played back during the reflection sessions. The purpose of this approach was to prompt the teacher to critically reflect on his or her teaching actions. According to Moustakas (1994), and Mostert (2019), this method is called the stimulated recall method. The information from the reflection and the video was used in data triangulation.

1.7.2.10 Cheng's self-directed learning instrument (SDLI)

Cheng's self-directed learning instrument (SDLI) was used to measure self-directed learning. With the growing trend of preparing students for lifelong learning and for jobs not yet existing, we had to consider theory and a mechanism to assist teachers in preparing learners for a rapidly changing world. Skills for the 21st century are no longer negotiable, but have to be implemented.

The theory of self-directed learning (SDL) has been increasingly applied in the context of higher education to determine teachers' views on their own self-directed learning. The current research shows a real need to foster the same behaviour in secondary and high schools. To foster lifelong learning and self-directed learning, an appropriate instrument to measure SDL abilities was needed. I administered a pre- and post-SDLI instrument (Cheng et al., 2010) which determined whether teachers' views on their own self-directed learning had changed as a result of the intervention.

1.7.2.11 Teacher Portfolios

On a voluntary basis, teachers were asked to submit a portfolio of evidence within two months of attending the short learning programme (SLP). The portfolios dealt with the infusion of indigenous knowledge in Natural Sciences classroom. The portfolio was divided into three sections:

(a) Growth portfolio;
(b) Showcase portfolio;
(c) Evaluation portfolio.

After the portfolios were completed and assessed, the teachers received 16 credits and NWU certificate, depending whether they had reached a minimum pass mark of 50%, or above.

1.7.2.12 Auto-ethnography

Throughout this research study, I kept a researcher diary on the events that took place. This diary served as an auto-ethnography – a personal narrative on how I experienced the intervention with teachers. This narrative was used to add to the richness of the data.

1.8 DATA ANALYSIS

The teachers' responses to the questions in the questionnaires were analysed. Saldaña's (2009) coding technique was used for the qualitative data, and codes, categories and emerging themes were distilled. With respect to the codes, the in-vivo coding system was used (codes taken from the exact words spoken by the participants). These were organised into categories and then into themes. The following instruments and strategies were used to generate and analyse data:

1.8.1 Pre- and post-VNOS and VNOIK questionnaire

The pre- and post-VNOS (Abd-El-Khalick & Lederman, 1999) and the pre- and post-VNOIK (Cronje, 2015) questionnaires were administered. Both the instruments were analysed and quantified using rubrics. For the VNOS instrument, I used insights from Lederman et al. (2002). According to Lederman et al. (2002), teacher responses can be characterised as either (a) naive views, or (b) informed views. For the VNOIK instrument, I used insights from Cronje (2015) on how to capture teacher's views. She suggests a rubric based on the following three levels when considering the views of teachers: (a) a naive or uninformed view (UI), (b) a partially informed view (PI), and (c) an informed and nuanced view (I). In this study, the researcher adapted VNOS (Abd-El-Khalick & Lederman, 1999) and VNOIK (Cronje, 2005) questionnaires for a Natural Sciences context.

1.8.2 Pre- and post-RTOP instrument

The RTOP instrument was used to analyse the teachers' lessons before and after the intervention. Likert-scales items were used to provide qualitative descriptions of dilemmas and successes in the classroom.

1.8.3 Pre- and post-SDLI (Cheng) questionnaire

The Cheng et al. (2010:1152) SDLI instrument, for determining own view of one's self-directed learning, measures four variables, namely, learning motivation, planning and implementation, self-monitoring, and interpersonal communication. The items consist of Likert-scale options, and quantitative data illustrate levels of perceived self-directed learning:

- 20–46: low level of SDL
- 47–72: average level of SDL
- 73–100: high level of SDL

Descriptive statistics were performed using SPSS Version 22 to enable comparison between pre- and post-responses.

1.8.4 Stimulated recall instrument

Artefacts such as video images and film have featured in the development of social research within sociology, anthropology, education and psychology (Jewitt, 2012).

The researcher used videos to probe and qualify meaning by observing how the teachers' pedagogy changed after the intervention. The use of video as a research instrument surpasses other forms of qualitative data collection data. It provides a fine-grained multimodal record of an event detailing gaze, expression, body posture, and gesture (*ibid*). I developed a guideline that helped me to probe into the teacher's experience and pedagogical orientation. The instrument was guided by Ramnarain and Schuster's (2014) insights on teacher pedagogical orientation.

1.8.5 Stress-management questionnaire

It is widely acknowledged that teaching is a challenging career, due to systemic pressures coming from officials, i.e., HoDs, principals, DoE officials and often parents. A number of studies globally have found teachers are at a relatively high risk for common mental disorders and work-related stress, as compared to other professions (Stansfeld et al., 2011; Wieclaw et al., 2005). Many researchers have found that teaching in today's world is placing greater health demands on teachers than before (Liu et al., 2018); since stress or dissatisfaction at work is associated with poorer wellbeing and depressive symptoms (Ahola et al., 2006; Kidger et al., 2016). This reported work-related stress, and the associated burnout, was the reason for including stress management in the professional development programme (Vazisup et al., 2011)

A questionnaire was designed that required teachers to explicitly identify their own professional development needs, which was analysed according to Saldaña's (2009) method of coding and theming.

1.8.6 Pre- and post-DNA barcoding questionnaire

The teachers spend two days at the University of Johannesburg (Auckland Park Campus). The researcher viewed this as a remarkable sacrifice on the part of the teachers who had to negotiate with their other weekend commitments to participate for the benefit of educational improvement. It is appropriate to reiterate that it takes an A-Team to make this sacrifice. During this excursion, teachers mixed with lecturers and researchers in research laboratories.

This new approach to science education originated from the Target Inquiry: Ohio schools' project that was run by Miami University, USA
The approach was aimed at fostering teacher's views on the nature of science, and to inspire science interest. During the laboratory and lecture sessions, teachers were afforded an opportunity to learn and experience real science in an authentic laboratory at the African Centre for DNA Barcoding. Teacher completed a pre- and post-questionnaire based on their experiences of this excursion. From the data I distilled a number of themes according to Saldaña (2009).

1.8.7 Natural Sciences pre- and post-questionnaire

The aim of this questionnaire was to assist the researcher in profiling the A-Team teachers. From the questionnaire, the researcher was able to capture information such as teaching experience, demographics, challenges in teaching Natural Sciences, and other information needed to inform the teacher development programme. From the data, a number of emerging themes were distilled according to Saldaña (2009).

1.8.8 Content knowledge pre- and post-questionnaire

Teachers were provided with a Natural Sciences pre-test and post-test during, and after, the intervention. The pre-test was compared to the post-test to evaluate if a customised teacher professional development intervention provides positive results or not.

1.8.9 Focus group and exit-group interviews

Teacher's focus group and individual exit-group interviews were firstly transcribed and then analysed using Saldaña's (2009) approach for deriving themes and making meaning.

1.8.10 SDLI instrument for determining teachers' views on their self-directed learning

I administered the SDLI (Cheng, 2010) instrument to determine whether teachers' views on their own self-directed learning changed during the intervention. The instrument consists of 20 items, utilising a 5-point Likert scale. The items cover four categories, namely, learning motivation, planning and implementation, self-monitoring, and interpersonal communication. This instrument was used pre- and post-intervention. A mean score for each teacher was determined.

1.8.11 Portfolio's assessment of the integration of indigenous knowledge into the Natural Sciences classroom

Rubrics were used to assess if the A-Team teachers were able to implement indigenous knowledge in the Natural Sciences classroom after the interventions.

1.9 INTERPRETING THE DATA USING CHAT AS THE RESEARCH LENS

I used Cultural-Historical Activity Theory (CHAT) in a conventional way, namely as a research lens on the personal plane, where the subject is an individual, in this case, the Natural Sciences teacher. The object in the activity system was the teacher's professional development and teacher's experiences of the contextualised intervention programme. The unit of analysis is always the person in context (Havnes, 2010), that is, the person imbedded within an activity system. An activity system is a construct derived from the work of Engeström (1987), a prominent researcher in the Vygotskyan tradition (together with researchers like Leont'ev, Luria and Veresov), and it assisted the researcher to understand how the A-Team teachers were embedded in a 'sociocultural context with which they continuously interacted' (Sebotsa et al., 2018:270).

Such an activity system also comprises tools relevant to the activity (e.g., PBL, teaching indigenous knowledge, and utilising shoestring science); rules that shape participation in the activity (e.g., the tenets of science and indigenous knowledge, and the guidelines in the CAPS curriculum); the community (all the stakeholders involved in the activity system); and, lastly, the division of labour required to carry out the activity. The latter would, for example, refer to the different 'roles' of the teacher, e.g., that of mediator of learning, critical-reflective practitioner, agent of change, and self-directed learner (life-long learner) (Mentz & De Beer, 2019). With this particular lens, the researcher was able to see how transfer took place in the Natural Sciences classroom after the intervention and what hindrances occurred that were unforeseen in the design of the intervention. The lens was also used to capture the affordances of the Natural Sciences teacher professional development programme (Sebotsa et al., 2018).

I have also used CHAT in a sophisticated way as suggested by both Engeström (1987) and Mentz and De Beer (2017), namely juxtaposing two interdependent activity systems on an institutional plane.

From the results of CHAT on a personal plane, the researcher was able to disseminate the data and zoom into the contradiction of control between the school and the A-Team intervention. Third-generation CHAT was used to study the six activity systems (as one bounded system) on an institutional plane. This view helped the researcher to generalise findings from the Natural Sciences classrooms in the Potchefstroom townships. The CHAT lens allowed a specific 'gaze' into the activity system, and it assisted in identifying 'tensions' or problems that teachers experience in their teaching of Natural Sciences (Mentz & De Beer, 2019). CHAT played a vital role in assisting the study in formulating design principles for enhancing future professional development in similar contexts. The auto-ethnography was used to further the understanding of data and to explain events from observations during the pre- and post-intervention. Codes were allocated to researcher narrative in diary and used to enhance the use and interpretation of CHAT.

1.10 THE ROLE OF THE RESEARCHER

Since the study used a mixed-method design, both quantitative and qualitative data were collected. The type of mixed-method design that was used is referred to as a procedural notation, i.e., 'the QUAL→quant model' (Gay et al., 2011:484), suggesting that the methodology is primarily qualitative with a lesser emphasis on the quantitative component (Creswell, 2013; Creswell et al., 2003). As a qualitative researcher, I acted as an 'insider' (emic) (Simon, 2011), that engaged the teachers in the indigenous knowledge intervention (SLP). The heart of qualitative research lies in 'the extraction of meaning from data' (Hesse-Biber & Leavy, 2011:151), i.e., the researcher interviewed and observed teachers to capture the social meaning people attribute to their experiences, circumstances and situations. From the individual descriptions, general or universal meanings are derived. To achieve this approach, the researcher must set aside personal biases, which is to 'bracket or suspend personal judgement' (Maree, 2016:77). These following measures explained below helped me be to remained objective:

1.11 VALIDITY AND RELIABILITY (TRUSTWORTHINESS AND CREDIBILITY)

Validity and reliability are crucial criteria in assessing the quality of research (Seale, 2004). All the instruments used in this study were assessed for their reliability and their validity, since, as Engelhardt and Beichner (2004:102) state, 'for the test to be useful and its results to be accurately applied and interpreted, it must be reliable and valid'.

Reliability relates to the 'extent to which an instrument provides similar results every time it is administered to the same sample at different times' (Engelhardt & Beichner, 2004:102).

To insure optimum validity in this this study, the researcher drew guidance from the four standards proposed by Eisenhart and Jurow (2011), as will be discussed in Chapter 3.

1.12 ETHICAL CONSIDERATIONS

According to Creswell (2013), ethical issues should be considered throughout the study, not only during the data collection stage. Generic ethical clearance was obtained for the NRF-funded project on indigenous knowledge (under which this study falls). Ethical clearance certificate reference number NWU-00271-16-A2 is provided in the appendices as appendix A1. Ethical clearance for this particular study was also obtained from the Ethics Committee at the North-West University as a few additional instruments, not included in the generic application, were used (see appendix A2-certificate reference number NWU-00473-18-S2). Teachers involved in this study gave informed consent that their photographs taken during the intervention could be utilised and published for research purposes.

1.13 SIGNIFICANCE OF THE STUDY

This study made contributions on five levels as discussed below.

1.13.1 Epistemological contribution

This study looked at epistemological border-crossing, where indigenous knowledge is infused into a Natural Sciences (Western) curriculum. Teachers' experiences of such border-crossing contributed to the findings. Based on these findings, recommendations were made for future teacher professional development programmes. These recommendations are discussed in Chapter 5.

1.13.2 Research contribution

In this study, CHAT was used as a research lens on two levels. One level was on a personal plane and the second level on an institutional plane. On the personal level or plane, CHAT was used to juxtapose two interdependent activity systems. In one system the object entailed teacher professional development and in the other system the object was transformative teaching and learning, intended to replace transmission mode teaching. The findings provided insights on how Natural Sciences teacher professional development programmes can be contextualised.

On the institutional level, where the subject was a phenomenon, and not a person, the object was transformed teaching underpinned by self-directed learning principles. This study, therefore, contributes to a growing body of literature on the versatility of CHAT as a research lens. I was also interested in teachers' views on indigenous knowledge. In addition, data from the adapted VNOIK questionnaire contributed towards the validation of Cronje's (2015) instrument, as her original study did not generate sufficient data to permit Rasch modelling for validation purposes.

1.13.3 Practical contribution

The SLPs empowered Natural Sciences teachers by developing their PCK. Insights from this study will also assist NWU developers to re-design future SLPs. This study formed part of a larger National Research Foundation (NRF) funded research project and a Fuchs Foundation project, Teachers without Borders, and the participating teachers were all provided with learning resources for their classrooms.

1.13.4 Design principles

This study reports on two cycles, with the 2018/19 cycle building on insights from previous interventions during the bigger generic project of 2016/17. Additional design principles, for such teacher professional development interventions, were distilled from the findings of this study.

1.13.5 Methodological contribution

One of the major contributions of the study is on a methodological level. Insights obtained from this study have contributed to expanding the current model of the profile of implementation (Rogan & Grayson, 2004; Rogan & Aldous, 2005; Petersen & De Beer, 2016). An additional domain, namely that of self-directed learning, was added to the framework. The SDL construct also has five levels (divided from 0-4), which will be discussed later in this dissertation.

1.14 NAVIGATING THE DISSERTATION

The following chapter division is used in the dissertation:

- Chapter 1: An Overview of the Study
- Chapter 2: Literature Review and Frameworks
- Chapter 3: Research Design and Research Methods
- Chapter 4: Analysis of Data and Major Findings
- Chapter 5: Summary of Findings, Conclusion and Recommendations.

Figure 1.5 below provides a further tool for navigating the dissertation, as it provides a conceptual roadmap or GPS to assist the reader.

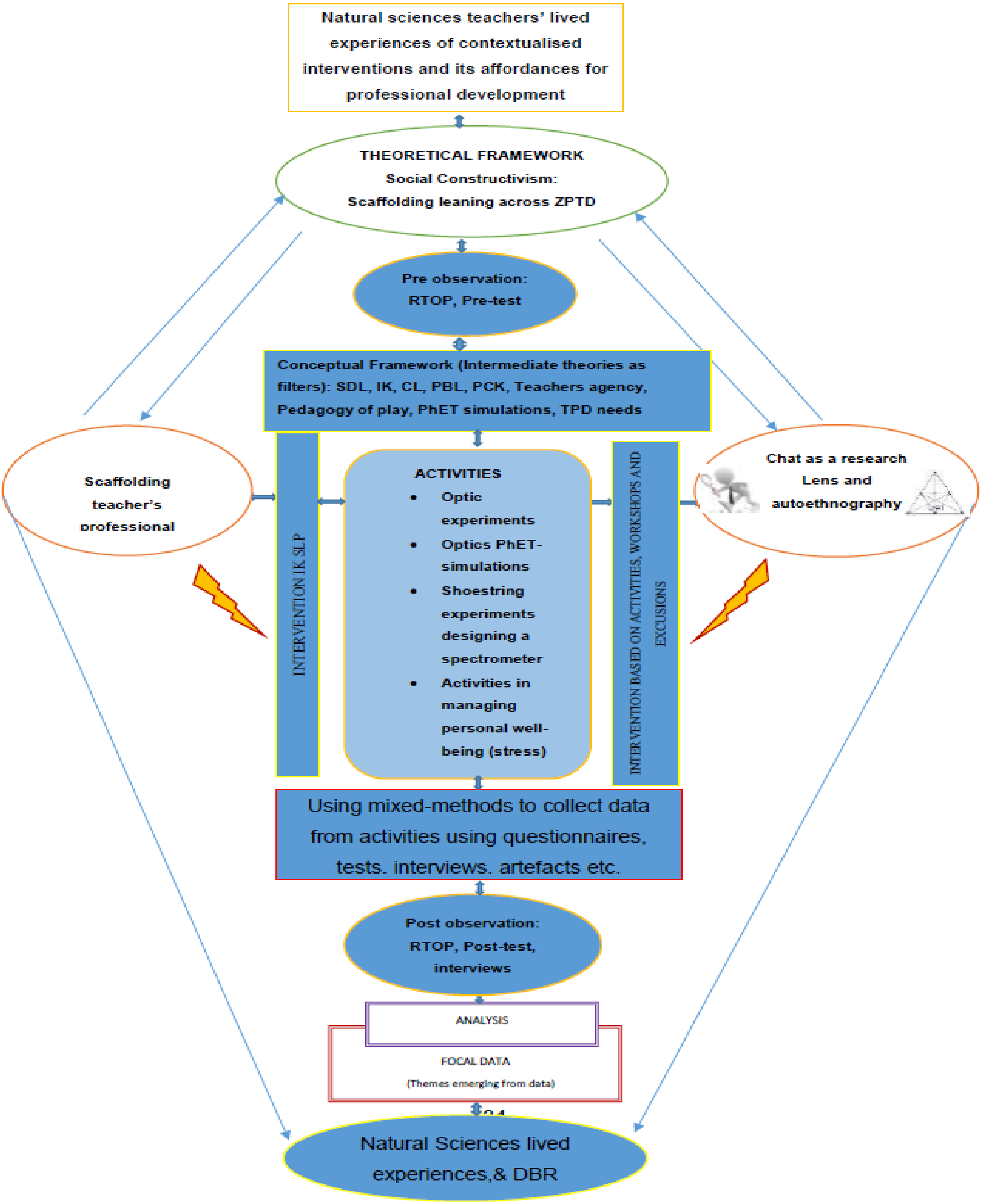


Figure 1.5: Navigation the dissertation

CHAPTER 2: A REVIEW OF THE LITERATURE AND THE THEORETICAL AND CONCEPTUAL FRAMEWORKS OF THE STUDY

'In a completely rational society, the best of us would aspire to be teachers and the rest of us would have to settle for something less, because passing civilisation along from one generation to the next ought to be the highest honour and the highest responsibility anyone could have.' Lee Lacocca (2006)

2.1. INTRODUCTION: 'RUNNING AWAY' AND 'STAYING BEHIND'

O'Brien (1977:297) explains the metaphors 'running away' and 'staying behind' as follows:

> The key to the metaphor lies, I believe, in recognising the paradox that in terms of Plato's metaphor something stays as it is, for example, continues to be fire and to be hot, or to be cold and to be snow, by running away. Plato's argument is that fire will either 'run away', i.e., it will escape the onslaught of cold, and so continue to be fire, or else it will perish. For in terms of Plato's metaphor if something which is characterised essentially by one of a pair of opposites, in the way that soul is, were to 'stay-behind' then it would have to 'accept' the opposite of the form by which it is characterised, and that it cannot do. Fire cannot be cold. Snow cannot be hot. The soul cannot be dead.

This passage argues the position that hot and cold, in a rational sense, cannot co-exist; and that fire cannot 'stay-behind' and 'accept' cold if the fire has to retain its status. While that is the context, I use this metaphor to express the dualism that science teachers experience. In my narrative, many science teachers have the zeal and passion for their work (Scheerens, 2016), e.g., the A-Team teachers in this study, but may lack adequate PCK.

Few will dispute the statement that science teacher education in South Africa has been severely criticised (Taylor, Fleisch & Shindler, 2019; Yükse & Sezer, 2017; Spaull, 2013). Ramnarain and Fortus (2013), as well as Petersen and De Beer (2012), argue that teachers may have passion for their profession, but many science teachers lack adequate content knowledge and pedagogical knowledge.

This situation creates a lukewarm teaching status (hot and cold are co-existing in this instance). The researcher asks the question: 'Is science education in South Africa approaching a deathbed?' Science teachers, at the coalface of teaching, need to address the poor quality of education (coldness). On the other hand, many of them are passionate and dedicated to teaching and experience the 'fire' of professionalism in them. It thus becomes important to support teachers in moving from ‘lukewarm’ to ‘fire’ status.

This can be provided by consistently engaging teachers in learning new knowledge and skills tailored to their own needs (Sebotsa, De Beer & Kriek, 2018), and by promoting lifelong learning during teacher professional development (Wang, 2019). According to Tiriri (2019), lifelong learning is the basis of strengthening 21st century skills. These skills are also the skills required by a self-directed teacher (Mishra, Fahnoe & Henriksen, 2013). According to the new development in the 21st century Framework, learners are required to take the initiative for their own learning. In the P21 Framework (enGauge 21st Century Skills, 2003) on life and career skills, taking the initiative and self-directedness are intertwined, and are regarded as significant to personal learning experiences (Caffarella, 1993). The International Society for Technology in Education (ISTE) Standards for students (2007), require learners to be capable of planning and managing activities and developing a solution or complete a project. These skills are indispensable for a self-directed learner and are also emphasised in the P21 Framework (enGauge 21st Century Skills, 2003).

Insights from Tiriri (2019) and Wang (2019) indicate that teachers need to take a stand on their self-development. According to Johnson and Johnson (1999:2) teachers take cognisance of their own teacher development in ‘a situation in which (a) the individual can define his or her own goals, (b) the goals are related to his or her central needs or values, (c) the individual is able to define the paths (i.e., procedures, strategies, resources) taken to achieve the goals, and (d) the achievement of these goals represents a realistic level of aspiration for the individual, that is, not too high or too low, but enough to be challenging’.

I am of the view that the SDL approach fits ‘hand in glove’ as a mechanism to support teachers in moving the 21st century skills agenda forward. Unlike the popular belief that 21st-century skills are only technological skills, Paige (2009) takes the view that 21st-century skills include technology skills, aptitude in critical thinking, communication, teamwork and problem-solving skills. These are elements required for a self-directed learner or teacher (Lee et al., 2014). To advocate change in the science education fraternity, and to move away from the ‘lukewarm’ status, we have to motivate the teachers to be self-directed learners, i.e., assist teachers during teacher professional development programmes, which should be built on self-directed learning principles. To improve the status of education in South Africa, researchers/ stakeholders should make it their priority to revise longitudinal and systemic teacher professional development programmes (Pretorius, 2015; Kriek & Grayson, 2009) that consider teachers' needs (Ramnarain & Fortus, 2013) within the structure of supportive communities of practice (Sebotsa, De Beer & Kriek, 2018; Antoniou, 2017; Jackson, De Beer & White, 2016: Pretorius, 2015; DoE, 2001). Clear design principles should be instilled to guide such programmes (Jackson, De Beer & White, 2016).

These design principles should also be rooted in the continual development of teachers, in order to enhance their pedagogical content knowledge (PCK) (Shulman, 1987). The science teacher should, by virtue of being a teacher, be guided by his/her pedagogical content knowledge to foster inquiring minds and 21st century skills in the next generation, and to keep the diversity of learners in mind. This is especially important in previously disadvantaged schools. Ramnarain and Schuster (2014) have shown that teachers in townships and rural areas often face more systemic pressure (e.g., from parents and school principals), than teachers in more affluent schools, and often their own pedagogical beliefs are marginalised due to systemic pressure.

It is the focus of this study to (a) inspire and capacitate teachers, (b) to enhance their PCK, and (c) to better prepare learners for a challenging 21st-century world and to set a standard of excellence by championing the status of quality teaching and education: ‘The most fundamental resource in the modern economy is knowledge and, accordingly, the most important process is learning’ (Lundvall, 1992:1).

This chapter aims to highlight failures (the past) and prospects (the future) of science education in South Africa.

I commence this chapter by providing a detailed picture of the state of science education in South Africa. I focus on perennial generic problems, as well as specific problems experienced by science teachers. This chapter also outlines the theoretical framework (social constructivism) and the conceptual frameworks that guide this study.
Social constructivism is used as the main theory. Cultural-Historical Activity Theory (CHAT), emanating from social constructivism, is used as a research lens. Mentz and De Beer (2019) view CHAT as a flexible meta-theoretical framework that could assist the researcher in interpreting data in complex research settings. Several intermediate theories constitute the

conceptual framework, and these theories can be seen as ‘filters’ over the CHAT research lens.

2.2 THE STATE OF SCIENCE EDUCATION IN SOUTH AFRICA

In order to establish and understand why science teacher professional development is a momentous consideration, it is necessary to zoom into the current state of affairs in science education in South Africa. The researcher will paint a series of interrelated portraits and compare South African challenges regarding science education with other countries. Taylor (2008b) and Metcalfe (in Keating, 2007) state that the quality of the education system is highly dependent on the quality of its teachers. Competent and capable teachers contribute towards learners' educational outcomes (McKinsey, 2007). McKinsey’s insights support those of Taylor and Metcalfe, as the McKinsey report highlights that no schooling system can rise above the limits imposed by the quality of its teachers. It is the priority of each and every country to have excellent teachers. Quality teachers do not only improve test scores, they have long-term positive effects on the socioeconomic status of the country (The World Economic Forum's competitive index, 2017-8). Good teachers are like candles; they consume themselves to light the way for others (Atatürk, n.d.). Are our teachers ready to ‘light’ the way for our learners, to prepare the learners for jobs which do not yet exist, and to improve the economy of our country? And are our learners ready to shine and improve their self-directed learning and to adjust in a forever-changing world? (The Covid-19 pandemic has shown how ill-prepared South Africa is, with its high inequality index, in implementing quality blended learning). Current challenges experienced in South African science education are discussed below.

2.2.1. Poor science results: Two decades later

According to the latest World Economic Forum's (WEF) competitive index for 2017 to 2018, South African mathematics and science education is ranked 128 out of 137 countries (Schwab, 2018). The WEF’s global information technology report of 2014 ranked South Africa 144 out of 144 countries in terms of the quality of mathematics, science and technology education (Businesstech, 2019). South African Natural Sciences learners continue to perform poorly in international benchmark tests such as the Trends in Mathematics and Science Study (TIMSS) (Sebotsa et al., 2018: 268; De Beer, 2016; TIMSS, 2015; Kriek & Grayson, 2009) and in the Southern and East African Consortium for Monitoring Educational Quality (SACMEQ) (Spaull, 2013), as highlighted in Chapter 1. The

WEF authors argue that the quality of schooling in a country is a powerful indicator of the wealth that countries will produce in the long run. Currently the youth unemployment rate in South Africa is staggering, and increased from 54.7% in the fourth quarter of 2018 to 55.2% in the first quarter of 2019 (Sebotsa et al., 2019:339; Stats SA, 2019; Mail & Guardian, 2019).

Whilst that is the case, Ann Bernstein contends that 90% of South African schools are failing to meet minimum standards of performance in science subjects, thus effectively undermining the potential of many young South Africans and hampering the national development goals (Centre for Development and Enterprise, 2011). Furthermore, the International Monetary Fund (IMF) is of the opinion that South Africa's poor education system is partly responsible for the low economic growth (Sebotsa et al., 2019; Businesstech, 2019). South Africa is failing dismally in science and mathematics education. The poor performance of learners in Senior Phase Natural Sciences speaks, amongst others, of poor teaching and learning taking place in our schools. The TIMSS-R investigation conducted in 1999 showed that grade 8 learners once again performed badly. The student performance was lower than the international mean score of 487, to be specific the score was 275. The mean score was also sadly lower than other developing countries such as Tunisia and Morocco (Naidoo, 2004; Howie, 2001).

A later TIMSS-R study conducted in 2003 similarly points out that no improvement has been made by South African mathematics and science learners (Reddy, 2004). South African learners participated again in 2011, but the decision was made to test the grade 9 learners instead. Since then, from 2002 to 2011, the number of learners who performed lower than the bench mark of 400, doubled from 10.5% to 24% (HSRC, 2011). However, this is far from the reference point of 400, and older learners were involved in the study. As a consequence, the Department of Basic Education embarked on the Annual National Assessments (ANAs) to identify the source of the problem with mathematics performance. The subject Mathematics is a requirement for the subject Physical Sciences. Significantly, it was found that problems with mathematics start as early as primary school.
The 2013 ANA results shockingly indicated that only 39% of grade 6 learners (primary school) and 2% of grade 9 learners (secondary school) scored more than 50% in mathematics (Sebotsa et al., 2019:338-339; Mail & Guardian, 2014). In addition to learners' poor performance, Venkat and Spaull (2015) report the following findings from the SAQMEQ study with respect to teacher competency:

- 79% of grade 6 mathematics teachers revealed content knowledge levels below the grade 6/7;
- 17% of grade 6 learners in South Africa were taught by mathematics teachers who had content knowledge below a grade 4 or 5 level;
- 62% of grade 6 learners were taught by mathematics teachers who had a grade 4 or 5 level of content knowledge;
- 5% of grade 6 learners were taught by mathematics teachers who had a grade 6 or 7 level of content knowledge;
- 60% of people teaching mathematics from grade one to grade six failed to pass tests for mathematics at the grade level taught (Venkat & Spaull, 2015);
- 16% of grade 6 learners were taught by mathematics teachers who had at least a grade 8 or 9 level of content knowledge. These results indicate that the problem with science and mathematics in the FET band is perpetuated by poor performance in the lower grades (Sebotsa et al., 2019: 340).

Taking cognisance of the Trends in Mathematics and Science Study, the World Economic Forum's competitive index, and the Southern and East African Consortium for Monitoring Educational Quality (SACMEQ), few people will dispute the fact that we are not making the grade, with our learners performing dismally poorly in mathematics and science.
In addition, the International Monetary Fund (IMF) is of the view that South Africa performs dismally poorly in mathematics and science in almost any international metric (Businesstech, 2019).

South African education is one of the largest constituents of government spending. In 2012, education comprised 20.6% of government expenditure in South Africa (World Bank, 2014). South Africa spends 5.4% of its GDP on education, which is high by comparable standards (Taylor, Fleisch & Shindler, 2019). A graph constructed by an advisory firm, the Boston Consulting Group (BCG), shows that South Africa spends more money than most of its peers on education – with worse outcomes (Sebotsa et al., 2019:339). Figure 2.1 below provides a synopsis of the poor performance of South African education compared to the other countries.

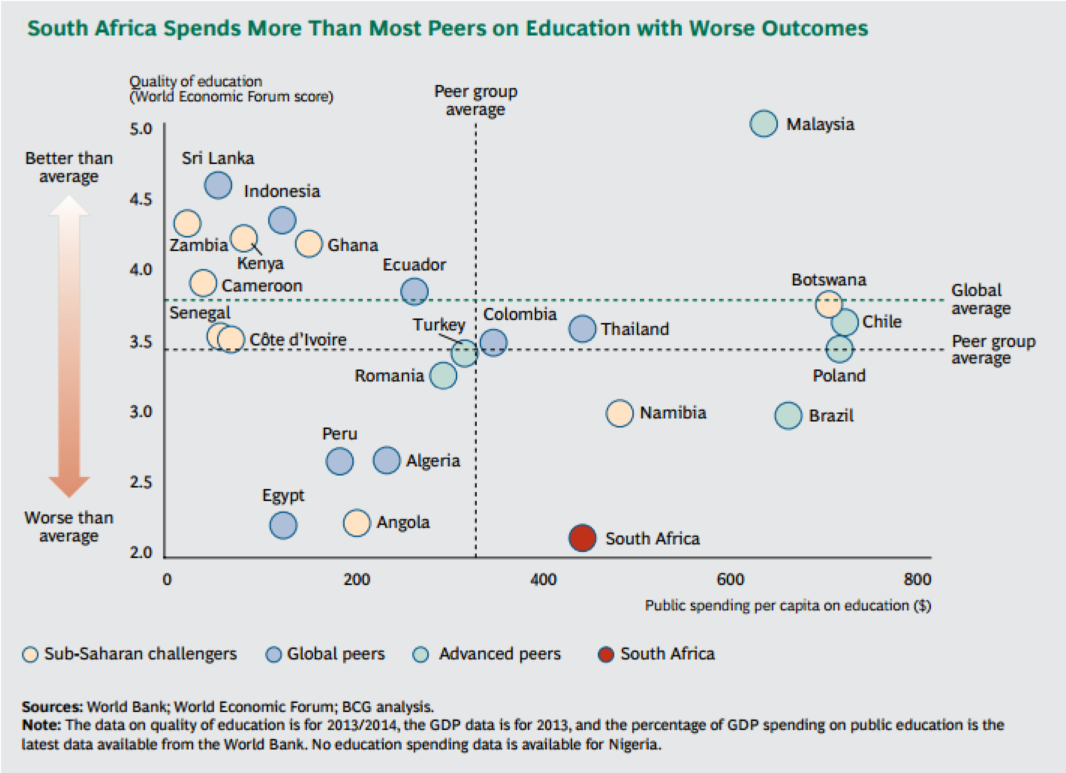


Figure 2.1: This graph shows how poor South African science education is relative to other countries (WEF, World Bank, and BCG analysis, 2013/2014)

Source:https://businesstech.co.za/news/government/89446/this-graph-shows-just-how-bad-south-africa-is-at-education

Science education in South Africa should be a national priority, so this state of affairs calls for a 'national emergency' declaration as it has a huge negative impact on South Africa's ability to be globally competitive. Most researchers direct the problem to incompetent teachers (Venkat & Spaull, 2015). Poor teacher quality and low levels of teacher competency are often cited as major drivers of South Africa's education crisis (Venkat & Spaull, 2015; Taylor et al., 2012:20). Bernstein (2011) is of the view that many South African science teachers do not possess science teaching competency.

The National Education Evaluation and Development Unit's (NEEDU) National Report of 2012 suggests that teachers are unable to ensure high quality education for learners 'either because they *won't* or because they *can't*' (Taylor et al., 2012:20). Where teachers and schools *won't* provide quality education, the result is lack of discipline among learners and this tantamount to poor performance. 'Where teachers *can't* provide quality education, professional development interventions should focus on improving and enhancing the knowledge base of teachers to equip them with the skills necessary for quality teaching and learning to take place in the classrooms' (Taylor et al., 2012:20). The above literature provides a strong argument that most of South African science teachers from grade 1 to 9 might not be adequately prepared to teach science and mathematics. In the view of the researcher the answer to this 'national emergency' is a holistic and a tailored approach to teacher professional development interventions. Science teachers' pedagogical orientations and PCK should be developed over sustained periods of time, and within supportive communities of practice (Sebotsa, De Beer & Kriek, 2018; Pretorius, 2015).

2.2.2 Teachers' lack of pedagogical content knowledge: *Who should teach?* A democracy later

It has become a general view that South African science education is a concern (Reddy et al., 2016; De Beer & Ramnarain, 2012; Ramnarain & Fortus, 2013). A perspective that perpetuates this concern is teachers' lack of pedagogical content knowledge. Shulman (1987) states that PCK distinguishes a teacher from a non-teaching content specialist. 'The differentiation is reflected in the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the background of the students' (p.15). Whether or not teachers help learners to have a good understanding of science remains unclear (Venkat & Spaul, 2015).

Do learners develop a nuanced understanding of the role of science in their everyday lives? This researcher opens the dialogue by engaging in a mediating conversation. The agenda in this section is based on reflecting on South African teachers' pedagogical content knowledge.

One of the three perennial reasons why teachers fail to teach science proficiently in South Africa is their lack of pedagogical content knowledge (PCK) (Reddy et al., 2016; Ramnarain, 2012; Petersen & De Beer, 2012). Lee Shulman first devised the term pedagogical content knowledge (PCK) in 1986. The term refers to a teacher's subject matter knowledge, and the skills of how to teach it to learners so that they comprehend the content (Reddy, De Beer & Petersen, 2016).

Research in education is interested in how teaching is related to student understanding and student outcomes. It seems clear that what a teacher knows has some bearing on how they teach and what students learn. Regrettably, when examining the relationship between measures of teacher content knowledge (i.e., grade-point average of students), only weak relationships to student outcomes are found (Gess-Newsome, 2015; Wayne & Youngs, 2003).

Learning to teach is very difficult; it has become one of the more researched phenomena in science education. Berliner (1988) is of the view that teaching for understanding is based on an authentic scholarship of practice. This requires a teacher who has a good content knowledge of the subject, and ways of teaching the content that acknowledge the notion of practice as being complex and interwoven. Since learning to teach is complex, it becomes important to explore how this influences the work of a teacher.

Loughran (2006) put it forward that in order to understand the relationship between teaching and learning we first need to understand the nature of the pedagogy of the teacher. Many researchers de-advocate chalk and talk pedagogy (Petersen & De Beer, 2012; Ramnarain & De Beer, 2013). This pedagogy is well renowned for its inability to produce learners who are self-directed in their own learning (Mentz & De Beer, 2019). It is important to look into the insights of why most teachers are not changing their pedagogy.

Pedagogy such as ‘chalk and talk’ or transmission mode in the South African context is well explained by the term ‘apprenticeship of observation’ (Lortie, 1975) and provides insight into why teachers are often comfortable with their pedagogies. Although the apprenticeship of observation is perhaps not widely known outside teacher education circles, what it refers to will be instantly recognised by most teachers (Michaela, 2014). The apprenticeship of observation describes the phenomenon whereby student teachers arrive for their training courses having spent thousands of hours as schoolchildren observing and evaluating professionals in action (Lortie, 1975).

This construct provides a reason why teachers teach as they were taught and assume that is the only spot-on way of doing it. Lortie (1975:62) writes that a student ‘sees the teacher frontstage and centre like an audience viewing a play’. However, he adds, whilst students can view the ‘frontstage’ behaviours, e.g., monitoring, correcting, and ‘chalk and talk’, they do not see the ‘backstage’ behaviours which are a crucial part of a teacher's job. Most researchers would agree that teaching is not centred on only one pedagogy and that, most crucially, a pedagogy that assumes that a teacher-centred approach is the only correct way.

Teaching for understanding becomes more difficult if one does not have a good idea why learners perform poorly after being taught. Further, this makes it unclear how to prepare teachers for the 21st century; and how to explore if teachers have the relevant PCK for these challenges. Below I focus on issues around teachers' PCK over the last two decades.

According to De Beer (2002), in 1996 only about 32% of South African science teachers were qualified and competent to teach science. In addition to that, a science audit exposed that more than 68% of science and 50% of mathematics teacherwere not in possession of formal subject training (DoE, 2001a). Ramnarain (2013) ascertains that most physical sciences teachers from township schools are deficient in content knowledge. Sebotsa, De Beer and Kriek (2018) highlight the fact that some of the Natural Sciences teachers still have underdeveloped content knowledge on the visible light theme more than a decade later. Mentz and De Beer (2019:51) comment: 'According to Kpangham (1992) and Osamwonyi (2016), teachers are members of an under-educated profession'. This highlights reason for a 'national emergency'.

Scholars such as De Beer (2007) and Muwanga-Zake (2004) lament the lack of ability of South African science teachers to meet curriculum demands. Most teachers have poor teaching styles and lack of didactical skills (Horak & Frickie, 2004:17; Ramnarain, 2012). Scholars such as De Beer (2007) redirect the problem to the education and training of teachers in the previous apartheid regime, Bantu education. Bantu education did not adequately develop the PCK of all teachers, as will be discussed.

This regime was characterised by the under-development of human potential (such as developing teachers' PCK; particularly the non-white South African teachers' professional development was marginalised). This links to the argument that teachers will mostly revert to their default model of teaching, and will teach as they were taught, hence exerting a conservative pressure on the teachers (Lortie, 1975). It is really disheartening to notice that 25 years into democracy schools still display Bantu education tendencies in their science classroom. Ramnarain and Shuster (2014) observed that many teachers teaching physical sciences in township schools are using teaching methods that are characterised by transmission mode approaches.

According to Armstrong (2015:3) ‘South Africa's legacy of inequality in education therefore continues, with historical divisions still playing a major role, despite massive resource shifts towards schools with lower socioeconomic status. One area in which the equalisation of resources remains a challenge, however, is that of attracting skilled teachers to poor and often remote schools’.

The consequences of Bantu education could still be realised in the outdated teaching practices and lack of basic content knowledge of many teachers which have resulted in poor South African teaching standards. The poor standards have resulted in the learning of mathematics, science and technology being compromised. These results could be argued as among the many reasons why learners cannot make sense of their science lessons, resulting in a generation of teachers who are further perpetuating the circle of mediocrity (DoE, 2001a).

Many teachers with under-developed PCK resort back to transmission-mode teaching and learning, such as ‘chalk and talk’ (De Beer & Ramnarain, 2012). I am of the view that ‘chalk and talk’ prevents self-directed and problem-based learning in the science classroom. The ‘chalk and talk’ approach assumes that learners enter the classroom as *tabula rasa,* focusing on memorisation and reproduction of knowledge, and this continues to fail our science education. Firstly, learners are not ‘empty vessels to be filled with knowledge’ (as traditional pedagogical theory had it). They are active builders of knowledge – little scientists who construct their own theories of the world (Piaget, 1970). Secondly, classroom teaching and learning should provide learners with a nuanced understanding of the nature of science (the syntactical nature of the subject, and its tenets) (Abd-El-Khalick & Lederman, 1999). Riga et al. (2017) agree with De Beer and Ramnarain (2012) that many teachers still use content-based, conventional transmission-mode teaching methods such as ‘chalk and talk’.

The traditional approach of teaching could be seen as fostering a lack of understanding in learners. In Berg and Brouwer’s (1991) study it was found that a third of the twenty physics teachers in the study were unaware of their learners’ misconceptions on the construct of visible light prior to instruction. A third of those teachers also held misconceptions which they transferred to the learner, thus propagating the confusion. The Berg and Bruwer study found that 37.5% of the teachers did not have well-informed content knowledge. Similar findings were reported in a study conducted by Smith and Naele (1991), where it was found that elementary teachers were unaware of students' misconceptions of light and shadows since they themselves held similar misconceptions. Fast-forward 27 years and Wahyuni et al. (2019) found that many pre-service teachers still had misconceptions in 29 subtopics of the concept of light. The authors' traced the origin of these misconceptions to the poor quality of teaching and learning, such as transmission mode.

This kind of teaching, namely transmission mode approaches, negatively impacts on science learning, and does not provide learners with an understanding of the nature of science. The approach does not favour 'out of the box thinking' and autonomous learning (Farahani, 2014). Teachers should become more aware of modern approaches that prepare learners for 21st-century thinking and skills – skills such as foundational knowledge (which is to know) meta knowledge (which is to act) and humanistic knowledge (which is to value) (Kereluik et al., 2013; Mentz & De Beer, 2019).

De Beer and Ramnarain (2012) and Riga et al., (2017) dispute the *tabula rasa* notion of Bowman (1993) that 'students are ... vessels to be filled'. Alvin Toffler provides a view that discards the previous traditional learning, such as 'chalk and talk'. He narrates the dimension as follows: *'The illiterate of the 21st Century are not those who cannot read and write but those who cannot learn, unlearn and relearn'* (Toffler, 1970:414).

Our education system has predominantly been influenced by transmission mode teaching which failed to influence teachers' pedagogical orientations. Alvin Toffler's notion of learning can make a profound contribution to tailor-made teacher professional development that addresses teachers' needs. In this study the researcher advocates for a similar notion on professional development of teachers, during which effort will be invested in challenging teachers to learn strategies such as the Jigsaw method, using the De Bono thinking hat, problem- and project-based approaches, etc., to foster 21st-century teaching skills. At the same time, they should unlearn approaches that are of less value, such as 'chalk and talk'. This will require teachers to engage as agents of change and to be proactive in their own professional development. I am of the view that this could be provided in a longitudinal and systemic teacher development intervention that will provide teachers with engaging pedagogies. The teacher professional development, if well sustained, may afford teachers with the unlearning and relearning opportunities. It is understood that our South African science classroom needs a 'make-over' and to be 'dressed' with approaches that will assist learners in not only improving their grades but also understanding the relevance of the content learned and its application.

2.2.3 Shortage of qualified science teachers

South Africa as an emerging economy needs to be internationally competitive, and this places an obligation on the country to produce innovative scientists and engineers (Mentz & De Beer, 2019:50). Caillods, Gottelmann-Duret and Lewin (1996) and Lewin (1992) share similar interpretations, namely that investment in science and technology education is seen as essential to economic and social development strategies throughout the developing world. Even though I agree with the latter scholars, the challenges facing South Africa make it almost impossible to make science education an investment. Currently the South African economy is growing at around 1.3%, the lowest in Sub–Saharan Africa, while its counterparts grow at an average of 2.3% (Benos & Tsiachtsiras, 2019).

South Africa's growth still suffers from an extreme skills shortage, primarily in the area of Science and Technology, coupled with poor quality education (Bernstein, 2011). Without a doubt, ‘good mathematics and science teaching and learning are a sine qua non for global competitiveness’ (Mentz & De Beer, 2019:50). The White Paper 1 on Education and Training emphasised the need to ‘raise the worker's level of general education and skill, to support the introduction of more advanced technologies…’ (Department of National Education, 1994:6). The White Paper on Science and Technology maintains that government ‘has a responsibility to promote science culture, science education and literacy amongst both children and adults ... and influence the attainment of equity by providing incentives for disadvantaged groups to study mathematics, science and achieve computer literacy’ (Department of Arts, Culture and Science, Technology, and Culture 1996:11). According to Naido & Lewin (1998), the new dispensation inherited a fragmented educational system, which failed to provide access to science education for the majority of the South African student population, and poorly serves those whom it does educate.

According to Jansen (2019:360), ‘a black child born to poor parents in a deeply rural area while attending a dysfunctional school on average has little to no chance of escaping a life of poverty despite the education received.’ The sad reality is that, of those students who pass their matric evaluation, only 0.5% attain university access to study science and mathematics related qualifications (Naidoo and Lewin,1998). The main reason for this is that learners' participation in Mathematics and Physical Sciences remain low in the abovementioned schools, with most students struggling to make the 30% pass mark in these subjects (*ibid*).

This domino effect is also noticed in the 0.5% students who gained access, but generally struggle to cope with tertiary study demands, as illustrated by university success rates of under 30% in science and mathematics qualifications (*ibid*). Before democracy, in 1991, many policies were prepared to address the perennial problems related to improving the quality of science and technology education and to increase learners' participation in these streams (Naidoo & Lewin, 1998).

The quality and quantity of science learners are to a large extent due to the shortage of science teachers and unqualified teachers. It is widely believed that schools are beset by shortages of teachers (Spaull, 2013; Bernstein, 2011).

While that is the case, every day of thousands and thousands school children are taught by teachers who are not qualified to do the job (Times Live, 2019). In this media interview, DA shadow education minister, Ian Ollis, said 'the implications of the situation were grave'. 'This means that, every day, teachers stand in front of a class without the necessary skills to teach the subject that they are teaching. It is simply wrecking the futures of children who have to be taught by teachers who are not qualified,' he said. For him, the solution lay in intensive training for new teachers. This implies – as is argued in this study – that mechanisms should be in place to address poor quality education in South Africa.

The South African Democratic Teacher Union (SADTU) has admitted that learners are 'not receiving the quality of teaching they are supposed to be getting' and further directed the problem to misallocation of resources – such as teachers teaching subjects they are not trained for. Another factor that was added was that teachers are not being properly trained. With science and mathematics being hit the hardest, the education authorities were of the view that the solution might have to come outside the South African borders (*ibid)*.

Answering to a parliamentary question by the Democratic Alliance, the national education department admitted that over five-thousand teachers are either under-qualified or unqualified (*ibid*). This unfortunate scenario was witnessed when the Department of

Education had to recruit foreign teachers to ease the shortage. According to Govender (2007:7), recruiting foreigners to teach sciences in South Africa was ‘window dressing’ the shortage of teachers and treating the symptoms without focusing on the origin of the problem. This approach was highly lamented by SADTU. A big move to employ foreign teachers is undesirable (Keating, 2007). In South African teacher education, the problem is the lack of qualified science teachers and failure to retain good science teachers. Even though recent literature does not make it clear whether the South Africa government is still hiring foreign teachers, it does indicate that international teacher mobility and migration are still increasing (Bense, 2016).

It is widely believed that low science teacher salaries could be another reason why students do not choose science teaching as a career. This argument is supported by Rumberger (1987), and Tye and O'Brien (2002), who state that lower salaries relative to alternative occupations are responsible for teacher shortages and that higher salaries would, therefore, help reduce shortages. This is also the view of Van der Berg (2002) and Katz, Apfelbaum, Frank and Miles (2018).

Bennell (2004:16) points out that ‘in economic conditions in which teachers and their families struggle to make ends meet, remuneration is likely to be a significant factor in motivating teachers and indeed in attracting individuals to the profession’. Research in low-income countries in South Asia and Sub-Saharan Africa indicates low levels of teacher motivation. Hall and Altman (2005) provide reasons why teachers leave the teaching profession in South Africa (see Table 2.1):

Table 2.1: Teachers’ reasons for leaving the teaching profession

FACTOR	PERCENTAGE
Teaching outside South Africa	4.1
Teaching at a private institution	3.9
Change to another career	24.6
Go back to university/college to study something different	4.4
Better salary	52.3
Other	9.2
Unknown	1.5

Source: Hall and Altman (2005:7)

If we examine the major reasons why teachers leave the profession it becomes evident that salary plays a vital role. The reason why most teachers leave their career is primarily due to the 'revolving door' phenomenon, where large numbers of qualified teachers leave their career for reasons other than retirement (Ingersoll, 2003). According to Tehseen and Hadi (2015:241), the most influential factors causing teachers to leave their job are 'working conditions, administrative support and student behaviour'. This low teacher moral tendency can further be linked to why teachers' absenteeism has increased from 8% in 2017 to more than 10% in 2019 (Businesstech, 2019). This is in contrast to the teaching profession in other countries.

If we look at Finland's education system, we notice that teacher training is well organised. In Finland, student-teacher tuition fees are fully paid by the government, and the student teachers are paid a salary while they are training (Darling-Hammond, 2017). Teachers are hired when they begin training and are guaranteed employment. The student-teacher programme is well designed and is grounded on a robust induction and professional development. What makes Finland's education system different from South Africa's is that compensation is high, relative to other occupations, and teacher professional development is part of the teacher's life cycle (Darling-Hammond, 2017; Darling-Hammond & Rothman, 2015).

Mentz and De Beer (2019) draw interesting parallels between South African education and Finnish education. The Finland educational system follows a strict and rigorous process when selecting students into teacher education programmes, and only 10% of the applicants are accepted. In contrast, in South Africa there is an 'insufficient professional screening of applicants prior to admission' (Deacon,2016:24).This issue talks to quality, and intend to grow the human capital of the country through best selection of teachers. According to Darling-Hammond (2017:292), 'Finland leapt from a relatively poorly educated nation to a 21st-century powerhouse with a current literacy rate of 96%, high graduation and college-going rates and top scores in all areas on the PISA assessments. It is no coincidence that teachers are highly respected and supported. The Finnish view is that teaching should be a long-term profession where people can grow into leadership positions and develop expertise over time.'

Looking also at Singapore, one notices that teacher candidates are well paid. According to Darling-Hammond (2017:298), teachers earn between30–50,000 Singapore dollars per year in salary, in addition to the relatively good salary, teachers also receive tuition, laptop computers and books as part of a contract with the Singapore government. The contract stipulate that teachers should teach at least for 3–5 years after graduating, depending on the kind of programme completed. According to Darling-Hammond (2017;298), “this structure, along with the supportive induction programme, enhances retention as well as recruitment. Salaries are commensurate with other fields like engineering, law and business. Singapore has shifted from just getting teachers, a key goal during the period of massive growth of its education system after independence in 1965, to providing teachers of quality. In 1997, the Thinking Schools Learning Nation reform explicitly redefined the role of teachers. As Prime Minister Gok proclaimed, ‘Every school must be a model learning organisation. Teachers and principals will constantly lookout for new ideas and practices and continuously refresh their own knowledge. Teaching will itself be a learning profession, like any other knowledge-based profession of the future’.

Darling-Hammond (2017) The global scale of the quality of education used by the Organisation for Economic Cooperation and Development (OECD) is indicated in Table 2.2. Singapore's education system is taking the lead, and Finland is at position 6. Both these countries invest in their teachers and ensure that teacher education is a national priority. They provide teachers with adequate compensation. According to Businesstech (2019) ‘the mathematics and science rankings were based on a combination of international assessments, the OECD's PISA test, the TIMMS tests, and TERCE tests (TERCE is a large-scale study of learning achievement, which was implemented in 2013. In total, 15 countries took part (Argentina, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru and Uruguay), as well as the Mexican state of Nuevo Leon (Mexico)’ (https://businesstech.co.za/news/lifestyle/87310/south-africas-education-system-vs-the-world/accessed 23rd April 2019).

Dolton & Marcenaro-Gutierrez (2011) used data from OECD's *Education at a Glance* publication to indicate that teachers’ salary increase results in learner results improvement. Britton and Propper (2016:76) found that a ‘10% increase in teacher wages translated into improvements in student performance of 5% to 10% and that a 5% improvement in a relative position of the earnings distribution has a similar effect on learner performance’.

Based on this findings above, I am of the strong view that it is time for the South African government to recalibrate their appreciate for the value of education and that of the teachers by compensating qualified teachers satisfactory while improving their human capital.

Table 2.2: Top 20 countries in terms of STEM education (Businesstech, 2019)

Online source: https://businesstech.co.za/news/government/89446/this-graph-shows-just-how-bad-south-africa-is-at-education/)

#	Country	#	Country
1	Singapore	11	Poland
2	Hong Kong	12	Vietnam
3	South Korea	13	Germany
4	Japan	14	Australia
5	Taiwan	15	Ireland
6	Finland	16	Belgium
7	Estonia	17	New Zealand
8	Switzerland	18	Slovenia
9	Netherlands	19	Austria
10	Canada	20	United Kingdom

The table provides a global view on countries that are performing well in STEM education and where teacher compensation is considered a priority.

Nations such as Finland and Singapore have a strong professional ideal for teaching and teacher professional development. These countries "celebrate teachers and treat teaching as an important profession with a knowledge base that must be mastered if students are to have equitable opportunities to teach" (Darling-Hammond, 2017:292). For example, Finland's efforts towards an equitable high-quality education system has relied substantially on creating a sophisticated profession of teaching in which all teachers hold at least a two-year master's degree that encompasses both strong subject matter and pedagogical preparation, and that integrates research and practice.

In Finland, teaching has become the most sought-after profession before medicine, and many teachers pursue a PhD and then remain in teaching (Darling-Hammond, 2017). This is difficult to compare with the South African education system, where in 2007 more than 56% of high school science teachers were under-qualified (Matomela, 2007:14). Unless a high calibre of science teachers are produced in the institutions of teacher training, the envisioned goal of socio-economic improvement would remain a pipe dream (Ogunniyi, 1986; Bernstein 2011). The Boston Consulting Group (BCG) urges South Africa to concentrate its effort on the long-standing problem areas which demand immediate attention.

The BCG shows that significant improvement is possible, including in the near-term, if the following becomes a priority:

- Teacher quality;
- Teaching basic skills;
- Reducing dropout rates (this can be achieved if the curriculum is made interesting, i.e., by decontextualising the curriculum. One possible way of doing that is integrating IK and Arts into science education. This will provide a more inclusive curriculum, and learners will start understanding what they are learning;
- Effective vocational-training alternatives for young people.

Due to page limitations, this study is based only on the quality of teachers, curriculum and resources. The literature on remuneration shaped my understanding of the state of teacher education and what other reasons influence the shortage of good science teachers. However, since this is not a central issue in my study, I am not going into more depth in this regard.

2.3 CURRICULUM TIMELINES IN SOUTH AFRICA: THE NARRATIVE OF A CENTURY OF LEARNING

2.3.1 Historical legacies of the curriculum: Curriculum as colonial process

It is crucial to provide a synoptic view of the curriculum timelines in South Africa, with a particular focus on how learning has been politically positioned in the previous and the current political dispensation. This, I believe, will provide a better understanding of the South African curriculum reforms. I begin my conversation by looking into the curriculum as a colonial process and further introduce a second notion on the post-apartheid curriculum. I draw insight from Kumar's (2019). *Curriculum in International Contexts*, which made substantial observations on how neoliberal policies impacted and continue to impact educational reforms in South Africa, Brazil, Mexico and India. In this section, I revisit the notion of neoliberalism and its influence on South Africa education over a century, borrowing most of the work from Kumar (2019:21-31). According to Marx and Marxian thinkers, neoliberalism is tantamount to imperialism and colonialism.

Colonialism and racism have been characterising and shaping the curriculum discourses in South Africa since the 17^{th} century (Kumar, 2019).
On 17 April 1658, the first formal school of the slaves was founded in South Africa by the VOC (*Verenigde Oostindishe Compagnie* or Dutch East India Company) (Kumar, 2019:23; Jansen, 1990). Most of these slave children were acquired by the VOC in the time of Jan van Riebeeck (regarded as the father of South Africa), and were perceived as identity-less subjects into whom everything that was necessary for their embodiment as slaves could be poured.

More than a century and a half later, the first department of education was established in 1839 in the Cape, according to South African History Online (SAHO). Superintendent-General James Rose Innes became the first head of the department and had a significant sway in the schools of the slaves. The curriculum during that period was characterised by religion, which became the ethos of schooling (Kumar, 2019). Jansen (1990) shares a similar understanding. The first European settlers advocated slave education which was predominantly characterised by Christian religious precepts. Schools were used as an instrument for the perpetuation of the religious power and hierarchy (Malherbe, 1925; Malherbe et al., 1937; Jansen, 1990). This situated religion as the most prominent curriculum tool: literacy enabled children to read the Bible (Jansen, 1990:195). The key questions that guided the curriculum were: 'what should be taught?' and 'who should teach?' The answer to this question was left to the church (Kumar, 2019: 23). As a colonial process, curriculum involved the degradation, displacement and destruction of local knowledge and identities of indigenous people (*ibid*).

When the British took over the Cape in 1806, education was fixed within economic development brought about notably by the discovery of diamonds in 1862 and gold in 1866

(Kumar, 2019:23). This development was pigeon-holed by rapid industrialisation and state formation (*ibid*), and this produced a power dynamic in South Africa which led to uneven distribution of resources and ideas (Jansen, 1990:196). This era of development was further perpetuated by ‘classic social groupings’ of the modern capitalist economy (workers, middle class, and capitalist). This brought about a huge conflict between modernity (represented by the colonial authorities and the religious conservatism of missionaries) and local people, who attempted to maintain their own customs and traditions (Soudien, 2010:22).

According to Jansen (1990:195) ‘education existed in South Africa long before the arrival of the British and Dutch colonist. Traditional African education was led by community elders through an oral tradition based on cultural transmission and was closely integrated with life experiences.’ To a large extent the ideology of the colonist at the time influenced the ‘natives’ to abandon their ways of doing, and marginalised traditional African education by pushing the colonial agenda forward.

In 1910 the Union of South Africa was formed, and it was made clear that the education of white children and black children was to be influenced by the church and the state respectively (Jansen, 1990). During this era, the colonisers wanted useful labour for expanding the economy and black communities were displaced. The predominant question was what the ‘native’ should be taught (Soudien, 2010:31). During these developments, which received considerable attention from the mission schools and industry, the ‘academic curriculum’ emerged, designed to bestow on African children a certain level of reading and writing (Soudien, 2010; Jansen, 1990). Such curriculum initiatives to teach the native were not well received and were not met with much support from the colonial authorities (Soudien, 2010:31).

The perspective of the authorities was that Africans were to be marginalised from writing and reading skills (Soudien, 2010:31). According to the colonisers, it was believed Africans only needed ‘pragmatic learning or industrial training’ (Soudien, 2010:31). Berr et al. (1971:379) also highlight that Sir Langham Dale and Sir Thomas Muir, the second and third superintendent generals of Cape education, established a curriculum which was aimed at providing blacks with cheap-manual labour skills. During this culture change for the Africans, neither the missionaries nor the colonial government considered African cultures, ways of doing, customs, history, traditions and values (Kumar, 2019:24).

In 1921 Charles T. Loram, who promoted the concept of industrial education in Africa as a member of the Phelps-Stokes Commissions on education in South and East Africa, addressed the question of the education of the natives and concluded that they were supposed to meet the needs of the colonial system. In an earlier letter to Booker T. Washington, Loram penned the following (Kumar, 2019: 24):

> I am taking advantage of my stay in USA to attempt to convince my fellow whites in South Africa that the example of USA proves that with proper training and education the Negro can be made a valuable asset to any country. *(Booker T. Washington Papers, Loram to Washington, December the 27th 1914: Box 5, quoted by R. Hunt Davis, 1984, as cited in Kumar, 2019:24).*

Fast-forwarding to the 1930s, the New Education Fellowship (NEF), also known as the 'modernist-minded group', came into sight, intending to do away with a racialised ideology of white supremacy. The New Education Fellowship argued 'educability' of the African indigenous people. The presentation was argued on a ten-year concept of IQ tests. R.F Alfred Hoernle, a major liberal, countered the racial stereotype and argued for the absence of any difference between the natives and the colonial children. Regardless of those insights, Charles Templeman Loram persisted in disenfranchising the voices on African education (Krige, 1997). Charles Loram worked in education, the Joint Council movement and the Native Affair Commission (NAC). He was also a chief inspector of Native Education, so one can comprehend the influence that was bestowed on him. During these times, the natives began to be very critical of colonial education, which denigrated the indigenous customs (Kumar, 2019:24). During this time, it was evident the colonials used the curriculum to advance and enforce the political advantage of the Europeans over the indigenous inhabitants of South Africa.

The racial focus which became the basis of the apartheid system became more prominent from 1948 to the end of the 20th century (Kumar, 2019), with laws such as the Race Classification Act categorising people based on their phenotype (Soudien, 2010:36) and leading to the segregation of universities and educational work. The Commission on Native Education (1949-1951) defined its aims as 'the formulation of the principles and aims of education for natives as an independent race, in which their past and present, their inherent racial qualities, their distinctive characteristics and aptitude, and their needs under the ever-changing social conditions are taken into consideration' (Report of the Commission, U.G. No 53/51:7, cited by Kumar, 2019: 29). The commission limited the capacity of a black child to perform on the level of a white child, concluding that an African mind is inferior (Kumar, 2019: 29), and out of these views, Bantu Education was born. This ideology limited the status of a black mind to that of a 'hewer of wood and drawer of water' (Kumar, 2019:29).

This was a curriculum of subordination, characterised by racial bias. Education was limited to rote learning (Soudien, 2010:36), laying the roots of a transmission mode which is still the order of teaching in most South African schools, more particularly in former township schools. We need to be more critical of why, after such a long period of democracy, we still have not set things right.

During the apartheid time, the segregation of the universities was the most prominent tool for displacement of the indigenous people from their intellectual ability and rights (Hoadley, 2010; Le Grange, 2016). According to Hoadley (2010) and Le Grange (2016), this ideology persists today. From the work of Kumar (2019:25-31), I have provided a summary of university segregation during racial South Africa, and of some of the events that guided the curriculum reform from 1658-1980 (based on literature informed by Bunting, 2006; Hoadley, 2010; Le Grange, 2014; and Kumar, 2019).

Table 2.3: Identifying the types of universities and the major events during the apartheid era from the 1950s to 1994, with the dawn of democracy (Kumar, 2019: 25-31)

Types of universities	Major events
White English-speaking (University of Cape Town, Rhodes University, University of Witwatersrand, and the former University of Natal (Bunting, 2006)	• Established in the 19th century when the British took over the colony (Le Grange, 2014:468). • Adopted Anglo values; connected to big business; viewed as members of intellectual academic community (Hoadley, 2010:133). • Promoted 'individual autonomy', maintained academic and intellectual autonomy as well (Enslin, 1984:186). • Were liberals.
Afrikaans-speaking (Stellenbosch University, University of the Orange Free State, Potchefstroom University for Christian Higher Education, University of Pretoria and the Rand Afrikaans University (Bunting, 2006)	• Creatures of the state (Hoadley, 2010:133) • Train teachers and civil servants for the apartheid state. • Rote learning characterised the pedagogy of the university (Kumar, 2019: 25 – 31). • Were radicals. • Christian National Education Policy (CNEP) dominated the Afrikaans universities. • Key feature of the National Party (NP). • Used autocratic approach called the 'fundamental pedagogy' (Le Grange, 2014:467).

	• The ‘fundamental pedagogy’ was very eminent in 1960-1980. • ‘Viewed educational theory as an independent human science with its own terminology, its own points of departure, its own method of investigation and verification based on the essential characteristics of teaching-learning phenomena’ (Le Grange,2010:183).
Black (Medunsa, University of the North, Vista University, the University of Zululand, and Fort Hare (Bunting, 2006). In terms of my study, Vista University is of particular importance, as its VUDEC campus (the Vista University Distance Education Campus) provided thousands of underqualified teachers the opportunity to improve their qualifications.	• Authoritarian and instrumental (Bunting, 2004:45 citing Hoadley, 2010:133). • Diluted curriculum as compared to their Afrikaans counterparts. • Undergraduate teaching institutions catering for underprepared, mostly black, matriculants (Hoadley, 2010:134). • Used autocratic approach called the ‘fundamental pedagogy’ (Le Grange, 2014:467). • Dominated by Afrikaans lecturers.
Indian (University of Durban-Westville) (Bunting, 2006)	• Similar in form to the Black universities, but came into existence in 1972 (UDW) and 1960 (UWC). Later under the regulation of the tricameral parliament (Bunting, 2006).
Coloureds (University of the Western Cape) (Bunting, 2006)	• Similar in form to the Black and Indian universities and were also subjected to the regulation of the tricameral parliament (Bunting, 2006).

Table 2.4: Enrolment in South African Universities 1958 (Kumar, 2019:31)

Enrolment in South African Universities 1958					
	White	Coloured	Indian	Black	Total
Orange Free State	1 709				1 709
Potchefstroom	1 474				1 474
Pretoria	6 324				6 324
Stellenbosch	3 694				3 694
Cape Town	4 408	388	127	37	4 960
Natal	2 530	31	373	188	3 122
Witwatersrand	4 756	22	158	73	5 009
Rhodes	1 098				1 098
*South Africa	6 144	204	601	1 179	8 128
Fort Hare		59	59	320	438
Total	32 137	704	1 318	1 797	35 956
Percentage of total	89.4%	2.0%	3.7%	5.0%	100%

*UNISA was non-racial from inception

During the 1970s and 1980s, there was massive resistance to the Christian National Education Policy (CNEP), primarily influenced by the People's Education for People's Power (PEPP). PEPP was strongly against the fundamental pedagogies of the time, which highlighted rote learning and 'chalk and talk' approaches. The movement advocated for social transformation through education in South Africa (Kumar, 2019:28). The movement was strong on the idea that education should be centralised around the community-oriented model, including parents, teachers, students and other community members (*ibid*), which is observed as the School Governing Body (SGB) in today's educational setting. This agenda was further carried forward by the National Educational Crisis Committee (NECC) (Kumar, 2019: 28). This committee was inspired by liberal and social-political views embodied in the Freedom Charter, Black Consciousness Movement and other organisations that wanted to do away with the racial dominance of the West in education.

These initiatives gained momentum and resurfaced after the lifting of political bans on political organisations such as the ANC. The National Education Policy Initiatives (NEPI) introduced under ANC government took up a stance against social injustice and provided a new lens towards the political transformation of South African society and education. This was further observed when the ANC took transformative decisions by initiating the National Education Coordinating Committee (NECC). The committee produced 12 reports, including a report on the curriculum whose outcome was centred on the idea of a unitary education which is free from race and gender inequality (Kumar, 2019: 28). This was followed by an interim syllabus (NATED 550) (Le Grange, 2010:188). The revision had less to do with content and implemented, rather aiming to remove racial content from the curriculum (Jansen, 1999:5). According to Jansen (2001:43), the curriculum 'was presented as an attempt to alter in the short term the most glaring racist, sexist and outdated content inherited from the apartheid syllabi'. The main obstacle facing black advancement into higher education in the early 1990s was – as it is now – the poor quality of much secondary school education, particularly in mathematics and sciences (Shaw, 1971), largely influenced by inadequate teacher training.

Let us consider VUDEC (Vista University Distance Education Campus). I trust the context of VUDEC will be of particular importance to highlight the significance of this study and reasons for systemic and longitudinal teacher training. To redress the divide in higher education the former Minister of Education, Prof. Kader Asmal, took a political decision to merge the University of South Africa (UNISA), Technicon SA and VUDEC (SAIDE, 1995) towards the end of 2003 to create a single inclusive dedicated distance-education institution (Van der Merwe, 2007), retaining the name University of South Africa (Mothata, 2007). The decision was based on the recommendations published in the National Plan on Higher Education (NPHE) (*ibid*). Kadar Asmal's decision was designed to steer equity and a merit imperative between UNISA, Technicon SA and VUDEC (Mothata, 2007; Van der Merwe, 2007).

VUDEC was an open distance university during the heyday of the apartheid government. The university was established to assist the majority of black students whom the government did not want in the former white universities of the radicals and the liberals (University calendar, 2003: 8). According to the National Teacher Education Audit and the South African Institute for Distance Education (SAIDE), teacher education in South Africa was at the centre of open distance learning and was the most expanding sector (SAIDE, 1995). VUDEC had a total of 18 000 students in 1994 (Vista MIS, 2003). More than a third of teachers in South Africa were involved in distance teacher training in 1995 (SAIDE, 1995). Between 1994 and 1995, the sector expanded with 23% new enrolments (SAIDE, 1995).

Even though access to teacher training was made possible on open distance, only 3% of Vudec students had access to email facilities in 2003 (Vista MIS, 2003), making it challenging to create an optimal 'open' 21st-century distance education. 'With regard to academic competencies, many Vudec students were underprepared for higher education and were aware that they would not have survived nor even been accepted at other higher education institutions' (Van der Merwe, 2007:545). A noteworthy 'number of students approached Vudec as `a university of last resort ... and the sad part is that they pass enough first-year modules to carry on with the second year, but many of them seriously battled to pass a degree …'(*ibid*). According to the Vudec manager 'many teachers in black schools are Vudec graduates and they tend to have engendered a loyalty to Vudec by having encouraged colleagues to study through us' (Van der Merwe, 2007:546).

It cannot be denied that VUDEC provided inadequate teacher education for a vast majority of black teachers (Vista University calendar 2003:8). According to the National Teacher Education Audit findings, the relevance and quality of teacher training and teacher education was very frail (SAIDE, 1995). The training did not focus on improving teachers' practice and reflective teacher skills (*ibid*). Many black teachers were exposed to distance education programmes in which there was a theory-practice divide (Mothata, 2007; SAIDE, 1995). Most distance institutions such as VUDEC viewed teaching practice as a form of assessment with little support given to student teachers (SAIDE, 1995:67). Further to that, the curriculum did not consider the realities of schools in South Africa and the contexts of teachers (SAIDE, 1995:67).

The need to integrate schools in teacher development was absent in most teacher courses (*ibid*). The audit also exposed a huge discrepancy and a lack of coordination in the delivery of teacher education, ‘often without any vision of the institutions to work towards improving the quality of teaching and learning in schools’ (*ibid*). Even though the VUDEC curriculum was ignored during the UNISA merger, it is still questionable if VUDEC teacher-students were adequately trained and supported when they officially became UNISA students. Many of the teachers and learners in the township schools are likely to be a product of a VUDEC education. It should also be made clear that the majority of above-mentioned teachers were part of the curriculum NATED 550, and it can be hypothesised that most of the democratic learners are still the product of such a curriculum. My second hypothesis is that NATED 550 has had a snowball effect, and teacher professional interventions should emphasise assisting teachers who are still paralysed by such a curriculum.

According to Skinner (1984), the NATED 550 curriculum was highly characterised by the behaviourist theory model. The theory was dominant in encouraging teachers to be banks of knowledge, and the teacher became a prominent source of knowledge. According to Msila (2007), Hoadley & Jansen (2009) teaching practice was predominantly content-led, and teaching was constructed directly from the textbook, which encouraged ‘chalk and talk’ approaches. In other words, learners were limited as recipients of knowledge, ‘tabula rasa’, during the teaching process (Msila, 2007; Hoadley & Jansen, 2009).

It was further stated that the content taught was biased and unrelated to the majority of the learners' experiences of the real world (Hoadley & Jansen, 2009). The highlighted shortfall of the curriculum was to develop learners' competences to deal with real-world challenges (Hoadley & Jansen, 2009). Moreover, the reason for that was that learners were not directly involved in teaching and learning (Hoadley & Jansen, 2009). The NATED 550 curriculum restricted the creativity of learners and teachers, since teaching, assessing and reporting were grounded in the behaviourist theory model. NATED 550 received tremendous criticism for failing to prepare learners adequately and this subjected the curriculum to reviewing in the post-apartheid era (Chin, 2007; Msila, 2007; Howie, 2003; Brooks, 2002). Even after the revision and the restructuring of educational transformation post-2004, curriculums remain glacially slow in transforming the educational space. Researchers such as Jeannin (2019) and Balfour (2015) are of the view that the post-2004 educational transformation focused largely on institutional change such as merging, de-merging and closing of some universities. This narrative provides some of the reasons why the curriculum and the pedagogical orientation of teachers were left unchanged.

The above perspective provides some of the reasons why most of the teachers of the physical sciences in impoverished provinces such as the Eastern Cape still follow NATED 550 pedagogical practice (Cobbinah & Bayaga, 2017). The researcher believes that similar trends are general across most rural and township schools. Hence this study involved holistic teacher professional development, assisting teachers in Ikageng and Promosa with their professional development needs with the aim of contributing to the redress of the academic injustice of the past.

2.3.2 Is CAPS still characterised by past ideologies or Western perspectives? Advocating for an IK-science curriculum

As mentioned in Chapter 1, the South African education system has been experimenting with the science curriculum since the dawn of democracy in 1994, and still has not achieved the stability it seeks. The current discourse on the 'decolonisation of the curriculum' bears testimony to this statement. The field of curriculum design and implementation has been in constant flux since its inception in the early 20th century and continues to shift and change (Breault & Marshall, 2010). The last quarter-century, in particular, has been characterised by what Levin (1998) has described as an epidemic of change. So far, South Africa has changed and revised many curricula since becoming a democracy in 1994, namely Outcomes-Based Education (OBE) and Curriculum 2005, and then the National Curriculum Statement, and the refined Curriculum and Assessment Policy Statement (CAPS). The South African school education system and teachers are still experiencing what I observe as curriculum fatigue.

Curriculum 2005 was introduced in 1997. According to Soudien (2010:14), it favoured older forms of privilege and continued to discriminate against black and poor children (Soudien, 2010; Jansen, 1997). Curriculum 2005 was further revised to produce a new curriculum known as the Revised National Curriculum Statements (RNCS) for grade 0 – 9 and National Curriculum Statements (NCS) for Grade 10-12, in the year 2000.

The revised curriculum resulted in the Curriculum and Assessment Policy Statement (CAPS), which was introduced in 2011. Critics of the school curriculum are of the opinion that it has failed to achieve social and economic advancement, which are two important goals in a democratic South Africa. Curriculum studies as a scholarly ground are still being criticised for an inability to ‘move on; discover and invent new worlds and new ideas’ (Morrison, 2004:487). According to Le Grange (2019), the curriculum is a polysemous term. This is due to the multi-faceted nature and meaning attached to the term curriculum by different scholars.

Commonly, the curriculum relates to what knowledge is included in teaching and learning programmes (Spencer, 1884). According to Martin (2003:9) ‘what knowledge is of most worth, and whose knowledge’, remain a discourse in the 21st century. The curriculum planners and the policymakers hardly made a noticeable contribution towards how knowledge should be observed after 1994. Hence the curriculum is still a sensitive conversation in South Africa 25 years into democracy. Le Grange (2019) further gives clarity on his understanding of the curriculum by referring to other scholars. According to Le Grange (2019:32) ‘this instrumentalist and utilitarian view of the curriculum is colonising in the sense that it proposes one way of knowing, being and becoming as *the* way of knowing, being and becoming’.

He further emphasises that ‘this dominant view of curriculum does not take into consideration the uniqueness of each individual, each person's peculiar desires, hopes and beliefs, as well as significations of race, gender, sexual orientation’, and so forth (*ibid*). Grumet (1976) provides an alternative view of curriculum to that of Tyler (1949) and describes curriculum as the stories that we tell students about their past, present and future. In the next section, a possible approach to the decolonisation discourse is provided by focusing on the affordances of an indigenous knowledge (IK) curriculum. My view is to integrate IK into the Natural Sciences curriculum to provide a contextualised curriculum and to address the curriculum of the past which is seen in the lens of the west.

2.4 THE DECONTEXTUALISED SCIENCE CURRICULUM: AFFORDANCES OF INDIGENOUS KNOWLEDGE IN THE CURRENT DECOLONISATION CONVERSATION #IK_MUST_RISE

A good volume of research went into the integration of indigenous knowledge (IK) in the Life Sciences curriculum (De Beer, 2016; Cronje, 2015; De Beer & Ramnarain, 2012). This is in contrast to the Natural Sciences and Physical Sciences curriculum, where a whisker of work has been done. Some researchers hold the view that teachers pay lip-service to integrating IK in a science classroom (Cronje, 2015; Cronje, De Beer & Ankiewicz, 2015; De Beer & Ramnarain, 2012). What is of great concern is that there were no pragmatic steps taken by the Department of Basic Education regarding the integration of indigenous knowledge into the Natural science school curriculum, the implementation is been left up to the teachers (Moyo, 2011).

The CAPS document requires Specific Aim 3 (Understanding the uses of Science) to be achieved during the learning process. Specific Aim 3 requires learners to understand and appreciate the use of Natural Sciences and indigenous knowledge in society and the environment. I identify this as very problematic, as this curriculum is generally omitted. Le Grange (2019) refers to Aoki's (1999) use of the *curriculum-as-plan*, and the *curriculum-as-lived*. Whereas indigenous knowledge is mentioned in the *curriculum-as-plan*, research shows that it often does not happen in the *curriculum-as-lived*. My interpretation is that IK is treated as a NULL curriculum (Le Grange, 2019) in the Natural Sciences classroom in particular.

The null curriculum is further perpetuated by the BEd curriculum in most universities (Le Grange, 2019:34). 'Le Grange is of the opinion that the null curriculum is what universities leave out – what is not taught and learned in a university'. An example would be the fact that indigenous knowledge is not taught in many universities or faculties of universities. This is regardless of many studies that provide means of inclusion of IK in sciences classroom (Mentz & De Beer, 2019; De Beer & Van Wyk, 2019; Van der Walt, Potgieter & Jagals, 2019; Marietjie Havenga, 2019; Olivier, Van der Westhuizen, Laubscher & Bailie, 2019; White, Bester & Sebotsa, 2019; De Beer, 2016; Cronje, 2015; De Beer & Ramnarain, 2012).

The lack of integration of IK in Natural Sciences curriculum could prevent us from solving certain local and societal problems such as improving water provision (e.g., the current saga, the Vaal River water quality), poverty, energy difficulties (e.g., the Eskom crises) and hunger, in which an IK perspective would provide different perspectives.

Science subjects should promote and develop skills that enable one to solve local and global challenges. At the moment, the Natural Sciences often do not provide such a holistic approach (Cronje, 2015; De Beer, 2016). The researcher is of the view that strong IK needs to be integrated in South African Natural Sciences curricula, as IK could address some of the shortfalls of traditional science (Cronje, 2015). Specified IK practices that embrace a set of knowledge themes on health, agriculture and technology should be incorporated into the school science curriculum in a valid and legitimate way (Zinyeka, Onwu & Braun, 2016).

The lack of integration of IK in Natural Sciences is seen by the researcher as 'leaving' the Natural Sciences curriculum behind. Zinyeka, Onwu & Braun (2016) suggest that the inclusion of IK in the curricula is an important component of contemporary science education (DoE, 2002, 2005; Minister of Health and Child Welfare, 2007).

This is the gap that this study will address. In this context, it is assumed that many teachers do not know how to implement indigenous knowledge in Natural Sciences to enhance the 'Western' CAPS curriculum as prescribed by the South African Department of Education (DoE, 2012). Many teachers express concern that they lack the necessary knowledge and skills to implement this knowledge (Sebotsa et al., 2018; Cronje, 2015; De Beer & Ramnarain 2012; Harrison & Greenfield, 2011). Many teachers do recognise the value of indigenous knowledge and the need to integrate this knowledge into science classroom (Cronje, 2015; Mothwa, 2011; Ogunnyi, 2007b), but fail to do it, due partly to their lack of pedagogical content knowledge in this field.

Integrating IK in the sciences curriculum has affordances of providing a framework to the decolonisation debate in South Africa. The question of whether teachers were prepared by institutions such as universities to integrate IK in the Natural and other science curricula remains the impetus for this study, and this calls for immediate intervention(s).
According to Webb (2011), pedagogical reasons have been cited as underlying the valuing of, and a growing interest in integrating IKS into the science curricula. Universities have a responsibility in their pre- and in-service teacher education to assist teachers with the necessary knowledge and skills to infuse indigenous knowledge in their teaching. The

question could be asked whether teacher educators at universities have the knowledge and skills to advance the indigenous knowledge agenda.

According to Shay (2015) it is imperative to decolonise the university curriculum, to ensure a radically improved curriculum and diversified academia. Citing De Beer and Petersen (2016:44): 'In July 2010 the Minister of Education released a statement on curriculum implementation (Motshekga, 2010), indicating that the design features of outcomes and assessment standards would be repackaged in subject-specific ways to provide greater details on topics and assessment to be covered each term'. A decade later no effort has been made by the minister to diversify the curriculum by integrating indigenous knowledge in Natural Science curriculum, and no effort has been made to train teachers in this regard.

This remains a problem that has not been fixed in the last 26 years of democracy. The repercussion of not capacitating the teachers with skills to teacher indigenous knowledge in the science curriculum could be assumed to be one of the factors that make learner performance in Natural Sciences a problem. However, the problem is intensified by the lack of expertise, in this regard, within university faculties of education.

2.5 EMBODIED, SITUATED AND DISTRIBUTED COGNITION (ESDC) PERSPECTIVE ON INDIGENOUS KNOWLEDGE CURRICULUM

By infusing strong IK into the curriculum, we might make science more interesting and more relevant for learners, and might improve performance (De Beer, 2016). According to Zinyeka, Onwu & Braun (2016), integrating IK into the school science curriculum is one way of maximising the socio-cultural relevance of science education for enhanced learner's performance. A reason for poor performance in science that is often overlooked is the affective domain of human thinking in science education (White, Bester & Sebotsa, 2019:250-251; De Beer, 2016). From an embodied, situated, and distributed cognition (ESDC) perspective, learning cannot take place in isolation (White, Bester & Sebotsa, 2019: 250-251; Hardy-Vallee & Payette, 2008).

According to Maxwell and Chahine (2013:67), effective learning takes place in an atmosphere of a learner's 'existing knowledge, background and environment'. They argue that indigenous learners exploring new concepts in their everyday settings find themselves able to construct knowledge in their own way. Dubinsky, Roehrig and Varma (2013) show us that experiences with an emotional stamp are more likely to be committed to long-term memory. This is supported by practicality, even research with engineering graduates shows that it is not the specific content of the degree that has mattered most or even the procedures that have been mastered; it is rather the way of thinking about the world and about oneself that is significant (White, Bester & Sebotsa, 2019:250-252; Sebotsa et al., 2019:350; Case, 2013).

My view is that the traditional method of teaching science in the Western perspective through introductory courses is a concern. There is something wrong with the curriculum if it distances itself from the reality of the majority of students – their knowledge and experiences with the environment – so that it appears irrelevant or alien (De Beer, 2016).

According to De Beer (2012) and De Beer and Whitlock (2009) the integration of indigenous knowledge into the science curriculum holds affordances of making the classroom more interesting and stimulating in a culturally diverse setting. The views of the latter scholars provide a basis for contextualising the curriculum by mainstreaming IK-science curricula. Botha (2012) indicates that, by doing so, the curriculum will enhance knowledge construction, as the curriculum would be reflecting diverse cultural backgrounds of learners. White, Bester, Sebotsa (2019:253) and De Beer and van Wyk (2019:119) make a strong argument that such a curriculum should be emphasised if the schooling system is to address the learner's affective domain and to make learning relevant, meaningful and interesting to its clients (learners). This is what this researcher refers to when arguing for a contextualised science curriculum of international standard, but most importantly of local relevance.

2.6 DIFFERENT VOICES ON AN IK-SCIENCE CURRICULUM

According to Le Grange (2010:18) 'If we consider the term "curriculum" in the wider more embracing sense, then it encompasses experiences both inside and outside the classroom. African indigenous education was predominantly abolished in the interests of European, foreign syllabi in schools. This stance has made the curriculum aloof to many students' ways of knowing, and distant from the realities of local people in terms of how they understand themselves in relation to nature. The detrimental effect of using a curriculum that does not address the everyday realities of students can result in some learners experiencing conflict between their existing knowledge and the knowledge of the various science curricula (De Beer, 2012).

Many students would then have to abandon their existing knowledge to make way for the new science concepts. For people from non-Western cultures, making the crossover to Western science requires assimilation that can marginalise or replace their own world views. In this context, it is important to focus on the work of Piaget's (1970) cognitive model and schema theory. Piaget (1970:706) advocated for either the 'assimilation of external elements into evolving or completed structures' if new constructs did not differ much from the existing schemata, or for accommodation 'that is necessary to permit structural change, the transformation of structures as a function of the new elements encountered' (Piaget, 1970:708) where the differences are significant. Furthermore, on a regular basis, learners have to 'cross-over' from IK to classroom science. This process is difficult and many learners fail to do such epistemological border-crossing, withdrawing instead from science education (Sebotsa et al., 2019:350; Van Rooyen, De Beer et al., 2006).

De Beer and Petersen (2015) argue for a more Afrocentric approach, such as including IK in science education. Even though most researchers argue for the inclusion of IK, many researchers on the other hand also argue that epistemological differences between the nature of science (NOS) and the nature of indigenous knowledge (NOIK) constitute a major challenge for an inclusive IK-Science curriculum inclusion.

I take cognisance that most of the research argues the substantive grounds of the two knowledges. Scholars such as Chambers (1980:2). Dei (1993), Howes and Chambers (1980) and Warren (1989, 1990) highlight that IK and scientific knowledge differs in subject matter, methodologically and epistemologically, because the forms of knowledge employ different methods to investigate reality (Sebotsa et al., 2019:250-251).

In the next section, a space for including IK in the science curriculum is negotiated, by focusing on the epistemological differences and similarities between the nature of science (NOS) (Abd-El-Khalick & Lederman, 1999) and the nature of indigenous knowledge (NOIK) (Cronje, 2015). This argument might afford teachers support in making decisions on how specific pieces of IK may be included in science themes and may further provide a nuanced understanding of the argument forward. Taylor and Cameron (2016:3) highlight and critique three epistemology-related perspectives that are inherent in the attempts at IK-science integration.

The authors provide three perspectives through which to reconsider the conversation of IK-Science integration curricula with a clear perspective, as follows:

- 1st perspective: Inclusive perspective, regarding IK systems as part of science;
- 2nd perspective: Exclusive perspective treating IKS and science as separated domains of knowledge. The exclusive scientific perspective has been that science is limited to studying the material world and has nothing to say about the metaphysical aspect, which is a component of indigenous knowledge systems;
- 3rd perspective: IKS and science are viewed as intersecting domains, of overlapping strands; in other words, the focus should be on the shared tenets of western science and indigenous knowledge.

In this study, I advocate for epistemological border-crossing between IK and science, and my views are strengthened by the third perspective, where IK and science overlap. This, I argue, will not focus on the difference but the similarities between the two knowledges. Figure 2.2 provides the author's pictorial differences and understanding of the epistemological differences in IK-science integration.

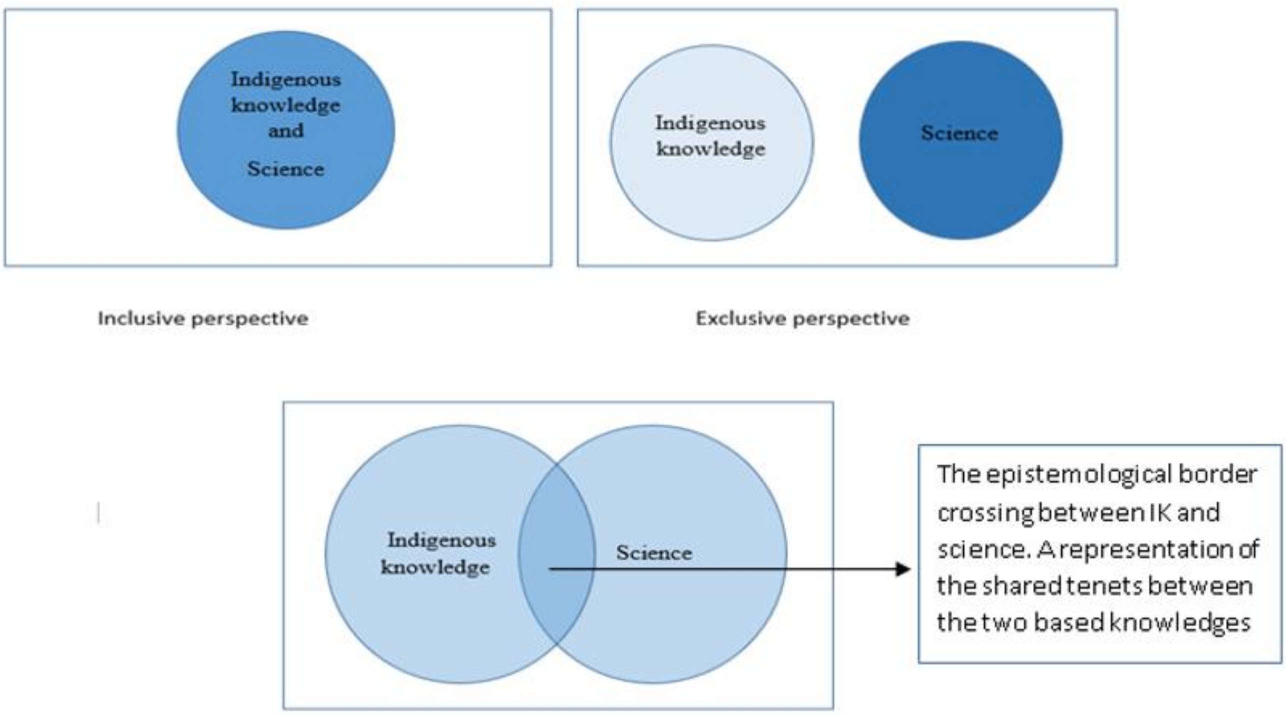


Figure 2.2: Researcher's representation and understanding of the epistemological border crossing between IK and science. A representation of the shared tenets between the two based knowledges based on Taylor & Cameron, 2016; and Zinyeka, Onwu & Braun, 2016.

Figure 2.2 depicts the epistemological border crossing between science and indigenous knowledge (Sebotsa et al., 2019:350-351; Cameron, 2016). This study supports the argument that the intersecting domain is crucial in making sense of the world; and where the focus is on the shared tenets, rather than different tenets (Sebotsa et al., 2019:350-351). Cronje (2015:42) has shown that there are many shared tenets when the nature of science and the nature of indigenous knowledge are compared, despite several differences (see Table 2.5):

- Both science and indigenous knowledge are empirical (although indigenous knowledge also has a metaphysical component);
- Both are tentative (and subjected to change), both are inferential, both are creative, and both are socially and culturally based as mentioned in the earlier text.

This could birth science teaching that acknowledges students' knowledge and culturally based ways of thinking which will almost certainly unlock potential to make science more meaningful to learners (Sebotsa et al., 2019:350-351; Cronje, 2015). It could also result in learning science which is not confusing but more interesting, since learners might not struggle to relate the two knowledge systems. Western knowledge systems and indigenous knowledge systems need not be in conflict. The space where indigenous knowledge and Western ways of knowing connect and overlap can be understood as the 'cultural interface' (Nakata, 2002). This can be a contested space, but can also be a space where different ways of knowing work together synergistically (Sebotsa et al., 2019: 350; Nakata, 2010).

Table 2.5: Table showing the tenets of NOS and NOIK (adapted from Lederman, 1999:917 and Cronje, 2015:42)

Tenet	Nature of science (NOS)	Nature of indigenous knowledge (NOIK)
1	Scientific facts can be altered over time by critique and technological changes, hence they are *tentative.*	*Resilient* yet *tentative,* IK is constantly changing due to knowledgeable elders' experiences and storytelling.
2	NOS is *empirical* knowledge resulting from the natural world through observations and experiments.	NOIK is *empirical* and *metaphysical.* Herbalists follow the scientific method through observations and experiments.
3	NOS is *inferential,* hence deductions made from experimental procedures and observations.	NOIK is *inferential*. Conclusions and interpretations made from investigational procedures and observations.

4	NOS is *socially* and *culturally* entrenched. Science is a human venture, whereas scientific theories and laws are evaluated by others.		*Socially* and *culturally* entrenched, IK encompasses traditions followed by a specific culture, spread through social gatherings.
5	NOS involves human interpretation, invention and imagination; hence NOS is *creative*.		NOIK involves human understanding, myths and imagination; hence NOIK is *creative*.
6	NOS is *subjective* (theory based). Scientists try to be objective but are human and will remain subjective due to prior knowledge and beliefs.		NOIK is *subjective.* Knowledgeable elders are inspired by prior knowledge, beliefs and spiritual influences.
7	Approached in a reductionist manner.		Approached in a holistic manner and includes a strong metaphysical character.

2.7 CONTEXTUALISED EXAMPLES THAT CAN BE CONSIDERED FOR NATURAL SCIENCES CAPS

The common elements between IK and 'Western science' as it is captured in the CAPS are outlined below. The four features of IK which are consistent with modern science are as follows: (1) understanding systems as a whole and not as isolated interacting parts, suggesting an inductive approach to classroom science; (2) interaction between the learner and the person who holds the knowledge, suggesting teacher-learner and learner-learner interactions in the classroom science; (3) a strong practical engagement in everyday life, implying relevant as well as active learning in classroom science; and (4) the adult generation passes on the knowledge to new generations, that is, a communicative approach in classroom science (Sebotsa et al., 2018; Van Rooyen, De Beer, et al., 2006).

Thus, linking IK strongly in Natural Sciences and other sciences might improve South African science performance. This would result in what Gibbons (2000) calls mode 2 knowledge construction, namely context-sensitive science (Sebotsa et al., 2019:342-343; Sebotsa et al., 2018:269). This is further supported by De Beer (2016), who agrees that traditional healers who practise IK also follow a scientific method, namely making observations, formulating hypotheses, making predictions, deciding upon a suitable method for experimentation, recording results and analysing (Sebotsa et al., 2019:342-343; Sebotsa et al., 2018:269). De Beer thus emphasises that what a traditional healer does is not so much different to the modus operandi of a 'Western' scientist. It is thus possible to include indigenous knowledge in the science classroom, emphasising the tenets of science. To continue with the conversation, it is important to make it clear that grade 7-9 Natural Sciences 'Indigenous knowledge includes knowledge about agriculture and food production, pastoral practices and animal production, forestry, plant classification, medicinal plants, management of biodiversity, food preservation, management of soil and water, iron smelting, brewing, making dwellings and understanding astronomy' (NS CAPS, 2008:8). It is befitting to provide a similar or a different perspective of IK compared to the western science (Sebotsa, 2019: 342-343).

Next, eight Natural Sciences examples are used that show how IK and Western science (the CAPS curriculum) overlap and share synergies. In this section, I will provide a few examples of indigenous knowledge that could be used to contextualise the subject. The first three chemistry examples are on leather tanning, alcohol production and amageu. The subsequent three physics examples focus on thermodynamics, using the popular mat house in the Northern Cape; on energy change, using the Khoi San bow and arrow hunting technique; and on the construct of astronomy. These examples seek to explain the above themes from the African indigenous lens. They will be followed by two important examples on saponification and 'cannabis' marijuana. Such curriculum will provide learners with context-sensitive science that addresses their affective domain. Further this will address science that speaks to the community (Gibson, 2000).

2.7.1 First example: leather tanning

Traditional leather tanning could serve as a brilliant way of introducing endothermic reactions in the classroom. Traditionally calcium powder was obtained by grinding the bones of cattle and adding some potash to it. Next bird droppings were added to the mixture and applied to the soaked skins. The bird droppings are rich in uric acid, which lowered the pH, and this enhanced the denaturation of proteins, which again acted as a catalyst for an endothermic reaction with water molecules (White, Bester & Sebota, 2019:252; De Beer & Van Wyk 2019:118-119; De Beer, 2015; Zaruwa & Kwahe, 2014).

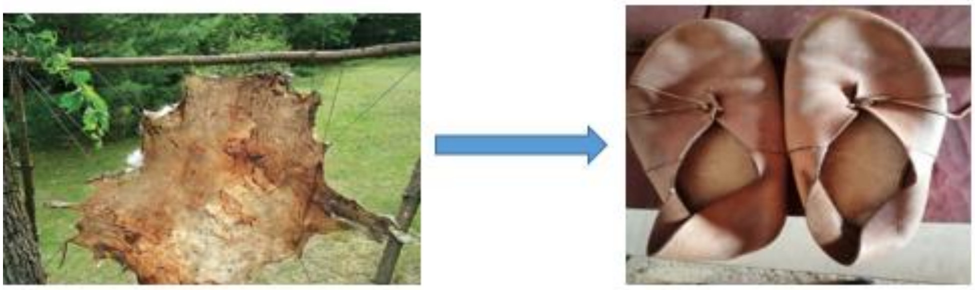


Figure 2.3: An example of leather tanning and shoe making: A lesson in chemistry

Sources:https://www.realworldsurvivor.com/2018/12/27/tanning-tutorial-turning-critter-hides-workable-leather/

https://aprilmunday.wordpress.com/2020/04/26/medieval-shoes-and-pattens/

Indigenous knowledge is used in leather tanning, and is similar to the content presented in Western curricula. The main difference is in the processes and new technologies. Societies across the world depend on their indigenous knowledge to solve their day-to-day socio-economic problems, address various environmental challenges, and adapt to change (White, Bester & Sebota, 2019:252; De Beer & Van Wyk, 2019:118-119).

When dealing with endothermic reactions in the chemistry curriculum, such traditional leather tanning could be used as an example to better contextualise a rather abstract concept, as suggested in Figure 2.3.

2.7.2 Second example: Umqombothi

Umqombothi is a ‘whisky-like’ alcohol that is produced by indigenous people of Southern Africa by fermentation of sugars (in millet, maize, and fruits such as marula) (SLP, 2016; Van Wyk & Gericke, 2018). The fermentation reaction of the sugar obtained from the ingredients or sugar cane is glucose (sugar) → enzyme → ethanol + carbon dioxide which is given by the chemical formula $C_6H_{12}O_{6(aq)} \rightarrow 2C_2H_5OH_{(aq)} + 2CO_{2(g)}$ (SLP). The CAPS Grade 10-12 Physical Sciences (DBE 2011b) mentions two basic links to alcohol fermentation. The first is the preparation of alcohols via different reactions of which the substitution’s reactions are the basic preparation method. The second, the principle of fractional distillation – the separation of liquids based on different boiling points – is illustrated by fermentation. This is an IK example of how to contextualise the science curricula for learners when the topic of anaerobic fermentation is offered

Figure 2.4: The production of alcohol across Africa: An example of how to contextualise the CAPS theme on fermentation

Sources: https://newshorn.co.za/umqomboithi-replaces-beer-brands-in-rural-areas/
https://taste.co.za/umqombothi-maize-sorghum-beer/

2.7.3 Third example: Amageu

Amageu is a widespread food or beverage to many African indigenous people and can be used as an example to mobilise the value of indigenous knowledge using this particular food. Spelling differs in the various languages: Setswana (mageu), Sotho (mahleu), Khoekhoe (Maxau), Xhosa (maHewu), Zulu and Northern Ndebele (amaRhewu or amaHewu). Amageu is a traditional fermented non-alcoholic beverage made from mealie pap or leftover food (Ngcoza, 2019). From the leftovers or mealie pap, a nutritional thirst quencher beverage was 'born' and called amageu or amarewu. It is a non-intoxicating beverage used for domestic drinking (*ibid*). It is also used as an energy boost during long hours of toiling in the fields. Amageu contains important nutritional elements such as Vitamin B, which assists with the nervous system and the digestive enzymes, and a lesser amount of saturated carbohydrates which provide the body with energy (*ibid*). With this particular example, I would like to draw closer to the process called fermentation, a scientific concept learners will come across particularly while focusing on the topic of chemical reactions in grade 8. What is of importance to this study is that indigenous people had empirical knowledge of the construct, and this knowledge can be used to contextualise the Natural Sciences curriculum. According to Ngcoza (2019:5), 'fermentation involves the conversion of starch into glucose. When the fermentation process is prolonged, the enzymes cause food to ferment further, producing alcohol. The glucose that is formed during fermentation provides people with less saturated starch or carbohydrates and produces energy when consumed'. This process of fermenting can also be extended to the making of 'umqombothi', a process known in Xhosa as 'ukuvundisa' (Ngcoza, 2019). What is of importance is to make a clear separation between amarewu and umqombothi.

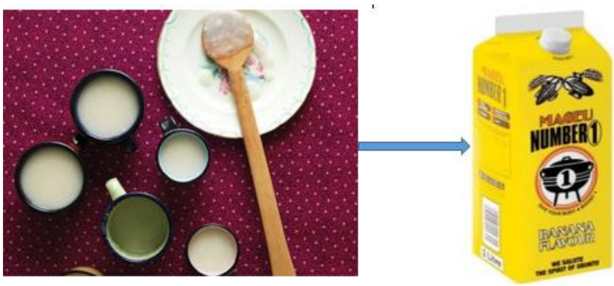


Figure 2.5: An excellent example of how to contextualise the science curriculum.
Sources: https://www.eatout.co.za/recipe/mageu/
https://za.pinterest.com/pin/494481234060726791/

Amarewu is a half-fermentation process which produces a non-intoxicating nutritious drink without malt being added (Soga, 1931). According to Soga (1931:401), 'for the preparation of amarewu, maize is ground to a fine meal, and a small quantity of wheaten flour or malt is added to it in order to produce slight fermentation. A sufficient amount of water is then added to prepare a thin porridge. The process of fermentation thins down the porridge until it is sufficiently liquid to be taken as a drink'. This is an example that can foster inquiry learning while offering a contextualised curriculum. For instance, using the scientific method, learners can investigate the difference in fermentation between amageu and umqombothi. Alternatively, they could investigate the chemical formula of the products mentioned. Both amarewu and umqombothi are fermented, though umqombothi is an intoxicating beverage. For umqombothi, the process is lengthier, and malt is added. Figure 2.5 provides examples of amageu, from home use to consumer product.

2.7.4 Fourth example: Thermodynamics

Thermodynamics is customarily taught in the physics curriculum. This example will refer to the traditional mat houses ('matjieshuise') of the Khoi-khoi, where the concept of thermal expansion is observed in hot and cold seasons. When it is hot, the reeds (*Cyperus marginatus*, or 'matjiesgoed') (Van Wyk & Gericke, 2018) expand (thermal expansion), allowing the reeds to store the heat. In the evening, the heat will be released to keep the place warm and ventilated (De Beer, 2015). This is an excellent example that could be used in the Natural Sciences classroom in the Northern Cape, where learners are accustomed to these 'matjieshuise'. The learners can be afforded chances to investigate the lifespan of the mat houses under different South African temperatures as one example. Figure 2.6 provides the reader with an example of a mat house.

Figure 2.6: An example of the reed mat house

Source:https://www.africanbudgetsafaris.com/blog/african-tribes-african-culture-and-african-traditions/

2.7.5 Fifth example: Kinetic energy

The bow and arrow of the Khoi-San hunters can be used to demonstrate the change of elastic energy into kinetic energy. According to the laws of energy conservation, energy cannot be created or destroyed but can be converted from one form to another. When the Khoisan and Zulu hunters stretch their bows to shoot arrows, the bow has elastic potential energy. The moment the arrow leaves the bow; this elastic potential energy is converted into kinetic energy. This kinetic energy will be instrumental to strike an animal down. It is unfortunate that the original indigenous descendants of South Africa might be marginalised from such a curriculum. Figure 2.7 illustrates the Khoisan people's bow and arrow technique.

Figure 2.7: An example of the bow and arrow of the Khoisan hunters

Source: https://tsena.co.bw/our-people

2.7.6 Sixth example: Astronomy

This example could emphasise why IK could be seen as being part of the history of science and why it is important for the production of new knowledge. During the historical development of astronomy people observed that the Moon and Sun and stars seem to move in predictable patterns, which could be used to measure time and develop different calendars. This gave rise to the concept of a year (a time period that includes the four seasons), a month (a time period from one full moon to the next full moon), and a day (a time period from one sunrise to the next sunrise).

This content is adapted from grade 9 Natural Science CAPS document (DoE, 2012; 35). People used these patterns in different ways, such as direction-finding and to denote times for planting and special holidays, and passed this knowledge on using stories. Our ancestors would not have survived if they had not been able to study the environment they occupied and depended on.

2.7.7 Seventh example: Saponification and cosmetics

In Africa, many plants have been used as natural sources of soap. Van Wyk and Gericke (2000:277) explain that these plants contain huge amounts of saponins that dissolve fat and oily substances. During soap-making the main ingredients are animal fat and lye which is customarily used to convert the animal fat or oil into soap. During this process, it should be made clear that the fat is hydrolysed by the caustic alkali, resulting in the production of soap and glycerol.

The soap that is formed is of the result of the potassium salt or the sodium of fatty acids. The chemical process of doing so is called saponification (*ibid*). The glycerol from the animal fat in the soap is commonly used as a moisturizer to protect the skin against the strong African sun rays. Soap-making in the African context used plants instead of NaOH (*ibid*).

Traditionally the indigenous people of Africa have used – or still use – plants such as *Helinus integrifolius* and *Noltea africana* for bathing, as cleaning agents (detergents) and for washing clothes (Van Wyk & Gericke, 2000:277). The aforementioned plants produce large quantities of foam when crushed and dissolved in water (*ibid*). This approach should help communities to improve the soap-making process and enhance indigenous knowledge and science process skills. It will further create an inclusive and interesting curriculum for the diverse South African learners. Figure 2.8 shows homemade soap from the Western Cape.

Figure 2.8: Soaps made by the teachers during the short learning programme on indigenous knowledge

Photographer: Josef de Beer. All participants provided consent that the photographs may be published.

2.7.8 Eighth example: Cannabis (dagga or marijuana)

The current big debate is based on the commercialisation and the agricultural perspectives of the plant *Cannabis sativa*, commonly known as dagga or marijuana (Figure 2.9). It is currently debated that cannabis has the potential of being South Africa's biggest economic asset, with a market estimated at R27 billion in 2023 (Business insiders, 2019). The plant is currently being used by the complementary health sector to treat a range of ailments (Riley, Vellios & Van Walbeek, 2019). The use of this plant for IK-science curriculum contextualisation is still to be investigated, but possibilities include links to curriculum topics such as: classification of plants, anatomy of dicotyledonous plants, life process of plants, and medicinal uses of plants.

Another mind-altering plant – this time an indigenous plant – is *Sceletium tortuosum*. This psychoactive plant has been used by the San, and is commonly known as 'kaauwgoed' (Dutch), or 'kougoed' (Gericke, 2018). In-vitro and in-vivo tests have been done on the active ingredients in the plant, and it has resulted in a pharmaceutical product called Zembrin (Gericke, 2018). A benefit-sharing agreement has been signed with the San Council. This demonstrates the entrepreneurial and economic affordances of South Africa's rich indigenous knowledge systems.

Figure 2.9: *Cannabis sativa*, a plant with many benefits
source: https://weedmaps.com/learn/the-plant/difference-between-indica-sativa/

2.7.9 Story-telling

Nowadays, STEM education is making way for STEAM (Science, Technology, Engineering, Arts and Mathematics). Some authors, such as Fulton and Simpson-Steele (2016), show that both arts and science require discovery, observation, experimentation, description, interpretation, analysis, and evaluation. The infusion of indigenous knowledge would move the STEAM agenda forward, as it will facilitate the infusion of arts in the STEM curriculum. Indigenous knowledge as an African trademark focused on story-telling. Story-telling is part of indigenous knowledge, and the inclusion of IK could be done through the use of short vignettes in the classroom (De Beer, Petersen & Brits, 2018).

All learners benefit from learning from diverse cultures and profit from learning indigenous knowledge, through experiencing different perspectives on the natural world, which enhances their creative problem-solving capabilities (Sebotsa et al., 2019:350-352; De Beer, 2016; Dei, 1993). If students move into professional, scientific careers, they may be more well-rounded and reflective scientists, engineers, resource managers, or health professionals (Aikenhead & Michell, 2011). By including indigenous knowledge in the science school curriculum, we would provide greater epistemological access to the national curriculum for the diverse South African school population (De Beer & Petersen, 2015). Furthermore, studies in multiculturalism in science education point to difficulties that students face in negotiating boundaries between their culture and the subculture of Western science, on which school science is based (Cameron, 2016; Jegede, 1995).

Hence, IK knowledge should be emphasised in the school curriculum, and the implementation should be done as a matter of urgency. Bantwini (2009:169) maintains that failure to implement successful new curricula still persists and it is argued that well designed curriculum reforms with impressive goals have not been successful because too much attention has been focused on the desired educational change and neglects how the curriculum change should be implemented, which has been linked to the Eurocentric approach. This argument is supported by the scholar Basil Bernstein (2018) who emphasises that it is not only the curriculum that should be assessed to tell something about education and society, but also the way the curriculum is actually implemented in the classroom itself. Indigenous knowledge is superficially integrated in sciences, as the literature concludes, and should be more fully integrated if South African sciences are to be improved culturally and socially (Sebotsa et al., 2019:351).

Figure 2.10: Teacher using engaging pedagogy of play to infuse IK in the science curriculum

Photographer: Josef de Beer & Tswakae Sebotsa. All participants provided consent that the photographs may be published.

2.8 AFFORDANCES OF IK-SCIENCE CURRICULUM USING PROBLEM-BASED LEARNING AND PROJECT-BASED LEARNING FOR TEACHER PROFESSIONAL DEVELOPMENT

This study takes the view that transmission-mode teaching denied and deprived South African teachers and their learners of fully developing essential 21st century skills such as problem-based learning (PBL) and project-based learning. Teachers should be acquainted with pedagogies for using PBL approaches. Problem-based and project-based learning provide the opportunity to create learning opportunities that are learner-centred and could enhance the self-directedness of the learners (White, Bester & Sebotsa, 2019; Sebotsa et al., 2019; Sebotsa et al., 2018).

Problem-based learning (PBL) is a social-constructivist teaching-learning strategy (Hassan, 2013:49-51). PBL entails authentic, unstructured, open-ended problem constructs which are used as a learning stimulus to solve real-life problems (Hmelo-Silver & Barrows, 2006:24-25). With this approach a real-world problem is considered as the starting point for learning (*ibid*). In a PBL approach the teacher takes the role of facilitator and oversees the learning process (Pawson *et al.,* 2006:104-106). In addition, learners are working collaboratively and are responsible for directing and constructing their own learning (Maurer & Neuhold, 2012).

By doing this the learners are the ones that are coming with different solutions to the problem (Maurer & Neuhold, 2012). It is important to use this particular approach as it provides students with skills to identify ways of solving the problem. This approach is tantamount to self-directed learning, as the approach aims at the 'self' and the 'self' is solving his or her problems. By doing this, the 'self' identifies the problem and the resources that will help the 'self' to get to the most reasonable 'self' solution. These are the skills that are required in the 21st century (problem-solving skills).

Barrows (1986:6-10) compiled a list of six characteristics of problem-based learning:
1. Learner-centeredness;
2. Learning in small groups;
3. Teacher in role of facilitator;
4. An authentic problem presented at the start of the learning process;
5. A problem serves as instrument for discovery;
6. Learning of new contents by self-directed learning.

Both problem-based learning and project-based learning are more concerned with problem-solving skills. The difference between the notions is as follows: Project-based learning is a form of situated learning in which the learners are strengthening their learning by working with and using ideas from the real-world context. Krajcik and Shin (2016:276) list the six features of project-based learning as follows:

1. Start with a driving question (a problem to be solved);
2. Focus on learning goals that students are required to demonstrate mastery of;
3. Students explore the driving question by participating in scientific practices- processes of problem-solving that are central to expert performance in the discipline;
4. Students, teachers and community members engage in collaborative activities to find solutions to the driving question;
5. While engaged in the practices of science, students are scaffolded with technologies;
6. Students create a set of tangible products that address the driving question.

In this study, IK will be integrated into CAPS themes using the PBL approach. For example, teachers were encouraged to engage learners in an ethnobotanical survey, utilising the Matrix Method developed by De Beer and Van Wyk (2011).

2.9 ADDRESSING THE LACK OF RESOURCES

Below the researcher provides the affordances of the science-on-a-shoestring approach for inquiry-based learning. Part of this section (2.9.1 and 2.9.2) has been published in the IISES and ISTE proceeding with references Sebotsa et al. (2019:345-346) and Sebotsa et al. (2018:270 & 274) respectively.

2.9.1 Science-on-a-shoestring experiments: developing teacher agency

One of the aims of teaching is to develop conceptual understanding among learners by using appropriate resources, especially visual resources that could assist the processes of accommodation and assimilation (Piaget, 1970). The socio-economic realities in the country lead to many under-resourced classrooms. Science-on-a-shoestring experiments (or, ‘frugal science’, according to Jackson, De Beer & White, 2016) are inexpensive and could achieve the same objectives as expensive apparatus; they will provide learners with a better understanding of the science content and guide them on how to follow inquiry learning approaches.

One often hears teacher comments such as ‘How can I be expected to teach science successfully without the necessary apparatus?’ ‘I do not have the material and therefore I am unable to teach science effectively!’ Teachers sometimes make such comments at cluster meetings (Sebotsa et al., 2019:345-346; Van Rooyen & De Beer *et al.,* 2006; 2004). Some schools are seriously under-resourced, while some have no resources at all (*ibid*). Approximately 70% of South African schools do not have either the infrastructure or the apparatus to teach science in the manner and standard that is recommended (Simelane, 2019)). The National Education Infrastructure Management System (NEIMS) statistics reaffirm this. In Table 2.6 below, we see that the percentage of ordinary schools in South Africa without laboratories ranges from 60% to 94% in different provinces. Whilst real experimentation with conventional laboratory apparatus and equipment is desirable, most schools in rural South Africa, as in other developing countries, face challenges of inadequate resources, particularly financial resources for acquiring apparatus and materials for imparting effective and efficient science education.

Table 2.6: Department of Education laboratories summary grid for ordinary schools

Province	*Number of schools*	*With laboratory*	*% With laboratory*	*Laboratory Stocked*	*% Stocked*	*Without laboratory*	*% Without laboratory*
Eastern Cape	5 676	493	9	110	2	5 183	91
Free State	1 615	337	21	103	6	1 278	79
Gauteng	2 031	813	40	287	14	1 218	60
KwaZulu-Natal	5 931	719	12	221	4	5 212	88
Limpopo	3 923	235	6	59	2	3 688	94
Mpumalanga	1 868	213	11	53	3	1 655	89
North West	1 674	269	16	72	4	1 405	84

Northern Cape	611	180	29	67	11	431	71
Western Cape	1 464	513	35	259	18	951	65
TOTAL	24 793	3,772	15	1,231	5	21 021	85

Source: National Education Infrastructure Management System (NEIMS), May 2011:2.

Potchefstroom is a town situated in the North-West Province, and the site where the study is conducted. Statistics highlight that 84% of ordinary schools in this province do not have laboratories. The province has 1,674 schools, and only 269 of these schools have laboratories. Out of the schools with laboratories, 72 have laboratories which are stocked with Natural Science laboratory apparatus. This means that 1,405 schools in the North West Province are without laboratories, as specified in the table above. The issue of resources is a controversial one and teachers in certain schools are stressed because they feel that they are expected to produce results without support or adequate resources. To avoid a hullabaloo similar to the Limpopo textbook saga, where schools were without resources such as textbooks, the challenge of resources should be diagnosed with new strategies and interventions.

An alternative in the form of readily available (shoestring) inexpensive apparatus could serve as the way forward. Particularly in South Africa, where resources such as teaching and learning equipment (laboratories as an example) are lacking (as in the context of this study) (Onwu, 1999; Kihumba, 2009), creative alternatives should be investigated. One feasible approach is shoestring science, which is called ‘science-on-a-shoestring’ in this study.

Science-on-a-shoestring training during teacher development could result in increased teacher agency as the teacher critically reflects on meaningful learning, and improvises both learning activities and resources. This approach could be seen as a meaningful way of solving such perennial issues and motivating teachers to do science practicals in schools. The researcher is of the opinion that science-on-a-shoestring approaches can alleviate the challenge of resources in under-resourced schools.

An example of utilising science-on-a-shoestring approaches could be drawn from the UNISA SDPSCO-8 (2009) physics study guide on Newton's second law, where a marble and ball are placed on a table and an approximately equal force F applied to both, the small mass causing the marble to move faster than the ball. This example illustrates the concept of force being inversely proportional to the mass.

The researcher is of the view that teachers will be positioned to increase their agency and foster an effective science classroom by using science-on-a-shoestring. According to Van Rooyen and De Beer (2006), if teachers are exposed to science-on-a-shoestring approaches, the exposure will stimulate them to become more resourceful. This might contribute to their agency to take responsibility for their circumstances and not to act as victims, and it could assist them in creating conducive learning environments in their classrooms. This will provide learners the opportunity to engage in authentic learning activities. These learning activities can probably provide the same nuanced view of the nature of science, while using inexpensive resources in under-resourced schools. During the intervention the A-Team teachers were provided with the skills of being agents of change in under-resourced Natural Sciences classrooms. The teachers were also guided on how to structure an inquiry lesson using science-on-a-shoestring in a Natural Sciences classroom.

In terms of Giddens' (1984) structuration theory, teachers will be in a better position to proactively use the existing structures (e.g., insufficient resources) to create learning experiences to give learners a better chance to improve their knowledge, skills, attitudes and values. A serious weakness with this argument, however, is that many teachers show a lack of agency and are apparently not able to improvise by using 'science-on-a-shoestring' approaches to emphasise concepts in the classroom (Van Rooyen & De Beer, 2006). The above-mentioned weakness will be addressed by assisting teachers to use 'science–on-a-shoestring' approaches during teacher professional development. In this intervention, the teachers will be shown how abstract concepts could be made concrete by using inexpensive 'science-on-a-shoestring' experiments.

Through science-on-a-shoestring approaches, the teacher(s) can highlight the tenets of science. Shoestring approaches could highlight tenets such as the empirical nature of science.

The teacher development also strongly focuses on teachers being agents of change. Being an agent of change should be addressed effectively during teacher professional development. We use the concept of agency from a socio-cultural perspective, enabling the examination of individual action in a way that gives priority to the social contexts and cultural tools that shape the development of human beliefs and ways of acting (Wertsch, 1991). How teachers think and act is always shaped by cultural, historical and social structures that are reflected in mediational tools such as the curriculum guidelines and standards set by government. The tools are not static; they continue to evolve as people use them (Vygotsky, 1962) in their professional practice (Tharp & Gillmore, 1988). Hence, teachers need to be enabled to act as agents who pay attention to their sense of self, their identity, their knowledge and contextual influences that have an impact on their teaching (Ebrahim, Verbeek & Mashiya, 2011).

Teacher agency influences and is influenced by the features of curriculum reform. In this context, teachers will adopt the official CAPS curriculum and pedagogic mandates. For teachers to function as agents of change they need to be subjected to transformative learning. The latter is associated with Mezirow's views (1977, 1981) and is consistent with the idea of effecting change. Mezirow (1977:157) argues that people's perspectives on reality are transformed as a result of reflection upon disjunctive or 'disorienting' experiences: when a 'meaning perspective can no longer comfortably deal with anomalies in the next situation, a transformation can occur'. Such transformation amounts to a paradigm shift (Ebrahim, Verbeek & Mashiya, 2011).

2.9.2 Interactive computer simulations (PhET simulations)

Earlier on I mentioned reasons that hinder South Africa's global competitiveness. One of the many reasons highlighted include the lack of resources such as laboratory equipment and inadequate ICTs in many classrooms. According to Ledward and Hirata (2011), the expansion of information technology has reshaped the labour market and fundamentally changed the economy in the 21st century. In this section I provide reasons why PhET simulations should be considered as an important resource to move inquiry-based learning forward in the 21st century classroom. The Physics Education Technology (PhET) Project entails interactive computer simulations for teaching and learning different sciences. The PhET simulations demonstrate principles in physics, chemistry, biology, earth science and mathematics (Sebotsa et al., 2019:347-348; Perkins et al., 2004).

These engaging interactive simulations can be used in classrooms or in laboratories. The PhET is based at the University of Colorado in Boulder and is a library of free online educational simulations created for teachers and students and available on computers, cell phones and tablets. The latter can be downloaded from https://phet.colorado.edu/en.

The PhET simulations could assist in promoting 21st century skills. The Partnership for 21st Century Skills (P21), provides four major findings from the literature (Ledward & Hirata, 2011:2-5):

- The world in which learners find themselves today is fundamentally different from before; the expansion of information and communication technology is transforming the nature of learning.
- 21st century skills establish new learner standards by integrating core-subject mastery and contemporary, interdisciplinary themes (such as civic literacy, global awareness, IK-science and environmental literacy).
- With the learning environment and teacher competency as primary factors, the development of these skills can be achieved in many ways (e.g., place-based, project-based, or problem-based learning).
- Although research in this area is relatively young, existing evidence links 21st century skills with positive learner outcomes.

Looking into the first finding from P21, it becomes clear that the learning environment for the learners is drastically changing, which necessitates teaching with effective technologies. It is because of such fundamentals that I argue for the use of interactive computer PhET-simulations in grade 8 Natural Sciences.

2.9.3 Technology as an effective cognitive tool for teaching and learning

Research has shown that secondary and high school learners' knowledge consists of a small number of facts and equations that are not effective for the interpretation of simple, real-world physical phenomena (Redish, Saul & Steinberg, 1998). This I believe influences some of the students' attitudes, interests, pedagogy and behaviour towards science learning. On the other hand, technology can be used to strengthen student learning and enhance pedagogy (Sebotsa et al., 2019:347-348; Dede, 2000; Ding, Ottenbreit-Leftwich & Glazewski, 2019).

Researchers reported that technology could be used effectively as a cognitive tool for teaching and learning in the classroom (Bruce & Levin, 2001; Bransford, Brown & Cocking, 2000; Schleicher, 2019).

New technologies, such as simulations, provide new opportunities for learning. They offer brand-new possibilities not accessible before. According to Bransford et al. (2000), new technologies can be used to:

- Provide exciting curricula based on real-world problems in the classroom;
- Provide scaffolds and tools to enhance learning;
- Give students and teachers more opportunities for feedback, reflection and revision;
- Build local and global communities that include teachers, administrators, students, parents, practising scientists; and
- Expand opportunities for teacher learning.

They further indicated that the most important reason for schools to introduce computers are to (a) give learners an important experience for the future, (b) keep curricula up to date, and (c) make the school a more interesting place.

Media and new technologies present a turning point in the educational system since they provide the basis to support the necessary changes (Jeschke & Keil-Slawik, 2004). There has been a great focus on the study of several types of teaching interventions intended to help students understand concepts or applications. To the researcher's knowledge none of these intervention(s) have been applied or used in Potchefstroom to assist Natural Sciences teachers to be self-directed in their learning, nor have empirically proven learning benefits been reported.

2.9.4 PhET simulations and self-directed learning – pedagogy of the 21st century

As discussed by Sebotsa et al. (2019:347-348), Thompson et al. (1996) defined simulations as demonstrations of an event or a model used to understand a phenomenon. Interactive computer simulations allow Natural Sciences learners to interact with a simplified version of a scientific process which is based on mathematical model. The model present learners with a visual representation of science topics that learners can investigate (Radinschi et al., 2017).

Utilising PhET simulations (ICTs) holds affordances to enhance learning and promote development of of 21st-century skills. These skills include using technologies and self-directed learning (SDL) skills (De Jong et al., 1998). With SDL, learners build knowledge themselves, and the learning process is symbolised by placing a great responsibility into the hands of the learner instead of the teacher (Knowles, 1975). This has the advantage of stimulating a learner-centred approach, sparking interest, using real life applications, placing learners in a social environment, and keeping learners active (Sherman & Kurshan, 2005), as compared to the 'chalk and talk approach', which disenfranchises learners' scholastic development, as the teacher is the focus, not learners (Petersen & De Beer, 2016).

Simulations are especially well-matched for self-directed learning that promotes 21st century skills: the use of PhET simulation encourages *discovery learning*, learners' experimenting and building knowledge as 'scientists' (Krajcik & Mun, 2014). In a simulation engagement, learners are provided with opportunities to provide the simulation with the input, observe the output, draw graphs and conclusions as scientists do (Lewis & Want, 1980; Van Joolingen & De Jong, 1997). Cigrik and Ergul (2009) and Ogbonnaya et al., (2010) reported increased learner achievements in science studies when computer simulations are used, and this interpretation is synonymous with the 21st century skills outcomes (Ledward and Hirata, 2011). Using computers as a learning aid goes beyond just working with apparatus, reading and memorising. The simulations use visual tools as an important part of learning, interpreting and understanding science content (Mhlongo, Kriek & Basson, 2011), implying a conceptual understanding if well used.

2.9.5 Advantages of simulations and how their use supports SDL and 21st century skills

Computer simulations such as PhET provide the learner with numerous advantages (Mhlongo, Kriek & Basson, 2011:14). According to Michael (2001) cited in Mhlongo et al. (2011:14) the advantages are as follows:

- Provide the students with the opportunity to engage in activities that may otherwise be unattainable.

- Enhance academic performance and learning achievement levels of students. In a study conducted by Betz (1996), it was found that students who supplemented their class readings with the use of a computer simulator performed better in their examination.
- Be equally effective as real-life hands-on laboratory experiences. Choi and Gennaro (1987) found that a computer-simulated activity was as effective as a hands-on laboratory activity in teaching the volume displacement concept.
- Foster peer interaction, an important principle of self-directed learning.
- Provide students with immediate and reliable feedback. By manipulating certain variables in the simulations, students can quickly obtain reliable data pertaining to lift and drag. Simulations of this type can also save time for both students and teachers.

2.9.6 Teachers' views and the need for teacher professional development in ICTs

The researcher is of the opinion that most educators prefer real-life laboratories to simulations. However, the benefit is that simulation technology can be used in a classroom that lacks science apparatus, and it is cost effective. To be able to gain from such benefits, teachers are required to devise relevant pedagogy to teach using simulations. The opportunity of developing self-directed teachers and 21st century skills depends on teachers' technological pedagogies. This might be more challenging if this pedagogy was not emphasised in teacher training. This transformation requires teachers to be agents of change. Teachers hold the key to student achievement, since they influence what and how students are taught (Tobin, 1998). Many of the teachers' choices in the classroom are driven by their beliefs and values (Cuban, 2001, 169; Stols & Kriek, 2011). Research shows that it is often difficult to change teachers' behaviours and views (Ding, Ottenbreit-Leftwich & Glazewski, 2019; Stols, 2011).

According to Lumpe, Haney and Czerniak (2000), teachers are resistant to change. A reason for this is that teachers' pedagogy is often based on their beliefs and values and these are difficult to change (Stols & Kriek, 2011). This resistance necessitates interventions that will provide teachers with 21st century pedagogies and new training that will encourage teacher change. Such initiatives could be provided during teacher professional development.

According to the 21st-century student outcome and support system framework (Ledward & Hirata, 2011:2) professional development is a major strategy to support the 21st-century skills outcomes. I am of the view that this framework can be used as one of the key drivers to change teacher's views on teaching, especially in the digital age. Furthermore, the framework can be used to support teachers in using technologies during teacher professional development. Figure 2.10 illustrates the 21st century student outcomes and support systems framework that makes provision for teacher development as a mechanism to assist teachers with 21st-century outcomes.

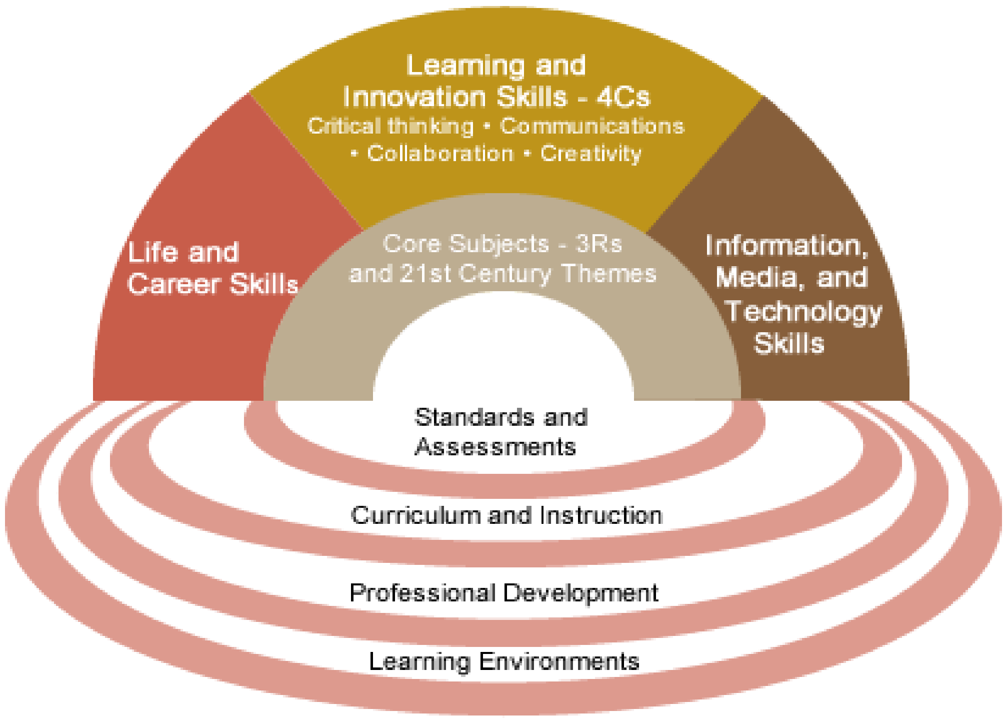


Figure 2.10: The 21st-century student outcome and support framework for professional development as a mechanism to achieve 21st-century student outcomes (Ledward & Hirata, 2011:2)

In this study, the researcher considered a professional development programme with the intention to assist the A-Team teachers to create a 21st-century classroom and culture by using interactive computer simulations in their classrooms. During professional development, I had to consider how to support teachers to be self-directed in their learning by considering 21st-century skills.

Thrilling and Fedel (2009) provide a guideline to conducting a systemic and longitudinal professional development that is aligned to 21st -century framework and skills, such as the one that focuses on the curriculum, instruction, new technologies and assessment, as follows:

- Experiential – engaging teachers in concrete tasks of curriculum design, implementation, and assessment;
- Learner-focused – grounded in teachers' own questions, problems, and issues (construct of SDL according to Johnson and Johnson, 1999);
- Collaborative – building upon the collective experiences of participants and the wider community (construct of SDL according to Johnson and Johnson, *ibid*);
- Relevant – connected to teachers' work and contexts (construct of SDL according to Johnson and Johnson, *ibid)*;
- Sustained and intensive – including ongoing support via modelling and coaching, during and after the programme (longitudinal and systemic intervention within a community of practice);
- Integrated with other aspects of school reform (based on CAPS curriculum and teachers' professional needs);

Research indicates that learners will find it challenging to develop 21st-century skills without the support of well-trained teachers who hold instructional knowledge in this domain (Ledward & Hirata, 2011; Partnership for 21st Century Skills, 2006). Research shows that many teachers are not well informed on 21st century skills and instructional technologies (Tan & Koh, 2014; Coban, 2003). According to the Partnership for 21st Century Skills (2006), and Ledward and Hirata (2011), well-thought-through professional development can assist teachers understand the importance of the 21st-century skills. To achieve the objective of 21st century skills such as integrating technologies, I further considered the work of Krajcik and Mun (2014) during the teacher professional development. Krajcik and Mun (2014:339-334) provide principles of effective technology use during teacher professional development as follows:

- Support the student in 'actively construct[ing] meaning based on his or her experiences and interactions in the world' (p. 339);
- Be 'situated in an authentic, real-world context' (p. 340);

- Provide cognitive tools to help ‘amplify and expand what students can do in constructing knowledge’, e.g., through software that ‘allow[s] learners to visualize complex data sets’ (p. 342);
- Support specified learning goals (p. 342) (construct of SDL according to Johnson and Johnson, date; and Knowles, 1975:19);
- Scaffold student capabilities by ‘support[ing] and assist[ing] learners in accomplishing a challenging task ... that would otherwise be unattainable’ (Krajcik & Mun, 2014:342) (construct of SDL according to Johnson and Johnson, 1999).

According to Hattie (2009:221) the effectiveness of learning with computers increases when:

- It is accompanied by the use of diverse teaching strategies;
- There is pre-training in using computers as a tool for teaching and learning;
- There are many opportunities for learning;
- Student is in control of learning;
- Peer-learning and feedback are optimised.

My research complies with Hattie’s directives as follows:

As regards the use of *diverse teaching strategies,* in my study teachers engaged in three different contexts of inquiry on the construct of visible light and compared which one was more effective or which combinations are complimentary. As regards using ‘science on a shoestring’, Wilson (2016) is of the view that pairing computer simulations in grade 8 with hands–on activities can further enhance learning for the learners, allowing them to explore the content on a deeper level.

With regards to *pre-training in using computers as a tool for teaching and learning*, this was achieved by the researcher and the co-supervisor Prof Kriek. Prof Kriek has supervised many students on the use of PhET simulations in the science classroom and is well-versed with such technologies. During the training she became pivotal in guiding the teachers on how to use the simulations.

I provided the teachers with a lecture on how to use the simulation for inquiry purposes, the teachers were provided with the theory-practice experience and were guided during the training (see Chapter 3, where I provide photographic evidence).

With regards to *many opportunities for learning*, the teachers were provided with tablets after the intervention. Tablets were installed with the required software to enable teachers to use them in their classroom after the training.

With regards to *student is in control of learning*, teachers were allowed to work on their own. The teacher professional development used ZPDT as a framework. Consequently, all five conditions as stated by Hattie were met in this study.

The advantages of PhET simulations (Thrilling & Fedel, 2009); the principles of using technologies; and the insights of De Jong et al. (1998) shaped my decision on how to guide the teacher development in using PhET simulations. De Jong et al. (1998) are of the view that teaching with PhET simulations can promote 21st-century skills and engage learners to be self-directed in their learning. This view provided me with inferential decision to consider a teacher development that is guided with the definition of self-directed learning as according to Johnson and Johnson. In the teacher professional development I considered the following strands of the definition:

- The activities and the professional development should be considered as a process;
- Individuals should take the initiative, with or without the assistance of others;
- The A-Team should be able to diagnose their learning needs;
- , The A-Team members should be able to formulate their own learning goals;
- The A-Team should be able to identify human and material resources for learning;
- The A-Team members should be able to choose and implement appropriate learning strategies and evaluate their outcomes.

2.9.7 Can the concept of *Homo ludens* provide learners with agency and create a student-centred approach?

The researcher is of the opinion that technology holds the key for making learning more fun for the students and teachers. It provides learners with the opportunity to play. Such pedagogy could result in learners engaging with the learning content as the playing human, *Homo ludens* (Huizinga, 1955). Podolefsky, Rehnand and Perkins (2013) are of the view that play is important in science education, but is often overlooked in the science curriculum. Play is often viewed as the opposite of work. Rieber (1996:43-58) and Hawkins (1974) provide us with a narrative that play should not be seen as distraction or at best as a break from the learning that is taking place in schools. According to Riber (1996:43-58) play consists of the following attributes of learning:

- It is commonly voluntary;
- It is intrinsically motivating;
- It involves active engagement.

I am of the view that PhET simulations entail game-like characteristics. If play is incorporated into the teaching and learning of the Natural Sciences, learning may become more interesting and stimulating for the learners. Hawking (1974), on the other hand, equates play with work and describes play as 'productive messing about'. Hawking further views play as very much like what scientists do when approaching a new and unfamiliar problem or subject. According to Bonawitz et al. (2011), providing learners with opportunities to 'mess about' can lead to deeper and more meaningful exploration and learning; whereas providing specific instructions can limit creativity and exploration and result in surface learning (*ibid*).

The late Dr Karyn Purvis, a former child psychologist at Rees-Jones, and director and co-founder of the Institute of Child Development at Texas Christian University, identified the following relationships between learning and play:

> Scientists have recently determined that it takes approximately 400 repetitions to create a new synapse in the brain unless it is done with play, in which case, it takes between 10 and 20 repetitions'

Podolefsky, Rehnand and Perkins (2013) have found that play can be an important part of using computer simulations for secondary schools:

- Play has affordances of increasing learner agency and support of student-centred pedagogy during a simulation-based classroom activity;
- The scholar revealed that a short amount of play at the beginning of class led to a more student-centred, inquiry-based classroom;
- Play appears to acclimatise learners with the simulations and provides learners with a sense of autonomy.

In their study Podolefsky, Rehnand and Perkins (2013) used exactly the same simulations we used in this intervention, namely bending light (focusing on constructs of visible light). The difference in this context is in South Africa and USA learning dynamics. The scholars focused on grade 5, whereas in my study the focus was on grade 8 and 9 Natural Sciences studies. It will be important to see if the agenda of play will resurface in the respective classrooms during lesson observations.

2.9.8 PhET simulations as laboratory tool for problem-based learning and practical work

Practical work is an avoidable and indispensable part of experiential learning. It validates theory and most importantly it prepares students to apply science. Research has indicated that learners who are in schools without laboratories do not fully develop science process skills. The PhET simulations can provide science process skills to such schools, and can be used to promote science teaching in classrooms as well (Mhlongo, Kriek & Basson, 2011). According to Azar and Sengülec (2011), PhET investigations promote student learning, help students to develop a positive attitude towards science and more notably engender permanence of knowledge.

Since PhET simulations promote interactions and forsters learning, and computers and cell phones are technologies most learners are comfortable with, it was out of this argument that my assumption was that students will enjoy using these technologies. Without a doubt, the young generation of today are the 'digital natives' of our world.
They often spend more time playing video games, checking email, exploring the web, and texting than generations before them (Prensky, 2001).

These gadgets can be used as a studying intervention to promote 21st century science skills. From the researcher's perspective, Gen Z learners (born between mid-1990s and early 2010s) are more familiar with technologies, and the same learners are not allowed to bring cell phones to schools. The researcher is of the opinion that these technologies should not be confiscated, but should instead be used for learning purposes. According to (Mhlongo, Kriek & Basson (2011:17-18) 'interactive computer PhET-simulations could facilitate science process skills such as identifying and controlling variables, stating hypotheses, operational definitions, graphing and interpreting data, and experimental design'.

Although the PhET simulations are free, teachers and schools do not always have the equipment (hardware) for such software, and during this teacher development workshop, the researcher provided teachers with CDs and tablets for engaging in simulations of relevant experiments to use in the Natural Sciences classroom (thanks to funding from the Fuchs Foundation). Studies such as Linn, Eylon and Davis (2004), Zacharia and Anderson (2003), Triona & Klahr (2003) and Linn & His (2000) have indicated that students who prepare for laboratory activities using PhET simulations make greater conceptual gains, and are more capable of integrating knowledge, than those who use the textbook and solve additional problems. Linn & Hsi (2000) and Linn et al. (2004) have showed that using PhET simulations as a learning tool assist srudents with collecting data, and serve as a medium of communication and also supports students' mastery of concepts and ability to integrate knowledge.

According to Gardner (1983), simulations support virtual-spatial learning style and this afford students with the opportunity to understand the world through seeing and expressing ideas graphically. PhET simulations provide students with virtual-spatial style where practicals include simulated material and apparatus. The value of science laboratories is acknowledged by the National Research Council (2006), but the value of simulated alternatives for hands-on physical laboratories is contested by the National Science Teacher Association (2007).

Hands-on or traditional laboratories advocate design skills, while simulations laboratories advocate focus on conceptual understanding. However, research indicates that PhET simulations have become a popular alternative to traditional expensive laboratories due to the fact that PhET simulationsare more manageable, safe, cost-efficient, clean, flexible, and rapid than physical experiments (Triona & Klahr, 2003; Zacharia & Contantinou, 2008).
A number of studies have demonstrated positive learning effects of computer-simulated environments that support students to explore, test hypotheses, and analyse data as scientists do (Sun Lin & Yu, 2008; Yang & Heh, 2007; McElhaney, 2007; Gordon & Pea, 1995).

The researcher is of the view that using ICTs (interactive computer PhET-simulations) and science-on-a-shoestring approaches will give teachers and learners the opportunity to be hands-on, and manage the challenges of limited resources, while engaging in the 21st century skills teachers should possess (Sebotsa et al., 2018; Sebotsa et al., 2019).

2.10 TEACHER PROFESSIONAL DEVELOPMENT INTERVENTION

The state of mathematics and science education in South Africa is a cause for concern (Kriek & Grayson, 2009). Most of these concerns are directed at teachers. According to Kahle (1999:2), 'Schools are only as good as their teachers, regardless of how high their standards, how up-to-date their technology, or how innovative their programs.' Long-term sustainable improvement of mathematics and science education must therefore focus on strengthening teachers. Kahle (1999:1) indicates that the starting point and central focus to reform science education should be professional development of teachers. Citing Kriek and Grayson, professional development of teachers is not new. With the current science reforms, teacher professional development programmes still hold affordance to assist teachers in achieving better results from the learners.

2.10.1 Workshops and short courses

People working in teacher education have often not been formally educated for their roles as teacher educators (Korthagen, 2000). It is imperative to devise a strategy to address this taboo. One possible approach is to use workshops as a vehicle for professional development.

Cronje (2015) addresses workshops as a relevant vehicle to facilitate teacher professional development. She mentions circumstances where workshops were not well facilitated, and lament the limitations posed by one-day workshops or short courses that last a few days and assume educators in the process have been mentored and coached. Her example is the workshops presented by the Gauteng Department of Education, who are fashionable in this approach.

This study entails a teacher development programme which is longitudinal (over a period of two years) and systemic (following a 'whole-school' approach), creating a supportive Community of Practice (CoP) in which teachers' learning is scaffolded. A community of practice in this study referred to the A-Team and all the opportunities provided during the intervention. The CoP and PD intervention included workshops and activities in which the A-Team operated as learners, teachers and facilitators in an attempt to work towards an effective science classroom. Research points out that these workshops should be based on teachers' needs, or else the professional development programme might fail (Pretorius, 2015; Antoniou, 2017; Sebotsa, De Beer & Kriek, 2018). Hoban (2004) indicates that teachers do not benefit from workshops and short learning courses; that these should be supplemented by ongoing professional development processes. The teachers were further provided with an opportunity to register with the North-West University for a short learning programme (sponsored by the NRF and Fuchs Foundation) which addressed ways of integrating IK in the science curriculum.

2.10.2 A systemic and longitudinal teacher professional development intervention within a supportive community of practice

Some of the teacher professional development interventions are failing to achieve their desired outcomes. Kriek and Grayson (2009) state that the professional development of teachers is not new and that in recent years the way in which it is structured and delivered is being reconceptualised. The CDE (2011) report supports Dass' (1999:2) view that 'traditional one-shot approaches to development as piecemeal, workshop-type development programmes which are not effective and are inadequate in the context of current educational reform efforts'. According to the literature, teachers' continuous professional development programmes are too standard and do not accommodate the diverse needs of South Africa's teacher populace (DoE, 2010; Pretorius, 2015).

Ball & Cohen (1999:5) indicated that professional development of teachers is 'intellectually superficial, disconnected from deep issues of curriculum and learning, fragmented and non-cumulative'. In this study I used the guidelines for professional development as recommended by Rogan and Grayson (2003), namely:

- Implementation should consist of a series of small steps (thus a long-term process);
- The context of the school (teachers, learners, and environment) should be taken into account;
- The level of the teachers' pedagogical knowledge and experience should be considered.

All these aspects listed by Rogan and Grayson (2003) guided A-Team teacher professional development. Most interventions fail due to not taking account of the above recommendations in the initial stage of the teacher professional development intervention. The insights of Rogan and Grayson (2013) helped the researcher to further revise their 2003 framework of implementation. Cronje (2015:8) states that problem with many development programmes offered to teachers, such as workshops and short learning programmes, is that they cover policy aspects and do not address the practical needs and problems that teachers experience.

A 'one size fits all' approach is not a well-devised strategy in developing teacher professional development programme. When implementing effective teacher professional development programme one should firstly take cognisance of the teachers' needs and identify them to suit the programme (Bredeson, 2003; Pretorius, 2015). If one reflects on the NCS teacher professional development, it did not take into consideration teacher's needs.

Most of the interventions presented to the teachers were in a format of linear top-down approach as described by Hoban (2002) in which needs and problems of the teachers were neglected. Figure 2.11 provides a visual representation of the model used to implement NCS interventions.

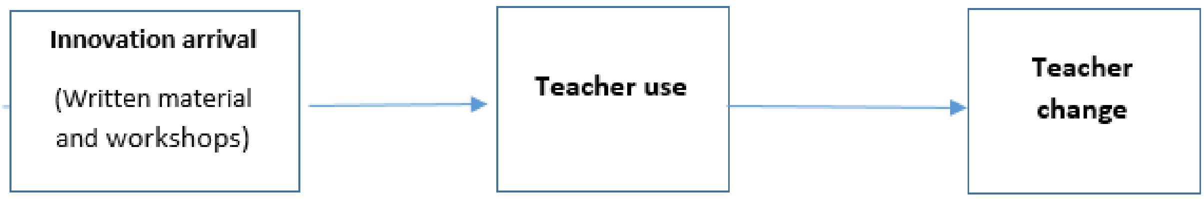


Figure 2.11: A linear top-down approach of innovation implementation. Source: Hoban (2012:13)

The top-down approach begins with written material and workshops developed by the policy maker. The material is then presented to the teacher via workshops and memos. With that notion **the innovation-arrival stage** is closed by the facilitator. After the receiving stage the necessary information is assumed to make sense to the teachers and they are expected to be able to use and apply the information. This is considered the **teacher-use stage.** After these stages it is assumed the one day-workshop shaped the teacher to change and that the classroom will change. This simplistic approach does not take other factors that hinder how change should take place, into consideration. According to Heban (2002), the top-down approach is a simplistic approach that assumes brief workshops and little back-up support will provide a classroom change. This approach can be amended by considering the following factors:

- Provide teachers with a systemic and longitudinal professional programme that takes their needs into consideration. Rogan and Grayson (2003) suggest that the implementation of such innovation should occur in manageable steps. In this study the teacher professional development programme was systemic and longitudinal. The programme ran over a course of two years.
- Provide a setting. Stols & Kriek (2005:16) mentions that the absence of professional teaching in schools is a critical issue that needs to be addressed. The best practice is to provide such a programme within a Community of Practice. The A-Team teachers in this study formed a Community of Practice in which they worked as five schools around Potchefstroom's Dr Kenneth Kaunda Education District.
- Provide guidelines and support where needed. Teachers addressed their professional needs and the programme was guided by these needs.

2.10.3 Profile of implementation in the zone of feasible innovation

Rogan (2004a) is of the view that sustainable teacher professional development must be considered within a well maintained CoP. Rogan and Grayson (2006) further provide a lens on how this professional development can be sustained. Rogan and Grayson refer to this sustainable development construct as the 'Zone of feasible innovation' (ZFI) in which they discuss a 'cocktail' of teaching strategies that go beyond the current practice, but are feasible given the school contest and parameters to sustain innovation. Rogan and Grayson (2003:1183-1184; 2004:159) provide a rubric for ZFI and coin it 'profile of implementation'. This profile describes different levels of implementation in a professional development intervention ranging from zero (0) to four (4).

The profile of implementation is further divided into four domains, namely classroom interaction, science practical work, science in society, and assessment. Peterson (2011) used the same framework on Rogan and Grayson (2003) in the same district as my study (Dr Kenneth Kaunda Education District in Potchefstroom). Petersen (2011) used the profile of implementation as a lens focusing on Life Sciences teachers' professional development. Petersen revised the framework to include level zero (0) to provide a more nuanced description of the teachers' knowledge and skills (or lack thereof). This adapted profile of implementation can be used as a tool to determine the needs of teachers in a professional development programme across classroom interaction, science practical work, science and society and assessment (Petersen, 2011) (see Table 2.7).

ADAPTED PROFILE OF IMPLEMENTATION				
	Classroom interaction	**Science practical work**	**Science in society**	**Assessment**
0*	○ Teacher presents transmission-type lesson in an unstructured way and reads mostly from the textbook; ○ Limited and ineffective media usage; ○ Learners passive and not engaged.	○ Practical work is seldom done; ○ Teacher uses limited and not well-planned demonstrations to assist in the explanation of concepts.	○ Teacher seldom uses examples from the learners' daily lives, and if used these are incoherent.	○ Written tests on lower cognitive levels; ○ Tests marked and handed out to learners.
1	○ Teacher presents organised lessons; ○ Uses textbook effectively; ○ Learners are engaged and respond to questions.	○ Teacher uses classroom demonstrations to help develop concepts.	○ Teacher uses examples from everyday life to illustrate scientific concepts.	○ Written tests are given; ○ Most questions of recall type; ○ Most tests marked and returned promptly.
2	○ Textbook used along with other resources; ○ Engages learners with questions that encourage deeper thinking and meaningful group work.	○ Teacher uses demonstrations to promote a limited form of inquiry; ○ Learners participate in 'cookery book' practical work.	○ Teacher bases lessons on specific problems faced by community.	○ Written tests include 50% of higher cognitive level questions.
3	○ Teacher structures learning along 'best practice' lines; ○ Learners engage in minds-on learning activities.	○ Practical work to encourage learner discovery of information.	○ Learners actively investigate the application of science & technology in their own environment.	○ Written tests include 'guided discovery'-type activities; ○ Assessment includes other forms such as reports.

4	○ Learners take major responsibility for own learning and undertake long-term investigations and projects; ○ Teacher facilitates learning.	○ Learners design and do open investigations.	○ Learners actively undertake a project in their local community and explore long-term effects of community projects.	○ Open investigations and community-based projects included in final assessment; ○ Learners create portfolios.

Table 2.7: Summarises levels 1–4 of Rogan and Grayson's (2003:1183-1184) profile of implementation.

*****Petersen and De Beer (2011) added a further level 0 to include teachers with insufficient SCK and PCK (Petersen, 2011).

In my research I adopted the revised Rogan & Grayson profile of implementation by Petersen (2011). This framework supports a longitudinal and a systemic professional development. According to Rogan & Grayson (2003), the profile of implementation should consist of a series of small steps (thus a long-term process). The revised Rogan & Grayson (2003) was complimentary to the social constructivism theory which is the theoretical framework of my study, namely the zone of proximal teacher development (ZPTD) (Warford). The ZPTD is used as a theory in this study to assist teacher's development from their actual development to their potential development within a CoP (See chapter 2 section 2.9). In this study the ZFI will be used to assist the theoretical framework to achieve its objective. The theoretical framework looked into the teacher development in four manageable stages, from self-assistance to recursion (de-automatization) and these two constructs helped the researcher to trace the teacher's movement from level zero (0) to level four (4) using the revised Rogan and Grayson profiling.

The insights of profiling teacher's movement with respect of the above helped the researcher to revise Rogan & Grayson profile of implementation by Petersen (2011). The revised profile of implementation included a new domain, namely self-directed learning to the framework to provide a more nuanced view to a longitudinal and systemic teacher development programme within a CoP. The self-directed descriptions added to the framework are as follows ranging from level zero to level four:

- Level 0: There is no evidence of SDL; the teacher does not show interest in ongoing professional activities.
- Level 1: There is minimal evidence of SDL; the teacher indicates that he/she has professional development needs, but there are no concrete learning goals identified.
- Level 2: The teacher formulated learning, but there is limited evidence that learning resources or learning strategies were identified
- Level 3: There is clear evidence of SDL: learning goals, resources and applicable strategies were identified. However, there is no evidence of evaluating the learning actions
- Level 4: Strong evidence that the teacher is self-directed learner i.e., (a) The teacher can define his or her own goals, (b) goals related to central need, (c) able to set a path to achieve the goal, (d) the goal is realistic not too high or too low, but enough to be

challenging; (e) the teacher evaluate his or her own learning; and (f) and the teacher promotes SDL in his/her classroom.

The following scale is been used 0 noncompliance and 4- highly compliant. The scale increases in the ascending order, from non-compliance to compliance.

Rogan and Grayson (2003) and Petersen (2011) did not pertinently state that teachers need to be self-directed learners during a professional development programme within a CoP, and this additional domain would remind curriculum developers and researchers of its necessity. According to Rogan & Grayson (2003) a teacher can only be developed from his or her actual development to the next level, meaning from the scale zero (0)-four (4) a teacher can only shift one level at a time. My hypothesis is that if teachers are self-directed in their learning then a longitudinal and systemic teacher professional development hold affordance on moving the teacher more than one level in Rogan and Grayson profiling. The researcher is of a strong view the revised framework will be assist teacher development programs in Dr Kenneth Kaunda Education District in Potchefstroom, and other schools in a similar context.

2.10.4 Self-directed learning

One of the most important constructs of the conceptual framework for this study, was self-directed learning. Functioning effectively in the 21st century society requires one to possess adequate social capital and one such skill is self-directed learning (SDL) (Bourdieu, 1986). When one gives attention to the Self-Directed Learning Instrument (SDLI) of Cheng et al. (2010) one makes the following links with SDL:

(a) Learning motivation;
(b) Planning and implementation;
(c) Self-monitoring;
(d) Interpersonal communication.

It is not surprising that SDL is now considered strongly in the context of higher education (Cheng et al., 2010). If one takes learner motivation and interpersonal communication from the above elements of SDL one easily concludes that these elements are ‘silent’ in most South African township schools.

Taking into consideration Ramnarain and Schuster's (2015) view on teacher's pedagogical orientation, most township schools are not experienced by learners as inviting learning spaces. It is with the above view that I advocated for SDL from Hiemstra and Brocvkett (2012:158) model of the Person-Process-Context (PPC) for SDL. In this model I contest that teacher professional development in previously disadvantaged schools should be considered from the socio-political context (Hiemstra & Brockett, 2012:158; De Beer, 2019) due to the imbalances of 'pedagogical capital' of most townships schools teachers. Below I provide the PPC (Hiemstra & Brockett, 2012).

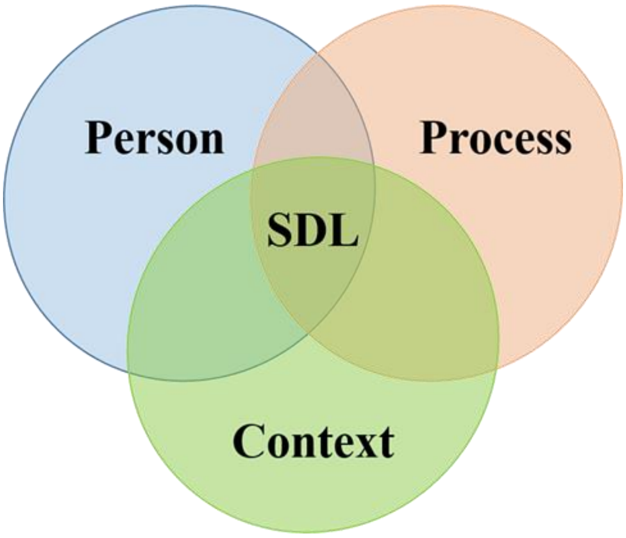


Figure 2.12: SDL from Hiemstra and Brockett model (2012:158)

Why I emphasis context in this study is because most learners sit in the classroom for a minimum of twelve (12) years before finishing school observing a teacher talk, and this pedagogy become embodied and embedded in the learners' schemata. This is why most learners after finishing matric they assume they can be able to stand in front of the learners and start to teach (Lortie.1975). Lortie refers to this term as 'apprenticeship of observation'.

When the in-service teachers study towards a bachelor of education degree (B.Ed.) the university requires the students to reverse the entire twelve years in a minimum period of four years. This could be another reason why we observe the 'washed out' effect (Zeichner & Tabachnick, 1981) due to systemic conditioning of 'siting behind the teacher'.

I think if we centre stage longitudinal and systemic professional development within a CoP with an agenda of SDL we will capacitate teachers as agents of change inter-alia develop ‘cognitive apprenticeship’ as well.

My hypothesis was that If the teachers can have SDL skills and are incubated in a well-established longitudinal and systemic teacher development within a CoP a transformative change will be evident in their classes. I am of the view the teacher will be able to move much constructive in Rogan & Grayson profile of implementation revised Petersen (2011).

The following section informs the theoretical and conceptual underpinnings. Below find a ‘GPS’ that guided the theoretical and the conceptual frameworks in this research.

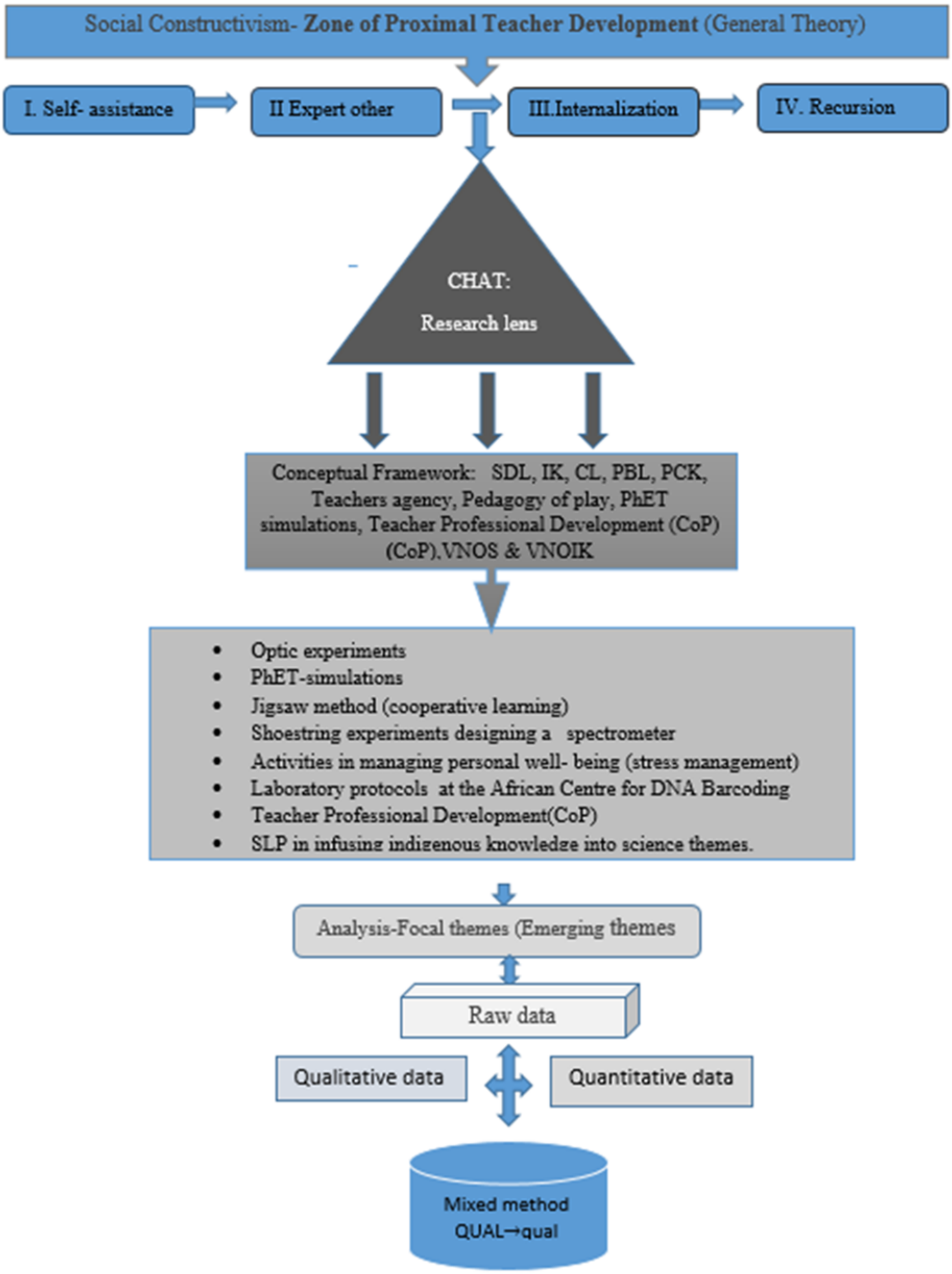


Figure 2.13: An illustration of the theoretical and conceptual frameworks of the study

2.11 THEORETICAL FRAMEWORK: SOCIAL CONSTRUCTIVISM

This study is embedded in social constructivism as explained by Vygotsky (1978) as a theoretical framework. Social constructivism is well known for its purpose of acknowledging that learning takes place because of the interactions of people in a group (Vygotsky, 1986). In this study I represented a group as the Natural Sciences teachers' who participated in a teacher development programme within a community of practice (CoP). Teacher's knowledge is constantly re-shaped to accommodate the dynamic nature of schools and classroom (Lempert-Shepell, 1995). Looking into the insight of Lempert-Shepell the Vygotskyan approach seemed more appropriate as the focus is structured towards the participant's actual development to their potential development. Vygotsky refers this to this phenomenon as the 'zone of proximal development' (ZPD).

Even though his approach did not necessarily instil a particular approach to teachers' needs and did not provide the *how* part of the teacher development intervention, the concept of scaffolding teachers' learning across this 'learning zone' is useful. His insights still remain of paramount importance in bringing a paradigm shift in teacher education. The most noteworthy feature of the latter scholar is how he envisioned teaching and learning. Vygotsky saw teaching and learning as a holistic and authentic approach mediated by language; rather than the dominant IRE (Teacher initiate, student respond, teacher evaluate) view. Vygotsky (1986) stated, 'Direct teaching of concepts is impossible and fruitless. A teacher who tries to do this usually accomplishes nothing but empty verbalism, a parrot-like repetition of words by the child, simulating a knowledge of the corresponding concepts but actually covering a vacuum' (p.150). Unfortunately, the South African science curriculum is characterized by transmission-mode ('chalk and talk') teaching and learning (less effort is made towards construction of new and meaningful knowledge) (De Beer 2016; Cronje 2015), which denotes Vygotsky's analogy of learning towards an empty scholarship.

It was important for the study to first identify the problem, and then adopt a suited framework which guided the process of bringing elucidation of how teacher professional development in the context of previously disadvantaged schools in South African should be viewed. Teacher's development plays a pivotal role in science education. It was for the benefit of this study to look into a reformed professional development programme that takes into consideration teacher's needs.

The study based its framework initially on the work of Vygotsky. The challenge with continuing with his approach was particularly based on the lack of systemic guidelines on how to instil such teacher development programme. Warford (2011) who is also a social constructivist who followed in the footpaths of Vygotsky managed to accelerate Vygotsky's agenda forward. Warford influenced the literature by applying Vygotsky's (1986) well-known construct of the 'zone of proximal development' (ZPD) with respect to teacher education (namely the zone of proximal *teacher* development, or the ZPTD). In this study I used Warford's (2011) parlance on the well-known Vygotsky (1978) construct of the zone of proximal development (ZPD), namely the zone of proximal teacher development (ZPTD) as outlined in Table 2.7. Warford's ZPTD indicates how teachers' learning could be scaffolded from their actual to their potential development through four stages. The four stages are:

(I) self- assistance;
(ii) expert other assistance [stage I in ZPD) (Galimore & Tharp, 1990);
(III) internalization (automatization);
(IV) recursion (de-automatization).

In this study I focused on the professional development of the science teachers across this 'zone of proximal teacher development' within a well-thought-out community of practice, which I called the A-Team. The four stages of Warford navigated my study and I demonstrate how I applied these four stages during the intervention, as shown in Table 2.8.

Table 2.8: Warford's (2011:254) Zone of Proximal Teacher Development, which underpins this research study

ZPTD (Warford, 2011)	Samples of Interventions	Activities in this SLP/ workshops:
I. Self- assistance	Prior knowledge + experiences of teachers teaching visible light;	Highlight experiences of teachers in teaching optics in the past (This included a pre-test on visible light); Needs-questionnaire and teacher profile;
II. Expert other assistance [stage I in ZPD) Galimore & Tharp, 1990]	Analysis of teaching practices - observing lessons (Pre-RTOP, artefacts such as pictures and videos, field observation); Scaffolding and mentoring by peers and facilitators; Scaffolding by expects i.e., educational psychologist for stress management; Addressing strategies towards a more conducive classroom environment etc. Kirby-Bauer technique by a microbiologist, Dr Jaco Bezuidenhout.	Leading questions and follow-up discussions; Optic experiments (Designing a spectrometer and designing an inquiry based learning); PhET-simulations; Jigsaw method (cooperative learning); Shoestring experiments designing a spectrometer; Activities in managing personal wellbeing (stress management); Laboratory protocols at the African Centre for DNA Barcoding; SLP in infusing indigenous knowledge into science themes.
III.Internalization (automatization)	Journaling reflections; Analysis of teaching practices- observing lessons (Post-RTOP); Artefacts such as pictures and videos.	Developing an evidence-based portfolio, with reflections; Focus group interviews; The 'Stimulated Recall Method' enhancing teacher reflection; Discussion.
IV. Recursion (De-automatization)	Journaling; E-fundi (online forum).	Classroom observations; Individual exit interviews.

2.12 USING THE FOUR STAGES OF WARFORD TO SCAFFOLD TEACHERS' LEARNING

2.11.1 Self-assistance

Teachers are required to reflect on prior experiences and assumptions, then to write a learning autobiography in which they reflect on their professional development as the programme progresses.

- In this stage of self-assistance it was crucial for me to establish what prior knowledge teachers held. This was done by teachers engaging in group work (I observed the discussions closely). The participants completed a questionnaire that was designed to provide the researcher with the teacher's pre-intervention profile. I further provided the teachers with a pre-test to assess teachers' PCK with respect to visible light constructs as guided by the CAPS document in order to establish a clear understanding of how much the teachers understood the content of visible light. I further went to each class of the respective teachers to observe a lesson using the reformed teaching observation protocol (RTOP) instrument. This helped me to validate my approach and informed me on how to restructure the teacher professional to be more holistic in approach.

- Teachers were asked to provide their other professional development needs, not limited to teachers' content knowledge. This helped me to identify other needs which I might not have addressed in my preliminary finding that guided the intervention. The teachers' insights helped me to personalise the intervention to be authentic and consistent in Vygotsky's language of social constructivism. I was able to observe the first phase of self-assistance in Warford's language of teacher's professional development.

2.11.2 Expert other assistance

Warford referred to the next phase as the expert other assistance phase. The researcher shared the view of Van Lier (2004) in which expanded ZPTD, scaffolding happens on four levels.

- Inner resources (resourcefulness, self-access);
- Interaction with less capable peers ('we learn by teaching');
- Assistance from capable peers (scaffolding; mediation);

- Interaction with equal peers (if one member in a dyad undergoes development or change, the other is also likely to do so).

Below I provide evidence that qualifies the second stage of Warford's by applying Van Lier's perspective into my study. This achieved as follows:

Inner resources (resourcefulness, self-access)

At this stage the teachers had already identified their own challenges and needs, which informed this stage. During the teacher professional development, teachers' learning was scaffolded in an innovative way of doing science with cheap materials (science-on-a shoestring). According to Van Lier (2004), in the expanded ZPTD, teachers need to be resourceful. The intervention was designed to provide teachers with affordance of being an agent of change in a science classroom. This was achieved by the facilitators, in this instance the researcher and the study leaders, who provided teachers with skills on how to build a spectrometer. The teachers among themselves had to contextualise an optics inquiry-based learning after completing the building process.

Interaction with less capable peers and with equal peers

Teachers' learning was scaffolded through problem-based and cooperative learning methods. Prof De Beer, who is an expert in this field, demonstrated how to use the Jigsaw (cooperative learning) method in a science classroom as compared to the transmission mode. The focus was on 'field-based demonstrations of how innovative teaching practices are carried out in actual classrooms' (Warford 2011:254).

2.11.3 Internalisation (automatisation)

The teachers were involved in a focus group interview in which they shared their experience towards a tailored teacher development intervention addressing their needs. Teachers were required to reflect on their experiences and to give feedback. The teachers were observed during the coalface teaching phase to see if their pedagogical orientation had improved. Magnusson et al. (1999) used the term orientation to represent a general way of viewing or conceptualising science teaching. Teachers developed an evidence-based portfolio, with reflections.

The 'Stimulated Recall Method' enhancing teacher reflection and discussion provided an in-depth conversation on the teachers' choice of their pedagogical orientation.

2.11.4 Recursion (de-automatisation)

The whole intervention was further influenced by classroom observations after the stimulated recall method was used to probe any change in the pedagogical orientations of the teachers. This helped me to provide a clear teacher profile.

2.11.5 The concept of prolepsis

An important construct in my study is the notion of prolepsis; and it is related to the way in which Warford's four stages were implemented. Prolepsis is a technique which 'assumes that students know more than they actually do' (Van Lier, 2004:153). This will be further explained in Chapter 3, where I will focus on the intervention itself, but one example of prolepsis was where teachers were required to engage in polymerase chain reactions (PCR) at the African Centre for DNA Barcoding, during a two-day long intervention.

2.13 CONCEPTUAL FRAMEWORK

This chapter reviews the literature that underpins the inquiry into Natural sciences teachers' lived experiences of contextualised interventions and its affordances for professional development. The literature found its role in establishing a robust theoretical basis to address the research questions and ensure the objectives of the study as formulated in section 1.6 of chapter 1. Since the 'intermediate theories' guided the shape of this chapter, the researcher commenced by creating a strong emphasis on why the intermediate theories are a relevant approach to navigate this study. The researcher's line of thought was shaped and influenced by scholars such as Jabareen (2009), Dewey (1938) and Kaplan (1964) who advocate for a strong emphasis on building a conceptual framework using interrelated concepts or theories.

Jabareen (2009:49-62) noted that the present usage of the terms 'conceptual framework' and 'theoretical framework' is elusive and imprecise. In this study, I adopted the definition of conceptual framework as a network or 'plane' of interlinked concepts that together provide a comprehensive understanding of a phenomenon or phenomena as guided. Jabareen (*ibid*) further gives clarity on how concepts should form a conceptual framework.

He argues the conceptual framework as not merely a collection of concepts but, rather, a construct in which each concept plays an integral role. In this research, the concepts that constitute the conceptual framework support one another.

It is typical to use related concepts and or theories in sciences to solve problems. According to the insights of Dewey (1938) and Kaplan (1964), without the problem, there would be no need for theory or concepts. This further substantiates my choice of a conceptual framework that is built on concepts to solve a problem or problems. In Engeström's language, these concepts refer to 'intermediate theories'. In this study, the intermediate theories are integral and interlinked with the purpose of supporting the choice of the theoretical framework, which is to scaffold teachers across the 'zone of proximal teacher development' (Warford, 2011).

The conceptual framework in this study constitutes the following integral and related concepts which provide insights for such an intervention: teacher pedagogical content knowledge (PCK), teacher agency, learning through a pedagogy of play (*Homo ludens* = the playing human), PhET simulation (interactive computer simulation), affordances of indigenous knowledge in Natural Sciences, problem- and project-based learning, community of practice (CoP), and self-directed learning (SDL). Besides the research contribution, the framework provided a second opportunity, namely epistemological contribution, practical contribution and Design Principles for Natural Sciences teacher professional development interventions.

2.14 CONCLUSION

This chapter has delved into relevant literature and explained choices in terms of theoretical and conceptual frameworks. The constructs contributing to these frameworks have also been explored in terms of their application to this study. Third-generation Cultural-Historical Activity Theory (CHAT) developed from social constructivism (Engeström, 1987). CHAT, as conceptualised by Engeström (1987), was used as a research lens. This research lens is solidly rooted in social constructivism. CHAT will be dealt with in detail in Chapter 3 as it provides a powerful tool for the meta-analysis of emerging findings.

CHAPTER 3: RESEARCH DESIGN AND RESEARCH APPROACHES: MIXING THE METHODOLOGIES

Cohen et al. (2002:56) provide the following description of ethics in research: 'Ethics is a matter of principled sensitivity to the rights of others. Being ethical limits the choices we can make in the pursuit of truth. Ethics say that while the truth is good, respect for human dignity is better, even if, in the extreme case, the respect of human nature leaves one ignorant of human nature'.

3.1 INTRODUCTION: THE JOURNEY OF A THOUSAND MILES BEGINS WITH ONE STEP

At the start of every research study, one has to make critical decisions in order to sustain the journey of a thousand miles. These decisions should converge with the choice of the title, should provide a direct link to the purpose of the study, must be steered by means of the research questions that direct the study, and be rooted in the framework of the study. According to Mouton (2000), the study title should provide a synopsis of the methods used and also the methodology and research design. The inquiry title for this study is: Natural Sciences teachers' lived experiences of contextualised interventions and their affordances for professional development.

Due to the multifaceted and intertwined nature of the study, as elaborated in the conceptual framework discussed in Chapter 2, certain important methodological decisions had to be made. A mixed-method approach with a dominant qualitative component was deemed suitable. The approach imparted both rigour and richness to the inquiry (Kate et al., 2019).

3.2 INTENTIONS OF THE RESEARCH: REVISITING THE RESEARCH QUESTIONS AND THE OBJECTIVES OF THE STUDY

The research questions in my narrative guided and shaped the choice of research approaches. According to Mouton (2000:57), 'research design is tailored to address different kinds of questions', the study explored the following research questions:

(a) Primary research question

What are Senior Phase Natural Sciences teachers' lived experiences of participating in a longitudinal and systemic professional development intervention, aimed at addressing their specific professional development needs? Given the complexity of this study, the secondary research questions were framed as follows:

(b) Secondary research questions:

- What is the role of a professional development programme in assisting Natural Sciences teachers to develop more nuanced views of the tenets of science?
- What is the role of a professional development programme in assisting Natural Sciences teachers to develop more nuanced views of the tenets of indigenous knowledge?
- What are teachers' experiences of implementing contextualised problem-based learning (PBL) in the Natural Sciences classroom?
- What transfer of newly acquired knowledge and skills took place in the classroom, after the series of professional development interventions?
- How do teachers' views of their own self-directed learning change during the intervention?
- What are teachers' experiences of using science-on-a-shoestring approaches in the classroom?
- What difficulties do teachers experience in using PhET-simulations (ICTs) in the classroom?
- How do teachers contextualise lessons after the intervention?
- What are the experiences of the A-Team teachers after engaging in authentic investigations in a real science laboratory at the African Centre for DNA Barcoding?
- What insights do an auto-ethnography offer when evaluating the intervention?

Interlinked with the research questions are the objectives of the study. The objectives of this study are derived from each of the research questions:

- To determine what views teachers held of the nature of science, before and after the intervention.
- To establish what views that teacher’s hold of the nature of indigenous knowledge, before and after the intervention.
- To research teachers' experiences of implementing contextualised PBL in the Natural Sciences classroom.
- To research teachers’ use of PBL in their classrooms and what transfer took place in the classroom, after the professional development intervention.
- To analyse teachers' views of their own self-directed learning prior to and after the intervention.
- To provide a rich description of teachers' experiences of using science-on-a-shoestring approaches in teaching optics in the classroom.
- To determine the difficulties teachers experienced in using PhET-simulations (ICTs) in the science classroom.
- To analyse teachers’ contextualised lessons after the intervention.
- To research teachers’ experiences of engaging in authentic investigations in a real science laboratory at the African Centre for DNA Barcoding.
- Engaging in an auto-ethnography to provide more insight into, and a thick description of, the value of the intervention.

3.3 THE INTERVENTION PROGRAMME

After the research proposal was approved by the Self-Directed Learning (SDL) committee and the EDU-REC ethics committee at North-West University, I followed all the necessary protocol and channels in order to inform all stakeholders about the interventions and the study. I also notified the Department of Basic Education (DoE) Dr Kenneth Kaunda Education District of the interventions and the study. Further, I had meetings with all the respective principals and teachers involved (directly or indirectly) in the study.

With the participants (A-Team) further conversations were held to clarify the interventions. Discussions were held regularly via social platforms such as WhatsApp, emails, and telephonically as well as during the interventions. I used an independent person to obtain ethical consent from the participants.

The intervention programme was comprehensive, and included aspects such as class visits, a short learning programme (SLP) on indigenous knowledge for two days at the North-West University, a two-day hands-on engagement with DNA technology at the African Centre for DNA Barcoding, University of Johannesburg, as well as shorter workshops on diverse themes such as PhET simulations, science-on-a-shoestring approaches, cooperative learning approaches and stress management. For instance, the A-Team was provided with opportunities for using inquiry-based learning approaches in the Natural Sciences classroom. These interventions were focused on their specific professional needs, within a supportive community of practice (CoP). The focus was also on contextualising the curriculum, improving the teachers’ PCK, providing teachers with resources and skills, and enabling teachers to be resourceful in their respective classrooms (Pretorius, 2015), as well as self-directed in their learning (Sebotsa, De Beer & Kriek, 2019). (Refer to the meeting agendas in the Appendices E1, E2, E3, E4 and E5)

The intervention programme had a particular focus on scaffolding the A-Team's professional development. The scaffolding was provided around the Warford's construct of the zone of proximal teacher development (ZPDT) as discussed in Chapter 2, which underpins the intervention. Within the ZPTD, a supportive environment was created in the form of the CoP to assist the teachers in improving their subject knowledge with more competent peers. Based on ZPTD theory, it was hypothesised that the A-Team teachers (with the required support) will be able to develop professionally from their actual development to their full potential development within a CoP (Pretorius, 2015). The anticipated growth is demonstrated in Figure 3.1 as follows.

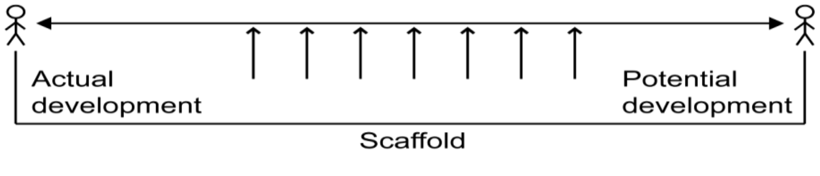


Figure 3.1: Warford's Zone of Proximal Teacher Development (ZPTD) within a Community of Practice (CoP)

The growth and experiences of each teacher during the intervention were profiled and are discussed in Chapter 4 using Rogan and Grayson’s (2003) profiling of implementation heuristic. The images below depict the researcher and the co-supervisor during one of the interventions. Participants provided consent that their faces may be shown.

Figure 3.2: Images from the A-Team intervention with Mr Sebotsa (researcher) and Prof Kriek (co-supervisor)

Photographer: Josef de Beer. All participants provided consent that the photographs may be published.

3.3.1 Self-assistance

In this section, different images are provided to represent teachers' development, according to Warford's stages of ZPTD, during different stages of the intervention. Various artefacts are provided in an attempt to demonstrate Warford's stage of teacher development process, namely self-assistance. In Figure 3.3 teachers are working on their own, illustrating Warford's self-assistance stage.

Figure 3.3: Teachers engaging in self-assistance

Photographer: Tswakae Sebotsa. All participants provided consent that the photographs may be published

3.3.2 Expert other assistance with a more capable peer

The intervention also included the second stage of Warford's expert other assistance with a more capable peer as expanded by Van Lier (2004). Below I provide a collage of artefacts ranging from wellbeing assistance, PhET inquiry learning assistance and resource assistance, to assistance from the African Centre for DNA Barcoding; provided according to teachers' expressed needs. For illustration, the teachers mentioned that their job was stressful and requested wellbeing support.

3.3.2.1 The A-Team's wellbeing

An education psychologist was invited to deliver a workshop on techniques of stress management. The psychologist used different therapies to help the teachers with skills to cope more effectively with life issues and mental health problems. The teachers went through the techniques individually and as a group. Figure 3.4 shows teachers engaging in wellbeing issues during one of the interventions.

Figure 3.4 Teachers engaging in a therapy session were afforded skills to cope with life challenges
Photographer: Tswakae Sebotsa. All participants provided consent that the photographs may be published

3.3.2.2 Engaging pedagogies: The A-Team teachers as agents of change

An intervention on real laboratory learning was identified from the teachers' needs questionnaire. Prof Kriek and the researcher provided the teachers with skills relevant to the design and implementation of an inquiry-based lesson using different resources in the Natural Sciences classroom. Teachers had to attempt to develop an optics inquiry-based learning lesson using technologies, science-on-a-shoestring approaches (cheap resources) and a traditional optics kit. The teachers were provided with tablets installed with PhET simulations. This ICT approach was intended to provide the teachers with more nuanced 4IR (4^{th} industrial revolution) skills pedagogy, fostering ways of teaching using ICTs and demonstrating inquiry lessons. The teachers used everyday resources to build a spectrometer. Using the science-on-a-shoestring approach, they had to contextualise an inquiry lesson using cheap resources.

This further engaged the A-Team teachers as self-directed learners according to Johnson and Johnson's (1999) interpretation of SDL. The following process was followed:

The individual is able to define his or her own goals:
The objective of the teachers was to build a spectrometer. During this activity, the teacher first had to define his or her goal for this particular activity.

The goals are related to his or her central needs or values*:*
As mentioned earlier, teachers mentioned lack of resources as a prominent reason not to do inquiry learning in their respective classrooms. The goal was related to the teachers' need to make an inquiry-based lesson in a Natural Sciences classroom.

The individual is able to define the paths (i.e., procedures, strategies, resources) taken to achieve the goals:
The teachers were provided with tips and videos on how one can create a spectrometer. From the insights of the videos and tips, the teachers had to find their strategies on building spectrometers. Further to this, teachers identified which materials were suited to accomplish the activity

The achievement of these goals represents a realistic level of aspiration for the individual, that is, not too high or too low, but enough to be challenging:
The spectrometer activity required teaches to think outside the box. The activity was realistic, not too easy and not unnecessarily difficult. The optics kit was used in a similar way. The teachers had to use the optics kit to design an inquiry activity based on optic phenomena. The aim of the activities was to help teachers contextualise an optics inquiry lesson using different resources.

The teachers compared their PhET simulation, science-on-a-shoestring and traditional optics kit experiences. The theme of the intervention was tailored around the A-Team as an agent of change for a self-directed classroom. The hypothesis was that these strategies would help the teachers to navigate inquiring lessons in under-resourced classrooms. Hence during the intervention, the A-Team teachers were engaged in pedagogies and strategies that accelerated teacher agency (Pretorius, 2015).

Figure 3.5 shows teachers participating in pragmatic pedagogies to stimulate teacher agency and inquiry learning in a Natural Sciences classroom.

Figure 3.5: The facilitator explaining how inquiry-based learning can be achieved in a Natural Sciences classroom utilising different approaches

Photographers: Josef de Beer & Tswakae Sebotsa. All participants provided consent that the photographs may be published

3.3.2.3 Teachers without borders: Excursion to the African centre for DNA barcoding

Teachers attended a lecture and practical laboratory session at the African Centre for DNA Barcoding at the University of Johannesburg (UJ) for two days. The practical laboratory sessions allowed the teachers to extract DNA from plants. From the extracted DNA teachers identified the species by doing Polymerase Chain Reaction (PCR) protocol, and analysed the genetic code using the BLAST programme. PCR is a widely used method in molecular biology. This technique is used to replicate a specific DNA segment. The referred segment is then amplified to generate thousands to millions of more copies of that same DNA segment.

The extracted DNA is then used for a wide-range application, including biomedical research and criminal forensics. The intention of the visit was to provide the teachers with techniques of identifying the plant species and to do authentic science. This was done with the aim of working with expert peers who would assist the A-Team with more nuanced open inquiry and to familiarise the teachers with the nature of sciences (NOS). Figure 3.6 gives images of the excursion at the African Centre for DNA Barcoding.

Figure 3.6: A journey of the A-Team with the guidance of the expert other as conceptualised by Warford (2011) and Van Lier (2004) at African Centre for DNA Barcoding at UJ

Photographer: Tswakae Sebotsa. All participants provided consent that the photographs may be published

3.3.2.4 Assistance from capable peers (scaffolding & mediation)

During the design of a spectrometer, the PhET simulation inquiry lesson, and at the African Centre for DNA Barcoding, the teachers automatically started to work together. Apart from facilitator assistance, peer mentoring also occurred as teachers helped each in identifying which resources were the best fit for the activities.

Ramaila (2012) refers to this connection as a mentee-mentee relationship, where teachers work together in the spirit of helping each other. With this view, the teachers scaffolded one another across the zone of proximal development (see Figure 3.7 and Figure 3.8).

Figure 3.7: Assistance from more capable peers

Photographer: Tswakae Sebotsa. All participants provided consent that the photographs may be published

Professor De Beer, who is the supervisor of this study, and the researcher held a workshop for the A-Team. During the workshop, the teachers were trained in different teaching methodologies, such as cooperative learning and problem-based learning. These approaches were attempts to equip the teachers with suitable strategies to be used in the Natural Sciences classroom (see Figure 3.8).

Figure 3.8: A workshop on cooperative learning and problem-based learning

Photographers: Josef de Beer & Tswakae Sebotsa. All participants provided consent that the photographs may be published

3.3.2.5 Interaction with equal peers

Humans are social beings; out of this understanding, a professional, safe CoP was established, as mentioned previously. The object was to create a platform on which teachers could engage, solve problems together and assist each other with their professional development. Figure 3.9 shows teachers interacting with equal peers. This strategy will be analysed in chapter 4 to provide insight into the affordances and limitations of such an approach.

Figure 3.9: Interaction with equal peers

Photographer: Josef de Beer & Tswakae Sebotsa. All participants provided consent that the photographs may be published

3.3.2.6 Recursion (de-automatization)

The A-Team members who attended DNA barcoding held a ‘graduation ceremony’ after completing their two-day course at the University of Johannesburg (Refer to appendix M3). Dr Speight Vaughn from Georgia State University (who did post-doctoral research at North-West University) was part of the ceremony in her doctorate regalia. Figure 3.10 illustrates the graduation ceremony at which teachers were celebrated for their work and investing in their professional development. Dr Neal Petersen, who is the deputy director at the School of Science, Mathematics and Technology Education, conferred the UJ intervention certificate to the A-Team teachers.

Figure 3.10: Celebrating the lifelong learning role of the A-Team teachers, after attending a course at the African Centre for DNA Barcoding at UJ

Photographer: Josef de Beer. All participants provided consent that the photographs may be published

3.4 SHORT LEARNING PROGRAMME ON INDIGENOUS KNOWLEDGE INTERVENTION

3.4.1 Introduction

The SLP on indigenous knowledge intervention is a two-day practical course offered by the Faculty of Education at the North-West University (NWU). The A-Team and the other teachers who attended the intervention were assisted with knowledge and skills to enable the border crossing between indigenous knowledge and Western knowledge in the Natural Sciences classroom. This intervention also helped the teachers to learn from different cultures and their indigenous knowledge. The most important goal of the SLP is, therefore, to assist teachers with pragmatic approaches to teaching indigenous knowledge in the Natural Sciences classroom. Another benefit was to assist the teachers with different methodological approaches. The ultimate goal was to help teachers improve their pedagogical orientation. This intervention was designed to provide the teachers with an opportunity to network and form a supportive community of practice (CoP) (Pretorius, 2015).

During the SLP, teachers were assisted with pragmatic approaches to use in the Natural Sciences classroom to get rid of the ‘ivory tower’ (theory–practice divide). The SLP took into consideration that most classrooms are not well resourced. The perks of attending the SLP included resourcing the teachers’ classroom. Figure 3.10 shows some of the resources provided to the participating teachers: (a) People’s Plants, a resource book for the classroom; (b) an autoclave for microbial lab work, given to teachers; (c) & (d) foldscope microscopes; (e) electric circuits, and (f) teachers were also provided with puppets and showed how they could utilise puppetry as pedagogy.

Figure 3.10: Some of the resources provided to the teachers attending the two-day SLP at North-West University

Photographers: Josef de Beer & Tswakae Sebotsa. All participants provided consent that the photographs may be published

3.4.2 The new dawn: The itinerary of the SLP and a pragmatic approach that speaks to South African science education

During the SLP teachers were involved in the following activities:

3.4.2.1 Laboratory activity: Kirby-Bauer technique for testing anti-microbial activity

Dr Jaco Bezuidenhout from the North-West University Microbiology department facilitated the session on the Kirby-Bauer technique for testing antimicrobial activities of plants. The activity was learner-centred and served to promote the self-directed learning of teachers. The reason for using SDL is that learners are responsible for their own learning, and the teacher plays the role of the facilitator. In all the activities in the SLP, the teachers were wearing an ‘SDL cap’. This means the teachers were the ones participating in the learning process, and they were responsible for their own learning. Since the activity was learner-centred the Kirby-Bauer technique was an ideal problem-based activity for the incorporation of aspects of indigenous knowledge by making use of simple science, which is tantamount to shoestring science. The teachers worked in groups and had to make use of the scientific procedure to test the antimicrobial activities of different plants.

According to the indigenous ‘pharmacy’, certain plants bring relief to certain diseases. For this activity, the teachers had to formulate a hypothesis and apply the scientific method to test the hypothesis. For example, teachers could hypothesise that, if a plant like *Sutherlandia frutescens* (the cancer bush) is used to treat microbial diseases, it must contain antimicrobial active ingredients such as alkaloids, and its effect can be tested in the laboratory. The procedure was provided as follows:

1. Preparing the plant material
    - Wash plant material with distilled water.
    - Shred plant material coarsely in a sterilised mortar.
    - Add distilled water and crush with a sterile pestle until a paste is formed.
    - Form a water solution by adding more distilled water.
    - Pour into sterile test tubes.

2. Preparing agar plates for testing the anti-microbial plant substances
    - Use bacterium *E. coli* or fungus *S. cerevisiae* (baker's yeast).
    - Sterilisation: place all materials that need to be sterilised on a rack above water

about 10 cm in depth in a pressure cooker and boil for about 15 minutes.

- Use 15x100mm petri dishes with sterilised plate agar or nutrient agar (a pack of tomato soup + enough gelatin to let it set in solid form).
- Use a sterile cotton swab to pick up and transfer microbes to the agar plate by smearing in at least three different directions to cover most of the surface.
- Grow bacterial cultures at 37°C for 16-24 hours and yeast for 24-48 hours at room temperature (23 - 27°C).

3. The disc-diffusion method

- Use forceps to select a 6cm diameter paper disc by its outer edge and dip into one of the prepared plant solutions.
- Place paper on agar plate - do not reposition or allow to slide on the agar plate once applied.
- Invert and immediately place in an incubator at 37°C for 24 hours.
- After incubation, measure the diameter of the inhibition zone surrounding each disc with a metric ruler (centre of disc to outer edge of inhibition zone).

4. Positive and negative control

Positive control: use household disinfectant (such as bleach) on a sterile disc.
Negative control: prepare in the same way as above, but use distilled water on a sterile disc.

5. Reporting the results

- Each group tabulates results.
- Learners write a detailed report in which they present all data (results) and come to a conclusion.
- Results may be depicted in graphs.

Figure 3.11 shows the A-Team teachers and the other CoPs engaging in the Kirby-Bauer technique during the SLP: (a) the A-Team teachers, (b) 2nd CoP involved in the SLP, (c) Dr Jaco Bezuidenhout, keystone member, (d) using petri dish to test antimicrobial activities of different plants, (e) 3rd CoP involved in the SLP.

Figure 3.11: The A-Team teachers with other CoPs engaging in the Kirby-Bauer technique

Photographer: Josef de Beer & Tswakae Sebotsa. All participants provided consent that the photographs may be published

3.4.2.2 Saponification activity: Washing away traditional cookbook experiments

The soap-making activity was a relevant practical to demonstrate the tenets of science and to engage the ‘learners’ in context-sensitive science (Gibbons, 2000). According to Van Wyk & Gericke (2018:277), a few plant species, such as *Salsola aphylla* (seepganna) and *Mesembryanthemum junceum* (asbos) have traditionally been used to make soap. These plants contain large quantities of saponins that can dissolve fats and oils. Soap plants provide lye, which can be used instead of sodium hydroxide in the saponification process. Mr David Pule, a Physical Sciences teacher, and the researcher (Mr Tswakae Sebotsa) facilitated the soap-making activity. Figure 3.12 shows the A-Team teachers engaging with other teachers in making their own soap during the SLP.

Figure 3.12: The A-Team teachers and other teachers doing a practical activity on soap making within a CoP with keystone species Mr David Pule and Mr Tswakae Sebotsa.
Photographer: Josef de Beer. All participants provided consent that the photographs may be published

3.4.2.3 The post-harvest physiology of cut flowers

South African science teachers should pride themselves on acquiring local and international indigenous knowledge in order to facilitate holistic, inviting, and exciting science content (Abah, Mashebe & Denuga, 2015). Indigenous knowledge is not restricted to African cultures only. Indigenous knowledge also includes Dutch knowledge. In this activity, the teachers had to solve a problem-based activity scenario on how to increase the shelf life of flowers. The scenario is provided below.

Problem: After harvesting flowers, the Dutch need to transport the flowers from Aalsmeer to Schiphol airport in Amsterdam, from where the flowers are transported to cities all over the world. When a plane with flowers lands in New York (for instance), the flowers need to be transported again to the flower market, and from there to flower shops all over the city. A person who buys flowers for her home would like the flowers to last for at least a week.

How can the shelve life of cut-flowers be extended?

Questions to consider in solving this problem:

- What causes cut flowers to wilt?
- Did the Dutch come up with any solutions?

In your small groups, design an experiment that your learners can do, to test Dutch wisdom in extending the post-harvest shelve life of flowers.

This problem-and project-based learning activity was facilitated by Prof Josef De Beer, who navigated the teachers through the activity. The teachers had to be self-directed in their learning and be able to identify their resources in this activity. Figure 3.12 shows Prof De Beer facilitating this learning activity on how indigenous knowledge can be integrated in the Natural Science classroom.

Figure 3.12: Prof Josef De Beer facilitating the SLP on indigenous plants and the post-harvest physiology of flowers

Photographer: Tswakae Sebotsa. All participants provided consent that the photographs may be published

3.4.2.4 Optics

Teachers were exposed to the topic of visible light using problem-based learning. The lesson should start with a 'driving question' to encourage learners to investigate the solution(s). Teachers had to design an inquiry-learning activity focusing on any optics topic in the Natural Sciences curriculum.

The activity had to address the affective domain of the learners by integrating indigenous knowledge in the chosen topic. Traditionally light has been an essential feature to most cultural groups in the world. For example, refraction and spearfishing is one example: The light that comes from the fish changes direction (refracts) when it hits the water surface; the person observing the water sees the apparent position of the fish, not the real position. This serves as an example of how refraction and apparent depth could be contextualised in terms of indigenous knowledge. This serves only as an example, as the teachers would have to plan their own signature lesson and consider the context and indigenous knowledge relevant to their learners.

3.4.2.5 Paper-based microscopes: Science-on-a-shoestring

According to NEIMS (2011), more than 84% of ordinary schools in North-West Province do not have laboratories, which make it necessary for teachers to be trained to be agents of change, able to identify their goals and resources to facilitate an inquiry science classroom even in an under-resourced classroom. During this intervention, the teachers were provided with foldscope microscopes, developed by Manu Prakash of Stanford University This paper-based foldscope is a 'shoestring' microscope which is portably, and designed to be durable, and it offers akin resolution quality as the conventional microscopes with a maginification of 140X and 2 micron resolution. The teachers had to explore how a paper-based microscope could facilitate problem-based learning in the Natural Sciences classroom.

Figure 3.13 shows the process from stage one (facilitation) to stage six (foldscope usage). Stage 1 represents a keystone species providing facilitation on the assembling and usage of the foldscope. Stage 2, the A-Team assembles the foldscope. In stage 3 the A-Team teacher has assembled the foldscope. In stage 4, a complete foldscope is demonstrated. In stage 5, the teacher uses the foldscope. In stage 6, the foldscope is used to zoom, and the foldscope is working like a traditional microscope. After assembling the microscope, the teacher was required to plan a lesson using a foldscope in the Natural Sciences classroom and to submit it.

Figure 3.1.3: The foldscopes – teachers engaging as agents of change and self-directed learners

Photographers: Josef de Beer & Tswakae Sebotsa. All participants provided consent that the photographs may be published

3.4.2.6 Ethno-biological survey in a Natural Sciences classroom

In this activity, the 'learners' were encouraged to record the traditional uses of plants and animals, either for medicinal, food or other uses. During the presentation, Prof De Beer provided guidelines and examples on how to use the ethno-biological survey and the Matrix Method (De Beer & Van Wyk, 2011) to determine the ethno-biological knowledge index (EKI) of people, and the Species Popularity Index (SPI) of indigenous plants and animals. Teachers were also provided with the techniques needed to determine the Species Popularity Index (SPI). Most of the teachers were encouraged by how the technique works. Figure 3.14 shows one of the teachers completing the ethnobotanical survey and Prof De Beer providing insights on how the technique works; and how it could be adapted for the Natural Sciences classroom.

Figure 3.14: (Top) Prof Josef De Beer, developer of the ethnobotanical survey (below) a member of the A-Team completing the survey

Photographer: Tswakae Sebotsa. All participants provided consent that the photographs may be published

3.4.2.7 Teaching strategy: Wearing De Bono's thinking hats with a cooperative flair

Cooperative learning was linked to self-directed learning, and teachers engaged in the basic elements of cooperative learning, as suggested by Johnson and Johnson (1999:70-71). This perspective provided guidance to teachers on how to use the jigsaw method and De Bono's thinking hats. Indigenous knowledge is almost new in most science classrooms. Teaching using culture and ways of doing can be a sensitive issue in diverse South Africa and many other countries.

One of the keystone members, Dr Lounell White, facilitated a session on the De Bono thinking hats; and the 'teachers as learners' applied the strategy and presented their findings. The question posed was: 'Is there space for both traditional medicine and Western medicine in South Africa?' Teachers worked in groups of six. Each teacher in the group used a different colour hat, as in Figure 3.15. They were provided with information, i.e., articles and the internet regarding the problem, and worked in their groups to discuss the issue at hand.

Each teacher argued from his/her specific point of view, as determined by the colour of their hat. Teachers were allowed ten minutes in a group to present their viewpoint and conclusions.

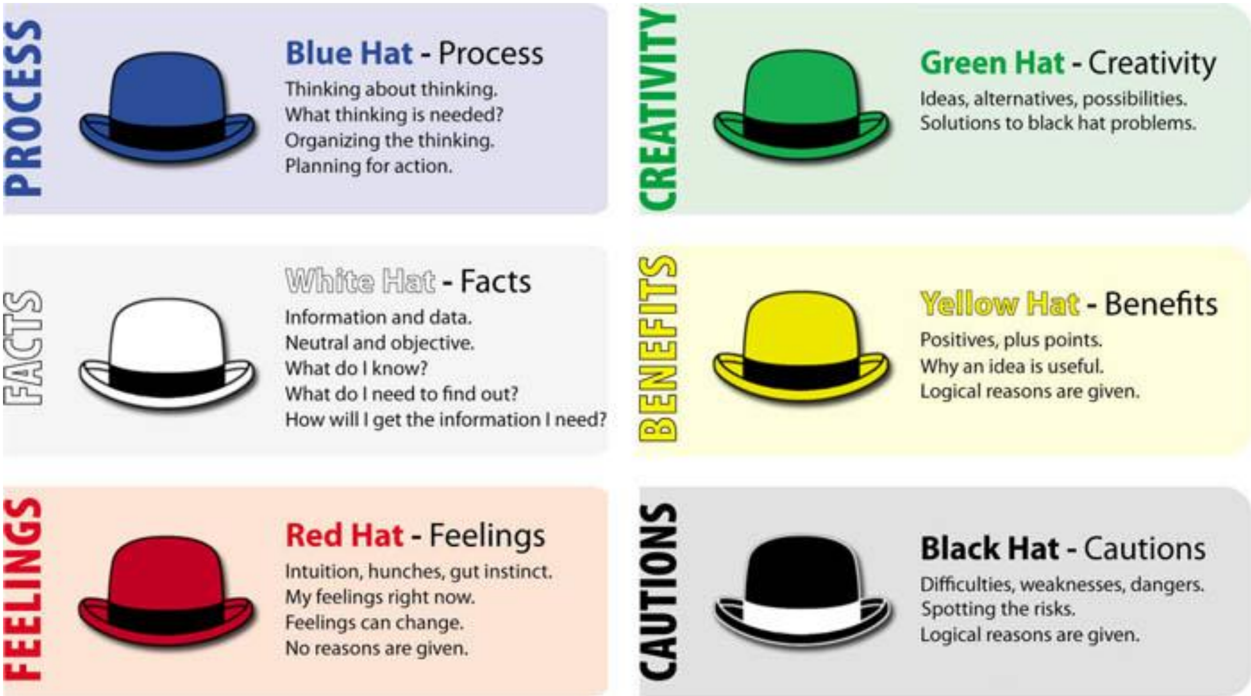


Figure 3.15: The strategy to use De Bono's thinking hats, (De Bono, 1985)

In Figure 3.16 the keystone member engages teachers in De Bono's thinking strategy

Figure 3.16: Left, Dr White presenting the six De Bono's thinking hats to the teachers. Right, the teachers are representing their insights on the De Bono thinking hat

Photographer: Josef de Beer. All participants provided consent that the photographs may be published

3.4.2.8 The STEM to STEAM agenda: Let's all play

Research shows that playing can facilitate learning. It has been found that when a person plays, he/she learns quicker than when he/she memorises. According to the late Dr Karun, it takes about 400 repetitions to create a new synapse in the brain, while with play it takes about 10 to 20 repetitions. She asserts that 'play disarms fear, builds connectedness, teaches social skills, and social competencies for life'. In this intervention, the teachers were afforded a chance to play while learning. One of the activities was to address the metaphysical aspect of indigenous knowledge in the IK-Science curriculum. The 'learners' were engaged as *Homo ludens* (the playing human) (Huizinga, 1957). With the new focus of moving from STEM to STEAM education, puppetry was also used as an approach to include the Art in STEM education.

Figure 3.16: Teachers engaging as *Homo ludens (*the playing human) in an attempt to move STEM to STEAM agenda forward

Photographer: Tswakae Sebotsa. All participants provided consent that the photographs may be published

3.4.2.9 Assessment

Teachers' learning was navigated on how to design meaningful learning and assessment, with particular focus on Lesson planning, Bloom's Taxonomy, and reflection. Teachers submitted a portfolio on these strands.

3.5 RESEARCH APPROACHES

Maree and Van der Westhuizen (2007) maintain that research design is determined by the aim of the study; and that the purpose of the research will influence the use of certain methods of data collection and data analysis' (Henning et al., 2004).

The aim or purpose of this study was to investigate what are Natural Sciences teachers' lived experiences of developing contextualised learning opportunities in their classrooms, after a professional development intervention.

Maree and Van der Westhuizen (2007) add their perspective to Henning et al. (2004) and propose that research methods should also be determined by the research questions. Henning et al. (2004) and Creswell (2009) provide insights into the choice of research design and research methods. The scholars are of the view that research design and research methods are not influenced by one factor alone but by a mixed bag consisting of the aim (purpose), the nature of the study, the theoretical framework, and the research questions. Mouton (2000) advances the conversation by highlighting the proposition that the title also shapes the 'design type' and should be considered in the factors shaping the research design.

3.6 RESEARCH DESIGN: A MIXED-METHODS, DESIGN-BASED RESEARCH STUDY

Research design is a central element of any study, as it orientates and aligns all aspects of the research. In this study, research design continuity was maintained from Chapter 1 to Chapter 3 as follows:

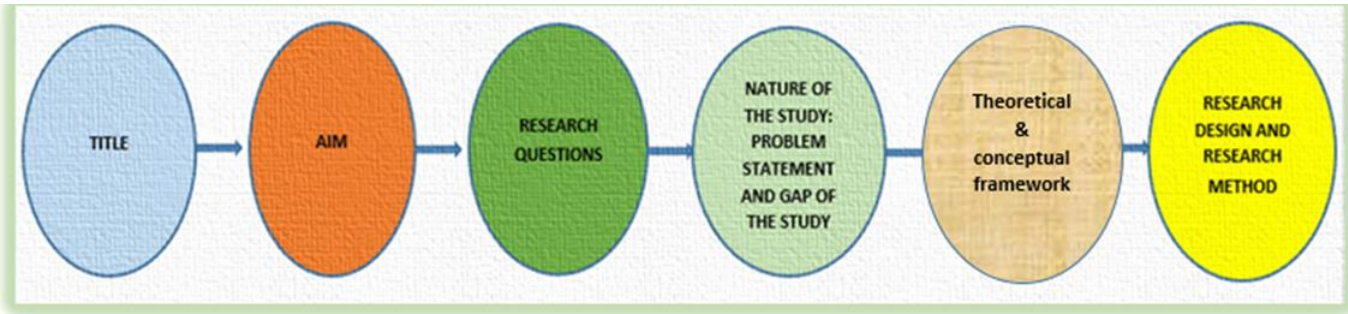


Figure 3.17: Author's representation of a chain-like relationship from the title to the research design and research methodology

A mixed-methods approach has been receiving 'hall of fame' recognition since the 20th century, and the approach is still widely appreciated for its strength of achieving a more complex understanding of research problems (Kate et al., 2019:696; Creswell & Plano-Clark, 2018). The approach of infusing qualitative and quantitative methods is acknowledged for producing rigorous and credible sources of data (*ibid)*.

It deepens the insight of the study by responding to complex human phenomena (Sandelowski, 2000). This notion is attained by making use of the in-depth, contextual strands of qualitative (inductive) and broader generalisation of quantitative perspectives (deductive) in a single study (qualitative and quantitative strands are explained in section 3.3.1. and 3.3.2). This is done with the intention of providing a more meaningful understanding of a complex phenomenon.

The study focused on multiple challenges facing the South African education system, as discussed in Chapters 1 and 2. The complexity of these challenges makes a one-size-fits-all approach impossible; instead it was necessary to use different methods to better understand the challenges and provide recommendations. The study used a mixed-method to collect empirical data and to answer the research questions. The strength of using a mixed-methods approach lies in its application to bridge a broad range of research questions and to provide a more complete picture of a complex phenomenon than either qualitative or quantitative data collected alone (Kate et al., 2019). According to Johnson and Onwuegbuzie (2004), a mixed-method offers the best opportunities for answering important research questions.

This research responded to 10 complex research questions that required the strength of deductive and inductive approaches. Hence mixed-method fits like a glove in this design decision to explain complex problems (Kate et al., 2019). I should clarify from the beginning that the 'mix-masala' of quantitative and qualitative inquiry does not necessarily qualify the design to be a mixed method. Sandelowski (2000:251) provides this study with a guideline that qualifies a mixed-method design. The guideline to the three levels of mixed-method (paradigm level, method level, and technique level) is provided below.

3.6.1 At the paradigm level

The term 'paradigm' is used in a number of dissimilar ways in 'The Structure of Scientific Revolutions' by Thomas Kuhn. According to Masterman (1970), Kuhn used the concept in more than 20 different ways. As Johnson et al. (2007:117) acknowledge, 'the dividing lines are much fuzzier than typically suggested in the literature' and 'positions are not nearly as "logical" and as distinct as is frequently suggested in the literature'. Creswell & Plano-Clark (2011) and Guba and Lincoln (1994) adopt the idea of paradigms as worldviews, each with a distinctive ontology (view of reality), epistemology (view of knowing and the relationship between the knower and the known), methodology (view of the mode of inquiry), and axiology (views of what is valuable). Paradigms, in this sense, concern higher-level belief systems and the way these link with research questions.

It should be stated at the outset that data collection and analysis techniques are not linked to paradigms (Berman, Ford-Gilboe & Camplell, 1998; Sandelowski, 1995, 2000). Researchers working in different paradigms can use similar instruments, e.g., interviews, observations and questionnaires; and treat their results differently depending on the instrument used and paradigmatic lens. This study was conducted in a constructivist paradigm. Constructivism as a philosophical worldview linked well with the qualitative element of the mixed-method approach for this study. According to Creswell (2004:4) this approach is fitting to be used for the study as ‘it is a means of exploring and understanding the meaning individuals or groups ascribe to social or human problem’. In addition, social constructivism is well known for its purpose of acknowledging that learning takes place because of the interactions of people in a group (Vygotsky, 1986).

Kuhn (1962 & 1970:176-183) recognises paradigms as being characterised by four constructs, namely:

- First, they centre on a specific problem or set of problems that are regarded as particularly significant in relation to the advancement of knowledge.
- Second, they are about shared practice. Such paradigms involve a shared understanding about which research techniques are appropriate for investigating that issue.
- Third, these paradigms involve a sense of shared identity. Based to some extent on the specialist area of research, this shared identity is reinforced through the processes of information exchange they use (specialist publications and conferences) and through the interpersonal networks that practitioners establish in relation to their area of research.
- Fourth, these paradigms operate through groups of practitioners operating in research communities.

Several authors (Denscombe, 2008:270; Pretorius, 2015; Antonio, 2017) argue that the use of ‘communities of practice’ as the basis for such a research paradigm is:

a. Consistent with the pragmatist underpinnings of the mixed methods approach;
b. Accommodates a level of diversity;
c. Has good potential for understanding the methodological choices made by those conducting mixed-methods research.

The concept of communities of practice, and teachers within a community of practice, align well with the social constructivism worldview (paradigm). In this study I represented a group of Natural Sciences teachers who participated in a teacher development programme within a community of practice (CoP).

3.6.2 At the method level

At this level the researcher aimed to align instruments and methods to the aims of the study, i.e., what methods to use to fulfil the aim of the study. Another important argument is how to align the research phenomenon to appropriate methods. According to Kate et al. (2019:711), ‘if the most appropriate and practicable study design is used for the research question, data integration is rigorous and results well reported a deeper and more meaningful understanding of a diverse range of research objectives can be achieved’. In the next section (section 3.7), I provide the reader with an integrated view of the research methods, instruments and data collection. According to Green et al. (1989:259) combination at method level can be used to expand the scope of a study as a researcher seeks to ‘capture method-linked dimensions of a target phenomenon’.

3.6.3 At the technique level

According to Sandelowski (2000:247-248), ‘the technique level of research is the site where combinations actually occur and is what is most often referred to in discussion of mixed-method research’. The combinations take account of sampling, data collection, and data analysis techniques (although not necessarily) comprehended as qualitative or quantitative. Data collection and data analysis techniques are dealt with below (section 3.7); sampling techniques are described in section 3.8 below.

3.7 RESEARCH METHODS, INSTRUMENTS AND DATA COLLECTION

This study used an exploratory sequential mixed-method approach, with the qualitative inquiry dominant, utilising elements of qualitative case studies, phenomenology and design-based research. Both quantitative and qualitative data was gathered by making use of pre- and post-questionnaires for teachers, interviews, classroom observations, and by studying artefacts such as teachers' portfolios. I have also used researcher auto-ethnography, in order to add to the 'rich description' of the phenomenon.

3.7.1 Views-of-the-nature-of-science (VNOS) questionnaire

I used the views-of-the-nature-of-science (VNOS) questionnaire that was developed by Abd-El-Khalick, Bell and Lederman (1998). This questionnaire assisted the researcher to determine the views that teachers hold of the nature of science, before and after the intervention. This questionnaire focuses on teachers' views of the tenets of science, e.g., that science is empirically based, that there is a difference between scientific theories and laws, that scientific knowledge is creative and theory-laden, etc. The VNOS instrument consists of ten open-ended questions based on the tenets of the NOS framework (Abd-El-Khalick et al., 1998).

3.7.2 Views-of-the-nature-of-indigenous-knowledge (VNOIK) instrument

The researcher used Cronje's (2015) views-of-the-nature-of-indigenous-knowledge (VNOIK) instrument. This instrument assisted the researcher to determine teachers' views of the nature of indigenous knowledge, before and after the intervention. This instrument was developed, based on the structure of the VNOS instrument, to capture teachers' views of the nature of indigenous knowledge. For both VNOS and VNOIK, pre- and post-questionnaires were completed. Both VNOS and VNOIK are instruments to capture qualitative data, but the analysis as described by Abd-El-Khalick et al. (1998) and Cronje et al (2015), involves a process of quantifying the qualitative data.

3.7.3 Qualitative, open-ended questionnaire

A qualitative questionnaire was developed to determine how teachers view their participation in the intervention (workshops and SLP), and in the community of practice.

3.7.4 Questionnaire to determine teachers' professional development needs

In order to determine the real needs of teachers, they were asked to complete a questionnaire. The tailor-made programme then addressed these specific needs.

3.7.5 Individual interviews with participating teachers

Pre- and post-interviews (exit interviews) with individual teachers were conducted, to capture teachers' 'lived experiences'. The main intention of the interviews was to probe deeper information from the participants. Gay et al. (2011) state the advantages of interviews as follows:

- Establishing rapport and trust relationships;
- The researcher can often obtain information that participants would [not?] provide on a questionnaire;
- The interview may also result in more accurate and honest responses, since the interviewer can explain and clarify both the purpose of the research and individual questions. An interview can follow-up on incomplete or unclear responses by asking additional probing questions.

3.7.6 Focus-group interview

A focus group interview was carried out with the teachers after they attended the DNA barcoding intervention at the ACDB. This stage is very important as it allows the researcher and the participant to critically engage on the affordances and limitations of such an intervention. Secondly, the researcher is provided with the opportunity to verify his observations, as well as to understand the teachers' lived experiences of the intervention.

3.7.7 Classroom observations

In addition, the RTOP (Reformed Teaching Observation Protocol) (Sawada et al., 2002) instrument was used during classroom observations, when observing lessons. This instrument assisted the researcher in making detailed observations regarding the classroom climate, pedagogies of the teacher, learner involvement in the lesson, etc. Each of the selected teachers was observed at least two times. This instrument helped to document how teachers use PBL in their classrooms, how indigenous knowledge was infused, and what transfer took place in the classroom, both before and after the intervention.

3.7.8 The stimulated recall method

During the last round of classroom observations, I also made (with the necessary permissions) video-recordings of the lessons. I then played sections of the lesson back during the interview with the relevant teacher, and prompted the teacher to critically reflect on his or her actions. This is known as the 'stimulated recall method' (Moustakas, 1994; Mostert, 2019), and it is an empirically rigorous self-analysing data collection tool used in especially phenomenological studies to elicit meaning.

The stimulated recall method (video elicitation) was used particularly with focus group interviews in this study. This helped the researcher to gain insights on the teacher's point of view, which shaped reflections on practice and on-going professional development. The stimulated recall method was used to prompt discussion, provide a basis for reflection or stimulate recall (Roth, 2009). According to Torchon (2009), video-based reflections should be based on three separate perspectives: reconstructing past thinking, post-activity narratives, or the construction of reflections on present and future actions. The stimulated recall in this study opted for video reflection according to these three perspectives of Torchon (2009). This was done by asking the teachers to first describe their views on the lesson observed. This was followed by the researcher selecting a snippet of the video and engaging the teacher on a detailed discussion. For instance, after the teachers observed the video, they were asked to 'call out' what they considered noteworthy in viewing. The video was played and paused at different segments to probe the teachers and understand their lived experiences. The stimulated recall method was a useful approach for the researcher to validate and cross-check the teacher's interpretations.

The "combination of the stimulated recall and the interviews is particularly useful in helping to generate accounts of the characteristics of 'invisible' phenomena, that is in contexts where something (e.g., work) may be 'invisibly buried in the routines of day-to-day activities or may be conducted in the silent, isolated activities of machine operation' (Schubert, 2006 cited in Jewitt & Carey, 2012:4) The following considerations, potentials and constraints on video data were considered as advised by Jewitt, 2012. In Table 3.1 advantages and disadvantages of using video recording are provided.

Table 3.1: Summary of the considerations, potentials and constraints of video data (Jewitt, 2012:8)

Considerations for video	Advantages	Disadvantages
• Need to link video-based data to social theories and themes • Understand the effect of video recording on data collection • Make sure the data is understood in context • Decide on the scale you will look at and how much data you need to address your question • Decide on analysis strategies for managing video data to avoid data overload • What status will you give your data in your data set – primary, secondary?	• Video can support an exploratory research design and extended data discovery • It can be 're-opened' for later analysis and capture things not noticed at the time of being present • Participants can use the camera to afford the researcher access to their life worlds • Video is sharable - participants can be invited to reflect and discuss it • It can be used effectively to support empirical comparison of strategies, style, and interaction across a data set • Video enables researchers to revisit a moment 'not as past but formerly present' • It can re-awaken the memories and experiences of a researcher or participant.	• Video data is limited and shaped by decisions in the field • Video data is partial: it includes and excludes elements • Video is primarily focused on the material external expression • It can be edited to represent the sequence of events in new ways • It usually provides one perspective on an event • It generally records interaction over short periods of time • Video takes time to watch and review and can be difficult to meaningfully summarise

3.7.9 The self-directed learning instrument (SDLI)

With the growing trend of preparing students for lifelong learning and for jobs which do not yet exist, self-directed learning becomes an important consideration. We had to consider a theory and a mechanism that would assist teachers in preparing learners for the rapidly changing world. The 21st-century skills are no longer negotiated, they are implemented. The theory of self-directed learning (SDL) is progressively applied in the context of higher education to determine teachers' view on their own self-directed learning. The current research shows a real need to foster the same behaviour in secondary and high schools.

In order to nurture lifelong learning abilities, an appropriate instrument to measure the SDL abilities of teachers is needed. I administered the Cheng et al. (2010) instrument, which determines whether teachers' views on their own self-directed learning during the intervention have changed. This 20-item instrument measures self-directed learning attributes in four domains, namely learning motivation, planning and implementing, self-monitoring and interpersonal communication.

3.7.10 Analysis of the teachers' SLP portfolios

As mentioned in Chapter 1, after the teachers had attended the SLP the A-Team teachers had to submit their portfolios of evidence. The submitted portfolio is divided into three following sections, namely:

- Growth: the A-Team had to demonstrate pedagogical content knowledge (PCK) development;
- Showcase portfolio: the A-team had to showcase best practice;
- Evaluation portfolio: used for grading purposes.

3.7.11 Auto-ethnography

Auto-ethnography is a promising qualitative method that gives voice to personal experiences, in order to come to a better understanding of sociological situations (Wall, 2008). Wall describes this methodology as emerging from postmodern philosophy, which legitimates various ways of knowing. Viramontes (2012:3) describes auto-ethnography as 'writing (that) involves personal expression about a particular event or situation'. This reflective writing considers one's own lived experiences of a phenomenon.

Throughout this research study, I have kept a researcher diary on the events that took place. My auto-ethnography is a personal narrative on how I have experienced the intervention with teachers. It is a hybrid of an *analytic auto-ethnography* (objective writing and analysis of the teachers' participation), and an *evocative auto-ethnography* (my personal introspection to allow the reader to connect with my own feelings and experiences) (Mendez, 2013:281). It supplements the quantitative and qualitative data obtained, in an attempt to provide a 'rich description' (Geertz, 1973) of the intervention.

3.8 POPULATION AND SAMPLING

The population was the teachers in Ikageng and Promosa schools in Potchefstroom, North-West Province, who are teaching Senior Phase Natural Sciences, as the research is aimed specifically at Natural Sciences teachers. In this case, the researcher selected teachers who were teaching grade 7-9 Natural Sciences to qualify the participants for this research and sampling purpose.

Purposeful sampling was used according to the following parameters, which delineated the study:

- Potchefstroom schools
- Natural sciences teachers
- Maximum of ten teachers formed a Community of Practice.

A purposive sampling method, as proposed by Creswell (2013), was used in sampling the 10 teachers who participated in the intervention. From this group, I only received six data sets from which I profiled the teachers in terms of their professional development from the pre- and post-data. Data from the six classrooms, or what Engeström (1987) would call six activity systems, led to data saturation, and what Geertz (1973) calls a 'thick description' of the phenomenon.

Maree et al. (2016) describe this method as used in special situations, like in this research, the number of teachers to be analysed is six, and each teacher represents an activity system with thick and comprehensive description. This number is sufficient to describe the phenomena under investigation, namely teachers' lived experiences of a contextualised learning intervention, and the affordances for a professional development and for Natural Sciences education.

Sampling was systematically followed by data collection, which provided the researcher with interpretive opportunities. In this mixed method study,data collection techniques such as unstructured and open-ended interviews and structured questionnairs were used. Further to that, instruments were used in combination to fulfil different objectives and to elicit rich data that will explain the complex research phenomenon. Instruments are well used here to make profile-bound descriptions.

The researcher used this approach to provide full justification from pre- and post-data in the intervention to profile the A-Team journey in a professional development programme within a CoP (Antoniou, 2017).

Using different instruments, allows for different forms of data to be collected, which collectively inform the findings through complementation and contradiction. This approach also acts as a development bridge between qualitative exploration and quantitative exploration of the phenomenon. According to Creswell and Plano Clark (2018), accumulating data from the same participants using the mixed-method approach allows the data to converge more easily. The strength of mixed methods approaches lies in this combining of data analyses. Because techniques are not tied to a paradigm, or to a set combination of methods, this allows innovative use of a range of techniques for different purposes. According to Sandelowski (2000: 251), three purposes include:

- Triangulation to achieve or ensure corroboration of data, or convergent validation;
- Complementary and contradictory data to help clarify, explain, or otherwise more fully elaborate on the results of analysis;
- Development, to guide the use of additional sampling, data collection and analysis techniques (Greene et al., 1989:259).

3.9 DATA ANALYSIS

Data analysis is an effort to make sense of text, numbers and image data (Creswell, 2013) which will provide answers to the primary and secondary research questions (Merriam & Tisdell, 2015). Questionnaires and interviews were transcribed, and the coding-to-theory approach was used to analyse the data, as suggested by Saldaña (2015). The teachers' responses were subjected to Saldaña's (2009) coding technique; with codes, categories and emerging themes being identified.

Saldaña's (2015) code-to-theory model was an appropriate tool to use as it demonstrated relevant relationships from the data collected. It also allowed the researcher to analyse complex phenomena. The in-vivo coding system was used (codes taken from the exact words spoken by the participants), which were organised into themes, as shown below:

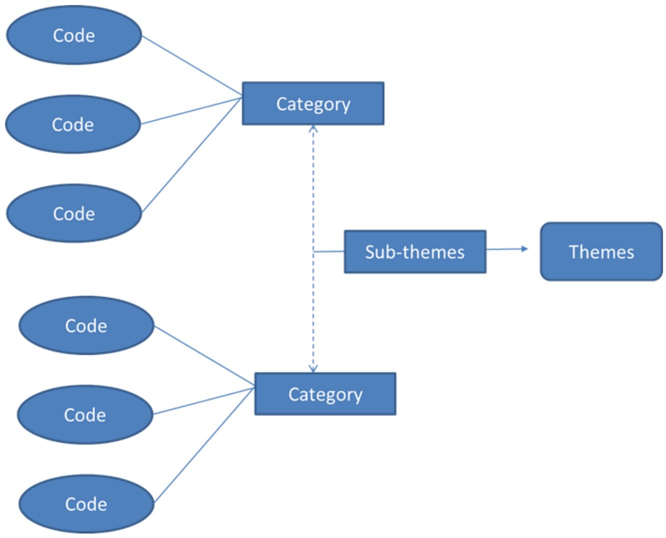


Figure 3.18: The code-to-theory model (Saldaña, 2013:12)

Coding was utilised to identify words or short phrases to create categories, which were then grouped into sub-themes, and finally into themes. The themes were used to understand the data collected.

3.9.1 Pre- and post-VNOS and VNOIK questionnaires

The VNOS (Abd-El-Khalick & Lederman, 1999) and VNOIK (Cronje, 2005) questionnaires were analysed utilising the technique described by Lederman et al. (2002) and Cronje (2015). According to Lederman et al. (2002) the responses from the VNOS questionnaire can be classified as either (a) naive or (b) informed views. In a similar fashion as Lederman et al. (2002),Cronje (2015) also categorised response from the VNOIK questionnaire as either (a) a naive or uninformed view (U.I.), or (b) a partially informed view (P.I.), and (c) an informed and nuanced view (I).

In this study, the researcher followed the same approach as Cronje (2015), and quantified the responses of teachers by using a rubric. An uninformed view was scored as 0, a partial view was scored as 1 and an informed view was scored as 2. The average score indicated the perceived overall view of the participants on the VNOIK (Cronje et al., 2015). The instrument has been used to measure the teachers' views on indigenous knowledge (Cronje, De Beer & Ankiewicz, 2015).

Table 3.2: Example of the table to code teacher responses to the VNOIK questions (Cronje et al., 2015:329)

Participant	Qu 1	Qu 2	Qu 3	Qu 4	Qu 5	Qu 6	Qu 7	Qu 8	Qu 9	Qu 10	Score

Note: Qu = Question; N/A = not answered; UI = uninformed view (0); PI = partially informed view (1); I = informed view (2)

Artefacts such as photographs were used as authentic evidence from the interventions and indicated various activities in which the teachers participated during the SLP. Observations were also noted. See the attached CD for the photographs and videos taken. The portfolios were assessed, and data was collected.

3.9.2 Pre- and post-classroom observations

The RTOP instrument was used to analyse the teachers' observed lessons. Likert-scale items were used in a qualitative 'trend' description to paint a picture of dilemmas and successes in the classroom.

3.9.3 Pre- and post-SDLI questionnaires

Cheng et al.'s (2010:1152) instrument for determining a subject's view of their own self-directed learning measures four variables, namely: learning motivation, planning and implementation, self-monitoring, and interpersonal communication. The items consist of Likert-scale options, and quantitative data illustrates levels of self-directed learning:

- 20-46: low level of SDL
- 47-72: average level of SDL
- 73-100: high level of SDL.

Descriptive statistics were applied using SPSS Version 22. I compared the pre- and post-responses.

3.9.4 Development of the stimulated-recall instrument

Artefacts such as video, images and film have featured in the development of social research within sociology, anthropology, education and psychology (Jewitt, 2012). The researcher used videos to probe and qualify meaning by observing how teachers' pedagogy has changed after the intervention.

The use of video to collect data provides the researcher a fine-grained multimodal record of an event. This further assists the researcher to gaze into details such as gesture, expression and body posture of the research participants, which other data techniques do not provide … I developed a guideline that helped me to probe into the teachers' experience and pedagogical orientation. The instrument was guided by Ramnarain and Schuster's (2014) insights on the pedagogical orientation of a science teacher.

3.9.5 Stress-management questionnaire

A questionnaire was designed that required teachers to explicitly identify their own professional development needs. Most teachers identified stress management as an important consideration during the intervention. Identifying teachers' needs during a professional development programme should not be viewed as a luxury but as a necessity. A number of studies globally have found teachers are at comparatively high risk of common mental disorders and work-related stress relative to other to other workers (Wieclaw et al., 2005; Stansfeld et al., 2011). In this research the teachers completed a stress management questionnaire. The questionnaire was divided into two parts, part A (stress-related themes) and Part B (the intervention). The questionnaire aimed to identify if the teacher is stressed due to work or other factors. Other factors evaluated by the questionnaire included: symptoms of stress, work, load, and exhaustion, amongst other. This was analysed utilising the coding technique described by Saldaña's (2015).

3.9.6 Pre- and post-DNA barcoding questionnaire

The teachers spent two days in an excursion at the University of Johannesburg (Auckland Park Campus) with real scientists. During the laboratory and lecture sessions they were afforded an experience to learn and engage with DNA technologies and performed experiences. The indent was to immerse teachers in the methods of science and also to address the science process skills. Before and after the intervention the teachers completed pre- and post-questionnaires followed by a focus group interview. Saldaña's method was used to distil themes and the data was compared to see if the intervention assisted the teacher with inquiry lessons in their respective classrooms.

3.9.6 Natural Sciences pre- and post-questionnaire

The aim of this question was to assist the researcher to profile the A-Team teachers'. From the questionnaire the researcher managed to capture teachers' teaching experience, demographics, challenges in teaching Natural Sciences and all the information necessary to inform the teacher's development programme.

3.9.6 Content knowledge pre- and post-questionnaire

Teachers were provided with a Natural science pre-test and post-test during and after the intervention. The pre-test was compared to the post to evaluate if a customised teacher professional development provides positive results or not.

3.9.7 Focus-group and exit-group interviews

Teachers' focus group and individual exit group interviews were firstly transcribed, and then analysed using Saldaña's approach of distilling themes and making meaning.

3.9.8 SDLI instrument for determining teachers' views on their own self-directed learning

I administered the Cheng (2010) instrument to determine whether teachers' views on their own self-directed learning changed during the intervention. The Cheng (2010) instrument consists of 20 items, utilising a 5-point Likert scale. The items cover four categories, namely learning motivation, planning and implementation, self-monitoring, and interpersonal communication. This instrument was used in a pre- and post-intervention setting.

3.9.9 The A-Team professional development journey: Profiling the teachers, in terms of the Rogan and Grayson (2003) zone of feasible innovation heuristic as adapted by Petersen (2011)

Below I provide a methodological tool and rubric to evaluate the A-Team during a two year professional journey. The tool that is used in this section is the profile of the teacher. In this tool I capture the teacher's personal profile (biography) the school and the classroom. The tool also captures most of the pre- and post-interventions that took place, including the excursions and the short learning programme hosted by North-West University. I further included the revised rubric to be used to capture the teachers' movement from their actual to their potential development. The tool is revised by the researcher to provide a more nuanced view by including the construct of the SDL from Petersen's revision on Rogan and Grayson's profile of implementation.

Table 3.3: Author's representation of teacher's professional growth from 10 March 2018

Pre- and post-intervention findings are described in the following chapter (Chapter 4).

Profile: TEACHER A

1. Personal profile (biography)
1.1. School and classroom

2. Pre-intervention data

2.1. Pedagogical orientation
2.1.1. Lesson observation, using the Reformed Teaching Observation Protocol (RTOP) instrument
2.1.2. Personal interview
2.1.3. Analysis of lesson plan
2.1.4. Content knowledge on optics

2.2. Teacher's A's views on practical (laboratory) work, inquiry learning, & the nature of science
2.2.1. Inquiry learning in Teacher A's classroom
2.2.2. UJ-DNA Barcoding (pre-questionnaire) and focus group interview
2.2.3. Views on the nature of science

2.3. Views of science and society
2.3.1. Portraying the role of science in society during lessons: evidence from the lesson observations using RTOP, lesson plan and interviews
2.3.2. Views on the nature of indigenous knowledge (VNOIK)

2.4. **Views on assessment/ Assessment practices**

2.5. Teacher's Self-Directed learning

2.5.1. (a) SDL instrument; (b) Lesson observation using RTOP

2.6. **Teacher's holistic wellbeing**

(a) Wellbeing (b) Professional development need(s)

2.6.1. Teachers wellbeing and stress management

2.6.2. Teachers Professional Development Needs

3. Post-intervention Data

3.1. Pedagogical orientation
3.1.1. Lesson observations using the Reformed Teaching Observation Protocol(RTOP) instrument
3.1.2. Teaching and learning (Lesson plan); analysis of lesson plan
3.1.3. Exit interview + Discussing the recorded lesson using stimulated video recall
3.1.4. Content knowledge on optics
3.1.5. Portfolio

3.2. Teacher's A's views on practical (laboratory) work, inquiry learning, & the nature of science
3.2.1. Inquiry learning in Teacher's A classroom (i.e., using PhET simulations, optic kit or science on a shoestring)
3.2.2. UJ-DNA Barcoding (Post questionnaire and focus group interview)
3.2.3. Teacher's views on the nature of science

3.3. Views of science and society
3.3.1. Portraying the role of science in society during lessons: evidence from the lesson observations using RTOP, lesson plan and interviews
3.3.2. Views on the nature of indigenous knowledge

3.4. Views on assessment/ Assessment practices
3.4.1. Reformed Teaching Observation Protocol (RTOP) and lesson plan
3.4.2. SLP Portfolio

3.5. Teacher's Self-Directed learning. 3.5.1. (a) SDL instrument; (b) Lesson observation using RTOP
3.5. **Teacher's holistic wellbeing** (a) Wellbeing (b) Professional development needs 4. Synthesis: Using Rogan (2004b:159) profile of implementation to assess teacher professional growth, and plotting their learning/ development

Table 3.4: Profile of implementation of science teachers (Rogan and Grayson 2003: 1183-1184 and Rogan 2004:159; taken from Petersen & De Beer, 2016:281-282 and revised by Sebotsa, De Beer & Kriek, 2019)

Level	**Classroom interaction**	**Science practical work**	**Science in society**	**Assessment**	**Techers Self-Directed Learning****	Quantitative analysis from SDL instrument of Cheng et al. (2010)
0*	○ Teacher presents transmission-type lesson in an unstructured way and reads mostly from the textbook. ○ Limited and ineffective media usage. ○ Learners passive and not engaged.	○ Practical work is seldom done ○ Teacher uses limited and not well-planned demonstrations to assist in the explanation of concepts.	○ Teacher seldom uses examples from the learners' daily lives, and if used these are incoherent.	○ Written tests on lower cognitive levels ○ Tests marked and handed out to learners.	○ There is no evidence of SDL; the teacher does not show interest in ongoing professional activities.	○ 0-24
1	○ Teacher presents organised lessons. ○ Uses textbook effectively. ○ Learners are engaged and respond to questions.	○ Teacher uses classroom demonstrations to help develop concepts.	○ Teacher uses examples from everyday life to illustrate scientific concepts.	○ Written tests are given. ○ Most questions of recall type. ○ Most tests marked and returned promptly.	○ There is minimal evidence of SDL; the teacher indicates that he/she has professional development needs, but there are no concrete learning goals identified.	○ 25-49

2	○ Textbook used along with other resources. ○ Engages learners with questions that encourage deeper thinking and meaningful group work. [check formatting]	○ Teacher uses demonstrations to promote a limited form of inquiry. ○ Learners participate in 'cookery book' practical work.	○ Teacher bases lessons on specific problems faced by community.	○ Written tests include 50% of higher cognitive level questions.	○ The teacher formulated formulates learning, but there is limited evidence that learning resources or learning strategies were identified.	○ 50-74
3	○ Teacher structures learning along 'best practice' lines. ○ Learners engage in minds-on learning activities.	○ Practical work to encourage learner discovery of information.	○ Learners actively investigate the application of science & technology in their own environment.	○ Written tests include 'guided discovery'-type activities; ○ Assessment includes other forms such as reports.	○ There is clear evidence of SDL: learning goals, resources and applicable strategies were identified. However, there is no evidence of evaluating the learning actions	○ 75-89
4	○ Learners take major responsibility for own learning and undertake long-term investigations and projects. ○ Teacher facilitates learning.	○ Learners design and do open investigations.	○ Learners actively undertake a project in their local community and explore long-term effects of community projects.	○ Open investigations and community-based projects included in final assessment. ○ Learners create portfolios.	○ Strong evidence that the teacher is self-directed learner, i.e., [(a) the teacher can define his or her own goals,(b) goals related to central need,(c) able to set a path to achieve the goal (d) the goal is realistic, not too high or too low, but enough to be challenging. ○ The teacher promotes SDL in his/her classroom	○ 90-100

Author's representation of teacher's professional growth from 10 March 2018 .* Addition to the original Rogan (2004b:159) Profile of Implementation by Petersen (2011:246). ** Contribution of this study to the original Profile of Implementation (Sebotsa, De Beer & Kriek, 2019)

3.10 INTERPRETING DATA USING CHAT AS A RESEARCH LENS: SEEING THE TENSIONS

Rogoff (1995) makes it clear that CHAT as a research lens can be used on different planes. She mentions three different levels, as follows: (a) on a personal level or plane, where the focus is on the activity of an individual (the 'subject' in the activity system is, for example, a science teacher, and the object is the teacher's 'professional development) (Mentz & De Beer, 2017:88); (b) on an interpersonal plane, where more than one 'subject' is present, e.g., the relationship between a teacher's teaching activities and a student's learning (with the teacher and learner as the two 'subjects' in the activity systems); and (c) on an institutional plane, where the focus is on a phenomenon (as the 'subject') and not on a real person. For example, Mentz and De Beer (2017:88-89) used CHAT to compare the South African and Finnish education systems. (See Figure 3.19(a), 3.19.4(b) and 3.19(c) below, which show how CHAT can used as a research lens on three different planes in an educational context.)

I used third-generation Cultural-Historical Activity Theory (CHAT) on a personal plane as suggested by both Engeström (1987) and Mentz and De Beer (2017), namely juxtaposing two interdependent activity systems (the A-Team intervention), with the transfer that took place in the classroom after the intervention. Furthermore, the third-generation CHAT was used to study the six activity systems (as one bounded system) – namely six teachers who were involved in the post-intervention phase, and for whom I developed profiles. The lens was further used to portray affordances of the Natural Sciences teacher professional development programme. The CHAT lens makes provision for a specific 'gaze' into the activity system, and it assisted in identifying 'tensions' or problems that teachers experience in their teaching for further research and recommendations.

Social constructivism provides CHAT with a unique gaze as a research tool that can help the researcher to interpret data embedded in a cultural and historical context. According to De Beer and Mentz (2019), CHAT can be used as a practical research tool that can assists the researcher to construe data set in specific cultural and historical contexts.

In this study, the group (subject) refers to Natural Sciences teachers who engaged in a tailored teacher's development programme which was informed by the teachers' needs and embedded in a Community of Practice (CoP) model. Mentz and De Beer (2019:85) have a similar view on CHAT as a lens and they share their view as follows: 'Cultural-Historical Activity Theory (CHAT) is a flexible meta-theoretical framework that can succour the researcher to interpret data from complex settings or activity systems and to distil finer nuances from the data.'

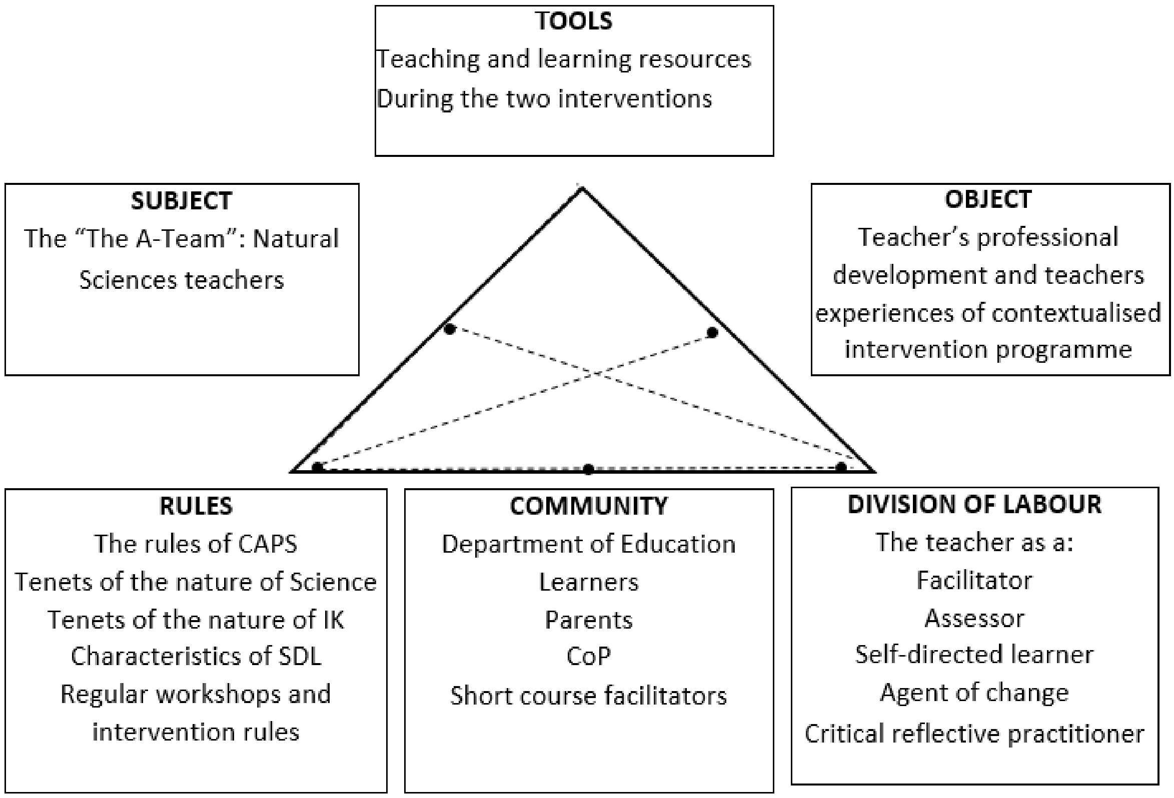


Figure 3.19(a): CHAT on personal plane. CHAT has the potential to provide a robust meta-theoretical framework for capturing the teachers' lived experiences (based on Sebotsa, De Beer and Kriek, 2019)

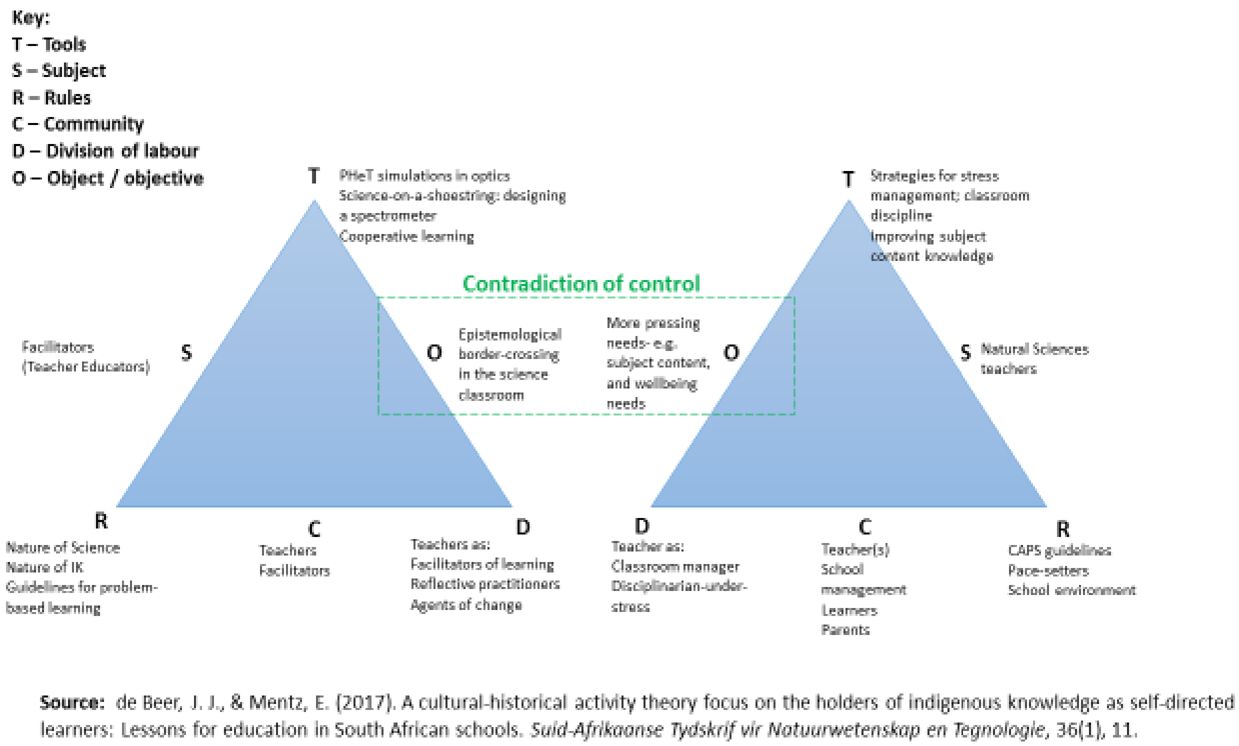


Figure 3.19(b): CHAT on interpersonal plane. Source: Beatty and Feldman (2009:19)

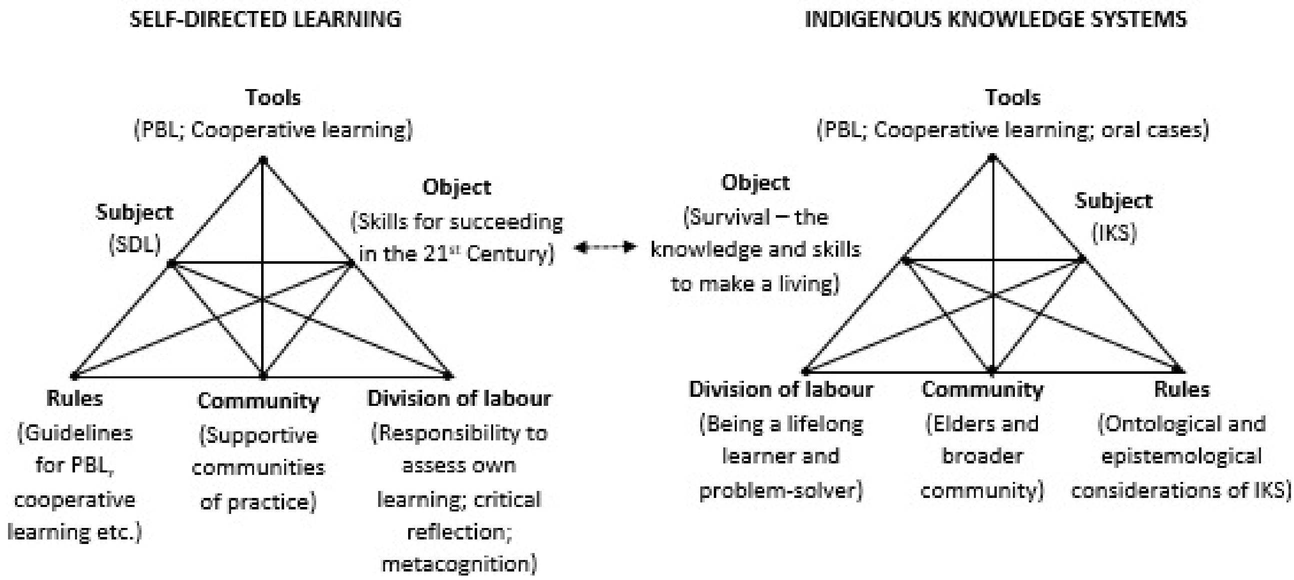


Figure 3.19(c): The use of CHAT on an institutional plane, according to De Beer and Mentz (2016)

Beatty and Feldman (2012) indicate that CHAT is, therefore, a versatile tool that can be used in different ways. However, the criteria in using CHAT should be well explained, and consistently applied. I used third-generation Cultural-Historical Activity Theory (CHAT) on a personal plane as my research lens, as suggested by Engeström (1987) and Mentz and De Beer (2017). I juxtapose two activity systems, and use CHAT as a tool to gaze into the activity systems, where in the one activity system the object is the teacher professional development and in the other activity system the object is transformed teaching and transmission mode. The researcher juxtaposed the two activity systems and analysed the tensions between the two objects, in order to identify what McNeil (2013) terms the 'contradiction of control', which stems from the tensions that occur between the objects in the activity systems when analysed. The third-generation CHAT assisted the researcher to study the six classrooms (as one bounded activity system) – namely six teachers who were involved in the post-intervention phase, and for whom I developed profiles. (This was possible, due to the similarity in data and findings).

After analysing the contradiction of control and the data that emerged from the six profiles was better understood, CHAT was again used on an institutional plane, with the intention to look at the subject and the object respectively. Where CHAT was used in the conventional way, the teacher (person) was the subject and the object was professional development. On the institutional plane, the subject becomes teacher professional development. This analysis assisted the researcher to conceptualise the design principles for teacher professional development underpinned by self-directed learning, as will be seen in chapter 5.

An activity system is a construct of Engeström (1987), a well-established researcher in the Vygotskyan tradition, alongside prominent researchers like Leont'ev, Luria and Veresov. Using activity systems as unit of analysis in research assists in many ways to understand how people are connected in a social-cultural context. The activity system comprises tools relavant to the activity system for instance shoestring approaches or PhET simulations.

The activity system comprises a subject, the rules that guide the subject, the object, which refers to the intended outcome, the division of labour entailed in carrying out the activity and the community which includes all stakeholders in the activity system.

3.11 QUALITATIVE INQUIRY

As stated earlier, this study is a mixed-method study with the qualitative inquiry dominant. Morse (1991b) used a notation system to represent mixed-method design. In this study I used QUAL→quant, where the use of capitalisation indicates the prioritisation given to each form of data, and the symbol ‘ → ’ indicates sequential data collection.

Qualitative inquiry refers to ‘a broad approach’ that qualitative researchers adopt as a means to examine social circumstances (Liamputtong, 2019:9). Orb, Eisenhauer and Wynaden (2001:93) make a similar claim: ‘qualitative researchers focus their research on exploring, examining, and describing people and their natural environment’. It is the purpose of this research to examine, describe and document the Natural Sciences teachers’ lived experiences of contextualised interventions and their affordances for professional development. This was achieved by answering the research questions in section 3.2(b), i.e., one of the research questions asks ‘What are teachers’ experiences of using science-on-a-shoestring approaches in the classroom?’ Thus, a qualitative research approach was appropriate as it allowed the researcher greater insight into the teachers’ experiences which are shaped by social (Natural Sciences classrooms) and cultural attributes of teachers (Toloie-Eshlaghy, Chitsaz, Karimian & Charkhchi, 2011).

There are many traits that separate qualitative inquiry from the quantitative approach (Liamputtong, 2019:9; Henning et al., 2004). According to Henning et al. (2004) qualitative inquiry is more focused on understanding a phenomenon and for in-depth inquiry. In this study phenomena are centralised in the primary question: ‘What are Senior Phase Natural Sciences teachers’ lived experiences of participating in a longitudinal and systemic professional development intervention, aimed at addressing their specific professional development needs?’

Liamputtong's (2019) understanding of qualitative inquiry is based on the researcher being able to interpret the actions of the participants. The meanings and interpretations of the participants are the crux of qualitative inquiry: 'Qualitative researchers can be perceived as constructivists who attempt to find answers in the real world' (Liamputtong, 2019:10). This approach explains how and why things happen (Den Brok, Mainhar & Wubbels, 2018:42). In this instance, the science classrooms in this study form parts of the real world of Natural Sciences teachers and I want to find a deeper meaning on how and why things happen in a particular fashion.

Fundamentally, qualitative researchers look for meanings that people have constructed and this will be captured using different instruments that will be explained later in this chapter, such as VNOIK, VNOS instruments, etc. Qualitative research is valuable in many ways. It offers researchers the opportunity to hear silenced voices, to work with marginalised and vulnerable people, to address social justice issues (Liamputtong, 2019:9-10), i.e., in this study the researcher's hypothesis was influenced by the literature. Most teachers have insufficient pedagogical content knowledge, and struggle to contextualise the curriculum (most universities did not train teachers to integrate IK in a science classroom), while unavailable resources in the science classroom marginalise teaching and learning in many South Africa science classrooms (TIMSS, 2015; De Beer, 2016; Kriek & Grayson, 2009). The context of the study qualifies this type of approach, which is more concerned with opportunity for teachers to express their own perceptions or experiences within their own contexts (Creswell, 2013).

3.12 QUANTITATIVE INQUIRY

Den Brok, Mainhar and Wubbels (2018:42) report that the 'assessment of learning and research applications have involved a variety of quantitative and qualitative methods, and important accomplishments within the field have been the productive combination of quantitative and qualitative research method'. As mentioned earlier, the study is mixed-method with qualitative approach dominant, and in this section I am providing the qualitative side.

According to (Liamputtong, 2019:10) the word 'qualitative' derives from the Latin word 'qualitas', which pertains to 'a primary focus on the qualities, the features, of entities' (Erikson, 2018:36). In contrast, the word 'quantitative' is from the word 'quantitas', which relates to 'a primary focus on differences in amount' (Erikson, 2018:36).

The choice of methods in this study was driven by the research questions (Creswell, 2002). One of the questions that directed me to use qualitative approach was: 'How do teachers' views of their own self-directed learning change during the intervention?' The instrument used to collect the data is Cheng and the instrument in nature measures qualitative data. Another instrument used was RTOP (Reformed Teaching Observation Protocol) (Sawada et al., 2002). The instrument was used during classroom observations, when observing lessons. The former and the latter instruments entail Likert scales.

In questionnaires, groups of items are built on scales, and the scales can be classified. However, due to the small sample, descriptive statistical analysis was only done on the Cheng instrument. Qualitative methods are, for example, often needed to provide deeper and more detailed insights into the more general trends (Den Brok, Mainhar & Wubbels, 2018:42). This approach assisted me in both triangulating and informing the data from the qualitative and quantitative approaches.

3.13 QUALITATIVE CASE STUDIES

Merriam and Tisdell (2016:37) describe a case study as 'an in-depth description and analysis of a bounded system' – in this case, at least five teachers (selected from the 10 teachers who attended the workshops/SLP) – as 'bounded systems', or, in Cultural-Historical Activity Theory language, 'activity systems'. In each of these systems, the teachers' lived experiences of using PBL (to infuse IK in science curriculum), the Jigsaw method (cooperative learning), 'science-on-a-shoestring' approaches, PhET simulations, Bar-coding investigations at the African Centre for DNA barcoding, optics experiments, and managing personal well-being, were captured. From the captured data the researcher revised a profile for each of the 'bounded systems' as a Qualitative case.

Each case provided a narrative of the actual to the potential development of each ‘bounded system’ (or a teacher in this case) over a period of two years.

3.14 PHENOMENOLOGY

This research has a pseudo-phenomenological character, as elements of phenomenology guided the study, even though the study was not completely phenomenological in nature. Merriam and Tisdell (2016:26) describe phenomenology as ‘the way of access to the world as we experience it pre-reflectively … pre-reflective experience is the ordinary experience we live in’. Unlike ‘pure’ phenomenological studies, this study drew on pre-determined theoretical and conceptual frameworks (such as Cultural-Historical Activity Theory). Since the third generation CHAT as conceptualised by Engeström (1987) was used as research lens, and Vygotsky’s social constructivism as theoretical framework, this study cannot claim to be a pure phenomenological study. However, I will capture teachers’ lived experiences of the intervention.

3.15 DESIGN-BASED RESEARCH

Plano Clark and Badiee (2010) reiterate that to make a unique and a meaningful scholarly contribution, it is very crucial that the researcher creates new knowledge to fill the gaps in the current literature. This qualitative research also had a design-based (DBR) character. Plomp and Nieveen (2010:13) describes DBR as ‘... the systematic study of designing, developing and evaluating educational interventions as solutions for complex problems in educational practice, for which also aims at advancing our knowledge about the characteristics of these interventions and the processes of designing and developing them’. The nature of the interventions in this study was centralised in providing support to various challenges literature and teachers addressed. As part of a larger design-based research project, the interventions were built on design principles for professional development to improve the interventions. The design of the interventions was based on the zone of proximal teacher development as suggested by Warford (2011), thus providing scaffolding between the actual and potential development.

In my final chapter I distilled design principles that could guide a next cycle of workshops or short learning programmes as part of professional development within a community of practice.

I deemed this approach most applicable in my position to represent the textual data, using a design-based method (Spry, 2001; Jones, 2008). Therefore, I described the data and findings systematically as I experienced them, including the observations and responses of the participants. This study reports on two cycles; the latter 2018/ 2019 cycle building on the insights of previous interventions in the bigger generic project in the 2016/ 2017 cycle.

I followed an explicit method in a design-based approach using multiple sources of collecting data, such as observations, interviews and other artefacts and an implicit approach by aligning these to the existing literature and theory (White, 2011; Pretorius, 2015; Antonia, 2017). In addition to the definition above, the principles for professional development identified from literature and summarised by De Beer and Kriek (2019:4) guided DBR in this study in the following way:

1. *Focus on specific content*: identify certain pedagogies with specific content in the classroom;
2. *Ensure coherence by aligning curriculum and policies:* this is vital to align indigenous knowledge with the current curriculum to ensure indigenous knowledge can be incorporated in the classroom;
3. *Engage in active learning*: hands-on activities are done at the intervention;
4. *Activities need to be practised:* cooperative learning activities are done by teachers during the intervention;
5. *Intervention must be worthwhile with regard to intensity and contact time*: portfolio as assessment and classroom visits;
6. *Teachers are actively involved in their own learning and aided to become reflective practitioners*: evidence of self-directed learning and reflection should be evident in their portfolios;
7. *Teaching resources are available for teachers*: current curriculum learning materials are developed for the intervention;

8. *Teachers are exposed to inquiry-based learning experiences*: problem-based activities are designed and completed at the intervention;
9. *Teachers' needs must be well-thought-out when designing the intervention.*
10. *Transfer must be researched after the intervention*: improvement follows from each intervention conducted in each cycle;
11. *Collaboration with the Department of Basic Education;*
12. *Theoretical framework should be followed,* in this case a social-constructivist perspective.

3.16 ROLE OF THE RESEARCHER

Since the study is set in a mixed-method design both quantitative and qualitative data was collected. This approach suggests that the methodology is primarily qualitative with a lesser emphasis on the quantitative component of data collection (Creswell, 2013; Creswell et al., 2003). As a qualitative researcher, I acted as an 'insider' (emic) (Simon, 2011), engaging the teachers in the indigenous knowledge intervention (SLP). The heart of qualitative research lies in the extraction of meaning from data (Hesse-Biber & Leavy, 2011:151), i.e., the researcher interviewed and observed teachers to ensure that there is extraction of meaning from data, i.e., the social meaning people attribute to their experiences, circumstances and situations.

Hence, the research has an element of phenomenology which was aimed at capturing the lived experiences of the educators. Maree (2016:77) describes phenomenology as a study that focuses on the meaning that certain lived experiences hold for participants, that is 'to determine what an experience means for the persons who have had the experience and are able to provide a comprehensive description of it. From the individual descriptions, general or universal meanings are derived. To achieve this approach the researcher must set aside his personal biases. That is to bracket or suspend personal judgement' (Maree, 2016:77). From the quantitative approach I acted as a neutral person: to take matters as they are in a nutshell I remained objective in my approach.

3.17 VALIDITY AND RELIABILITY

Validity and reliability are crucial criteria in assessing the quality of a research study (Seale, 2004). All the instruments used in a research project were assessed for their reliability and their validity, and, as Engelhardt & Beichner (2004:102) stated, 'For the test to be useful and its results to be accurately applied and interpreted, it must be reliable and valid.' Reliability relates to the 'extent to which an instrument provides similar results every time it is administered to the same sample at different times' (Engelhardt & Beichner, 2004:102). Validity is the 'extent to which a test measures what it claims to measure'. These constructs refer to the quantitative instruments, such as the Cheng et al. (2010) SDLI instrument.

Even though the reliability and the validity of the instruments used in this study were determined by their developers, it was taken into consideration that the instruments might be used in this study in another context. Credibility refers to the importance of the accurate presentation of the research results – the results should be presented in the same context that the researcher investigated (Nieuwenhuis, 2007). In this study, construct validity was ensured by asking a panel of experts to peruse the questionnaires and interview protocols. Artefacts such as photographs were taken (Creswell, 2013:181), to provide visual evidence, which aids in the validity of this study.

The VNOIK questionnaire was adopted from Cronje (2015), since it was conceptualised for Life Sciences, and it was adapted for the Natural Sciences. The VNOIK instruments were given to supervisors of the study to validate the instruments for validity and reliability. All questionnaires were given to Natural Sciences lecturers in the University of North-West faculty of education (Potchefstroom campus) to further check the content and language.

I also obtained the inputs from the NWU Statistical Consultation Services. In addition to the statistical consultation expert view, the VNOIK questionnaire was also given to the research experts in the Self-Directed Learning Research Focus Area and Self-Directed Learning scientific committee for scrutiny.

To ensure optimum validity in this study, the researcher drew guidance from the four standards proposed by Eisenhart and Jurow (2011). The general standards are set in place for a research process that cut across all forms of educational research such as this one. The standards will fit as follows in this research:

Standard 1: A valid study must show alignment (or fit) between the research questions, data collection procedures and analysis techniques. All of the above subject matters have a chain-like relationship.

Standard 2: A research study cannot be valid without credible reasons for a specific choice of subjects, data-gathering procedures, and analysis techniques. The researcher made sure that the study is credible, e.g., during data collection the researcher guaranteed confidentiality, more especially when dealing with interview sessions with the participants.

Standard 3: For this argument to satisfy this standard, the assumptions and goals embedded in the development and conduct of the study must be exposed and considered. The research goals were made clear to the participant and the study leaders were aware of this goal. The researcher's assumption and biases were minimised by triangulating this study and doing member checking. This assisted the researcher in ensuring trustworthiness as described by Creswell (2007:207-210).

Triangulation and member checking were done as follows:

Triangulation: More than two methods were used to produce data. In this study data was produced using multiple methods such as observations (RTOP), interviews with Natural Sciences teachers (personal interviews and focus group interviews), artefacts (pictures, audios and videos), questionnaires, etc.

By doing this it was ensured that the researcher's bias will be reduced and that different methods of generating data yield similar results.

Member checking: The generated data was taken back to the participants in order for them to judge whether what was written, understood and captured accurately reflected their realities. This was done during the final interviews with the teachers (exit interviews).

Standard 4: Valid research studies must include a discussion of values that are important or useful to the study; and its risks. The researcher considered the participants (the A-Team teachers) as important to this study. Their value and contribution were explained in terms of the possibility this study holds in contributing positively towards their skills and knowledge, with a particular focus on their own teacher professional development.

The participants were made aware that the study did not put them in any risk (as clearly stated in the ethics application, as approved). From the beginning of the research and during all the interventions and workshops the teachers were always reminded of their value and contribution towards the value of the study. The value of the study towards the researcher's academic development was always made unambiguous. This study prides itself in a systemic and mutual development towards both parties, the ‘A team’ teachers and the researcher, but most especially towards meaningful learning for South African learners.

3.18 ETHICAL CONSIDERATIONS

According to Creswell (2013), ethical issues should be considered throughout the study, not only during the data collection stage. Generic ethical clearance has been obtained for the NRF-funded project (under which this specific study falls) on indigenous knowledge (certificate reference: NWU-00271-16-A2) (See Appendix A1). Ethical clearance for this study was also obtained from the Ethics Committee at the North-West (certificate reference: NWU-00473-18-S2)(See Appendix A2) , as I have used a few instruments that were not included in the earlier (generic) application. Also, my supervisors wanted me as a novice researcher to experience the process of applying for ethical clearance first-hand myself, therefore the second application. The guidelines and ethical procedures as captured in policy documents of the university were complied with.

Informed consent and confidentiality agreement forms were completed by all the participants (see appendix D1). These forms ensured confidentiality of the participants and they will remained anonymous (pseudonyms were used in the study). Permission was obtained from the principals of the schools and the participating teachers. The teachers had a choice whether or not to participate in this research. The participants were made aware that the completion of questionnaires, interviews and any related activities was not compulsory to be part of this professional development intervention, which functioned on the basis of volunteering.

Confidentiality was considered most important, especially during the interviews and when the questionnaires were analysed. The research participants had access to the final research study. There were direct benefits for teachers participating in this study, as they were offered the opportunity to invest in their own professional development through attending SLPs, and were also provided with resources for their classrooms – for instance, teachers received optics science kits (with prisms and laser lights), foldscope microscopes (the foldscope is the ultra-affordable paper microscope), posters and textbooks.

CHAPTER 4: DATA, DATA ANALYSIS AND MAJOR FINDINGS: THE EMERGING PICTURE

'In God we trust. All others must bring data.' – W. Edwards Deming, statistician, professor, author, lecturer, and consultant.

4.1 INTRODUCTION

4.1.1 The context of chapter 4

The preceding chapters provided a platform for this particular chapter. In chapter 1, a question is posed: Can the phoenix rise from the ashes? (De Beer, 2018). The phoenix metaphor in this context seeks to understand if the state of science education will improve in South Africa, and how. According to the researcher, the answer is probably threefold. To answer this question, the researcher explored Natural Sciences teachers' lived experience of contextualised interventions, its affordances for professional development, and teachers' self-directed learning. The researcher formulates the hypothesis that a systemic and longitudinal teacher professional development intervention holds affordances to assist the teachers with their own professional development needs in order to improve the status of science education in South Africa.

In chapter 2, the focus was on establishing an 'ontological database' on the issues mentioned in chapter 1. This assisted the researcher in the following ways:

- Providing an in-depth understanding of South African learner performance and science teacher education.
- Fostering a nuanced understanding of South African schools and the history of schooling in the country.
- Understanding the South Africa curriculum and curriculum changes over the years.
- Reviewing the South African education system and benchmarking it with a few of the international communities who are performing well in science education.

This was done in an attempt to understand the ontology (what and how), and how different factors impact both teacher education and the country's dismal science performance.

In chapter 3, the researcher introduced and discussed the methodology to probe into the lived experiences of the teachers participating in a longitudinal professional development intervention, aimed at addressing the teachers' specific professional development needs. In this mixed-method research, the qualitative inquiry is dominant, as described in chapter 3. The qualitative data was collected through the focus group interview, individual exit interviews using the stimulated video recall method, pre- and post-classroom observations using the Reformed Teaching Observation Protocol (RTOP), pre- and post-intervention VNOS questionnaires, pre- and post-intervention VNOIK questionnaires, pre- and post-intervention generic questionnaires on Jigsaw and science-on-a-shoestring intervention, a professional development needs questionnaire, pre- and post-African Centre for DNA Barcoding intervention questionnaire, stress management questionnaire, and teacher portfolios emanating from the two-days short learning programme (SLP). The quantitative data comprised the pre- and post-intervention self-directed learning instrument (SDLI) developed and validated by Cheng, Kuo, Lin and Lee-Hsieh (2010) and post-needs analysis questionnaire. The data collected by instruments mentioned in chapter 3 is analysed in chapter 4.

In chapter 4, the researcher used an inquiry approach to record the teachers' lived experiences of contextualised interventions and the affordances for their professional development and self-directed learning. In order to achieve the latter, the researcher profiled the A-Team teachers. The profiling provides a perspective on how scaffolding of teachers' learning across the zone of proximal teacher development (ZPTD) leads to teacher professional development. This was made possible by plotting the teachers' progress on an adapted Rogan and Grayson Profile of Implementation. This Rogan and Grayson (2004b:159) profile of implementation is adapted in Knowles and Chen et al. (2010), where SDL becomes a new domain added in the revised profile of implementation.

This also serves as one of the contributions of this study, as the researcher agrees with Louws et al. (2017) that teachers should take ownership of their own learning, and that personal autonomy should be promoted in teacher professional development programmes. The researcher used cultural-historical activity theory as a research lens to analyse the tensions in the activity system and the contraction of control. An autoethnographic reflection by the researcher is also used to further understand the journey of two years of a tailored teacher professional development programme, and to further understand and enrich the research findings. The researcher presents the teacher's profiles as follows.

4.1.2 Teacher profile (generic)

In this chapter, I provide the structure that was used in profiling each of the six teachers. The researcher plotted individual teachers' growth movement by utilising the adapted Rogan and Grayson Profile of Implementation (see Table 4.2). In Table 4.2, I provide a rubric that informs the reader how the profile of implementation was conceptualised and which criteria were used. The rubric consists of a scale of zero (0) to four (4). Zero represents non-compliance and four highly compliant. The scale of compliance increases in the ascending order. In Table 4.3 I provide the reader with information on how the progress during a longitudinal and systemic teacher development programme was mapped and recorded using the revised Rogan and Grayson's (2003) heuristic. The pre- and post-intervention data informed this measurement of growth. I recorded professional development in terms of five domains, namely: classroom interaction; science practical work; science and society; assessment; and self-directed learning (SDL), a new domain added. The researcher will show how the revised Rogan and Grayson heuristic has the potential to assist many facilitators in structuring teacher professional development interventions more effectively by mainstreaming self-directed learning. It is imperative to take note that the profile of implementation traditionally only covers the first four domains; and that SDL is a suggested addition, as the researcher is of the opinion that SDL should be a *sine qua non* of all professional development interventions. Teachers should be treated as professionals, with a sense of personal autonomy in their learning (Louws et al., 2017), and this should be reflected in teacher professional development programmes.

The SDL domain in the revised Rogan and Grayson profile of implementation was informed by both a qualitative and a quantitative description. Mentz and De Beer (n.d.) state that quantitative approaches dominate self-directed learning research. Several quantitative instruments were developed, for example, the self-directed learning readiness scale (SDLRS) of Guglielmino (1977), the Williamson (2007) self-rating scale of self-directed learning (SRSSDL), and the self-directed learning instrument (SDLI) of Cheng et al. (2010). The latter SDLI was used in this study. However, Mentz and De Beer (2019) advocate for the use of mixed methods approaches in self-directed learning research, as the quantitative instruments alone often do not provide a 'thick description' of self-directed learning.

For this reason, I suggest two layers in the SDL domain in the revised profile of implementation, namely a qualitative description of the levels (to be aligned with the qualitative nature of the instrument), as well as a quantitative description based on the Cheng instrument. For the qualitative description, the SDL definition of Knowles was used to inform how the rubric will be used, as can be seen in Table 4.2. The qualitative data, gathered during personal interviews, mostly informed the depiction of a level, although other data sources such as lesson observations and artefacts also informed the outcome. Lesson observations were also used to observe if the teachers instilled SDL qualities in their learners.

The SDLI of the Cheng et al. (2010) instrument was used quantitatively to evaluate teachers' views of their self-directed learning in terms of the four strands, namely, learning motivation, planning and implementing, self-monitoring and interpersonal communication, see Table 4.1(a) below.

Table 4.1(a): Quantitative SDL heuristic used to evaluate teachers' view on SDL

PRE SDL VIEWS			
Sub-domain in the profile of implementation	Questions	Score of Teacher Y	Score of Teacher Y reported in percentage (%).
Learning motivation	Q 1-6	XX/ 30	XX
Planning and implementing	Q 7-12	XX/ 30	XX
Self-monitoring	Q 13-16	XX/ 20	XX
Interpersonal communication	Q 17-20	XX/ 20	XX
TOTAL		/100	XX

The SDL instrument is calculated out of a score of 100. The score is further divided in terms of non-compliance to compliance, as in Table 4.1(b) below. The scores are then mapped into the revised Rogan and Grayson (2003) profile of implementation in Table 4.2, with level 0 implying a score from 0 to 24 on the Cheng SDLI instrument; characterising a teacher whose views are strongly disagreeing with SDL. In contrast, level four (4) implies a score from 90 to 100 on the SDLI and characterises a teacher who strongly shares the views of a self-directed learner.

Table 4.1(b): Scale used to map teachers' professional development in terms of SDL

Non-compliance to Compliance	0	1	2	3	4
Score	0-24	25-49	50-74	75-89	90-100

Both the qualitative and quantitative descriptions were juxtaposed in the revised profile of implementation. A researcher can opt to either give a qualitative indication of SDL, or a quantitative measure, or both. Mentz and De Beer (2019) advocate for the use of Cultural-Historical Activity Theory as a lens in SDL mixed methods research. These authors state that CHAT could provide insight into dichotomous data, and explain possible differences between the quantitative and qualitative data. Later on, in the profiles, I highlight such dichotomous data, and will illustrate how CHAT could provide insight into this. Below see the rubric and the structure of how the A-Team teachers were profiled. The rubric in Table 4.2 was used to map teachers SDL post-intervention.

Aside from mapping the teachers' professional development in terms of revised Rogan and Grayson profile, the researcher also considered teachers' holistic wellbeing as this was a joint professional development need of the teachers involved in the intervention. The teachers' professional development needs are highlighted in this chapter.

Tabl Table 4.2. Profile of implementation of science teachers

#Level	Classroom interaction	Science practical work	Science in society	Assessment	Teachers' Self Directed Learning**	
					Qualitative analysis	Quantitative analysis from SDL instrument of Cheng et al. (2010)
0*	Teacher presents transmission-type lesson in an unstructured way and reads mostly from the textbook. Limited and ineffective media usage. Learners passive and not engaged.	Practical work is seldom done. Teacher uses limited and not well-planned demonstrations to assist in the explanation of concepts.	Teacher seldom uses examples from the learners' daily lives, and if used these are incoherent.	Written tests on lower cognitive levels. Tests marked and handed out to learners.	There is no evidence of SDL; the teacher does not show interest in ongoing professional activities.	0-24
1	Teacher presents organised lessons. Uses textbook effectively. Learners are engaged and respond to questions.	Teacher uses classroom demonstrations to help develop concepts.	Teacher uses examples from everyday life to illustrate scientific concepts.	Written tests are given. Most questions of recall type. Most tests marked and returned promptly.	There is minimal evidence of SDL; the teacher indicates that he/she has professional development needs, but there are no concrete learning goals identified.	25-49
2	Textbook used along	Teacher uses demonstrations	Teacher bases	Written tests include 50%	The teacher formulated	50-74

	with other resources. Engages learners with questions that encourage deeper thinking and meaningful group work.	to promote a limited form of inquiry. Learners participate in 'cook book' practical work.	lessons on specific problems faced by community.	higher cognitive level questions.	learning goals, but there is limited evidence that learning resources or learning strategies were identified.	
3	Teacher structures learning along 'best practice' lines. Learners engage in minds-on learning activities.	Practical work to encourage learner discovery of information.	Learners actively investigate the application of science & technology in their own environment.	Written tests include 'guided discovery'-type activities. Assessment includes other forms such as reports.	There is clear evidence of SDL: learning goals, resources and applicable strategies were identified by the teacher. However, there is no evidence of evaluating the learning actions, or critical reflection.	75-89
4	Learners take major responsibility for own learning and undertake long-term investigations and projects.	Learners design and do open investigations.	Learners actively undertake a project in their local community and explore long-term effects of community projects.	Open investigations and community-based projects included in final assessment.	Strong evidence that the teacher is a self-directed learner, i.e., the teacher can define his or her own goals, goals related to a central need, able	90-100

	Teacher facilitates learning.			Learners create portfolios.	to set a path to achieve the goal, the goal is realistic (not too high or too low), but enough to be challenging, and the teacher evaluates whether the learning goals were achieved. The teacher promotes SDL in his/her classroom.	

Source: Rogan (2004b:159); taken from Petersen & De Beer, 2016:281-282 and revised by Sebotsa, De Beer & Kriek, 2019. The latter authors suggest a stronger focus on Self-Directed Learning.

** Addition to the original Rogan (2004b:159) Profile of Implementation by Petersen (2011:246).*

*** Contribution of this dissertation to the original Profile of Implementation. (This has been published in the 2019 IISES Proceedings: refer to Sebotsa, De Beer & Kriek, 2019).*

Table 4.3(a): A heuristic to map teachers' progress during a longitudinal and systemic teacher development programme using the revised Rogan and Grayson's (2003) rubric. The SDL domain is the researchers' contribution.																									
PRE- (X) AND POST (0) INTERVENTION PROFILING HEURISTIC																									
	Classroom interaction					Practical work					Science and society					Assessment					Self-directed learning				
PARTICIPANT(S) IN TPD	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
TEACHER		X 0																							

4.1.3 The structure of the profile of the teachers based on two-year progress

Table 4.3(b): A description of the pre- and post-intervention findings are described as follows in chapter 4.

Profile: TEACHER A

5. Personal profile (biography)

5.1. School and classroom

6. Pre-intervention data

6.1. Pedagogical orientation

6.1.1. Lesson observation, using the Reformed Teaching Observation Protocol (RTOP) instrument

6.1.2. Personal interview

6.1.3. Teaching and learning (Lesson plan); analysis of lesson plan

6.1.4. Content knowledge on optics

6.2. Teacher's A's views on practical (laboratory) work, inquiry learning, & the nature of science

6.2.1. Inquiry learning in Teacher A's classroom

6.2.2. UJ-DNA Barcoding (pre-questionnaire) and focus group interview

6.2.3. Views on the nature of science

6.3. Views of science and society

6.3.1. Portraying the role of science in society during lessons: evidence from the lesson observations using RTOP, lesson plan and interviews

6.3.2. Views on the nature of indigenous knowledge (VNOIK)

2.4. **Views on assessment/ Assessment practices**

2.5. Teacher's self-directed learning

a) **Qualitative analysis of SDL** emerging from interviews, RTOP (to observe if teacher instils SDL skills into the learners), professional development, Teacher professional development needs questionnaire)

b) **Quantitative analysis of Teacher A's SDL, utilising the SDLI instrument**

2.6. **Teacher's holistic wellbeing**

(a) Wellbeing

(b)Professional development need(s)

2.6.1. Teacher’s wellbeing and stress management

2.6.2. Teacher’s Professional Development Needs

7. Post-intervention Data

7.1. Pedagogical orientation

7.1.1. Lesson observations using the Reformed Teaching Observation Protocol (RTOP) instrument

7.1.2. Teaching and learning (Lesson plan); analysis of lesson plan

7.1.3. Exit interview + Discussing the recorded lesson using stimulated video recall

7.1.4. Content knowledge on optics

7.1.5. Portfolio

7.2. Teacher A's views on practical (laboratory) work, inquiry learning and the nature of science

7.2.1. Inquiry learning in Teacher A’s classroom (i.e., using PhET simulations, optics kit or science on a shoestring)

7.2.2. UJ-DNA Barcoding (Post-questionnaire and focus group interview)

7.2.3. Teacher's views on the nature of science

7.3. Views of science and society

7.3.1. Portraying the role of science in society during lessons: evidence from the lesson observations using RTOP, lesson plan and interviews 7.3.2. Views on the nature of indigenous knowledge **7.4. Views on assessment/ Assessment practices** 7.4.1. Reformed Teaching Observation Protocol (RTOP) and lesson plan 7.4.2. SLP Portfolio **7.5. Teacher's self-directed learning (SDL)** a) **Qualitative analysis of SDL** emerging from interviews, RTOP (to observe if teacher instils SDL skills into the learners), professional development, Teacher professional development needs questionnaire) b) **Quantitative analysis of Teacher A's SDL, utilising the SDLI instrument** 7.6. **Teacher's holistic wellbeing** (a)Wellbeing (b)Professional development needs 8. Synthesis: Using Rogan (2004b:159) profile of implementation to assess teacher professional growth, and plotting their learning/development

4.2 PROFILE OF TEACHER A

4.2.1 Personal profile (biography) of Teacher A

Teacher A holds a BEd degree in Natural Sciences from the North-West University. Through the platforms provided in the A-Team professional development programme she applied for a BEd Honours degree in Natural Sciences for the 2020 intake, and at this stage of reporting she was accepted into the BEd Honours programme, and busy with postgraduate studies. In the pre-intervention personal interview, Teacher A mentioned that she had two years' experience of teaching Natural Sciences grade 7-9. Teacher A is a novice teacher who is under the age of 30. Her teaching philosophy is to be a lifelong learner who inspires South African learners.

4.2.2 School and classroom

The school resembles a typical township school in terms of demographics, consisting of 100% black learners, mostly from low-income families. The traditional class taught by Teacher A has 40-60 learners. The lessons observed were of a class consisting of 58 learners, with boys dominating in numbers. The ratio of boys to girls was approximately 2:1. According to a Natural Sciences questionnaire, Teacher A mentioned that she teaches in an under-resourced township school without resources such as a data projector, laboratory consumables and microscopes, and with no access to library services.

According to Teacher A, the existing laboratory is only utilised by the grade 12s. The researcher can confirm this based on observations during lesson observations (where the RTOP instrument was used). The classroom does not inspire inquiry minds and is dull, and none of the many posters that the teacher received at the first meeting of the A-Team intervention were displayed in the classroom. (Thanks to generous funding from the Fuchs Foundation, teachers were provided with resources, and it was disconcerting to see that these resources are not used.) The teacher did not succeed in creating an inviting learning space for the learners; nothing reminded the learners that, when they entered the Natural Sciences classroom, they were entering a 'different epistemological space' of investigating and solving problems scientifically. The school has a less equipped laboratory, and no access to internet facilities to assist the learners in engaging in and with 21st-century skills such as using technologies to solve Natural Sciences related problems.

4.2.3 Pre-intervention data: Teacher A

4.2.3.1 Pedagogical orientation of Teacher A

Teacher A had a teaching and learning philosophy prior to the intervention that is shared by so many teachers, namely that the best way of preparing learners for the examination, is through a lecturing-style approach. She was very dependent on the prescribed textbook during all observations and typical learner engagement in teacher-centred lessons. The answering of questions from the learners was in a ‘chorus’ format. The teacher's pedagogical orientation (of transmission-mode teaching and learning) is further demonstrated by the predominant culture of writing the notes on the chalkboard followed by question and answers, and a homework assignment focusing on lower levels in Bloom's taxonomy.

(a) Lesson observation using Reformed Teaching Observation Protocol (RTOP) instrument

(Refer to appendix G2 for the RTOP instrument, for the lesson observed prior to the intervention.) The teacher used transmission mode as a dominant teaching strategy, assuming learners as ‘tabula rasa’. The teacher asked questions and only about 15 learners were pseudo-involved in responding to the (lower-order) questions, refer to appendix G3. Other learners seemed tired, disengaged, or did not seem to understand. No inquiry activities emerged during the lesson observation. The learners did a class activity out of 12 marks consisting of questions predominantly on lower cognition level in Bloom's taxonomy (refer to classroom artefacts in the appendix G3).

(b) Pre-intervention interview with Teacher A

In an interview Teacher A mentioned that science is made to be boring and theorised; below the researcher provides snippets of the interview.

Teacher A: *‘Science is boring to the learners, and it is also boring to the teachers because it is only theory and we are repeating the same thing day in day out. It is never exciting because the learners are not excited.’* Through this view and the classroom observation, the researcher can conclude that the teacher finds science boring because it is not contextualised and related to the everyday life of learners. This response is further surprising, as one would think that she would attempt to address the affective domain in her teaching, and capture learners' interest by showing them what role science plays in society and inspiring inquisitive minds – this was a specific focus of the A-Team professional development intervention. There is, therefore, a lack of agency displayed by Teacher A, and to a large extent the teacher assumes science as being static and Eurocentric in nature, but she does not seem to realise that she can ‘decolonise’ the curriculum, through contextualisation for diverse learners.

(c) Teaching and learning (lesson plan); analysis of lesson plan

No formal lesson plan was presented during the lesson observation. The teacher had notes on a sheet of paper and a textbook to guide the lesson. Despite the lack of a formal lesson plan, the lesson was relatively semi-structured. For example, the teacher did not start the lesson by breaking down its objectives to the learners or at least sensitising the learners to the goals of the lesson. During the invitation stage of the lesson, the teacher introduced the lesson by asking the learners where animals receive their food. The learners' prior knowledge was activated through a short discussion, and the teacher centre-staged the topic by explaining how energy is converted from one form to another. The body of the lesson consisted of transmission-mode approaches (no learner-centred pedagogies were used). In terms of assessment, only a class activity was provided and no homework provided to the learners. In the closing stage of the lesson, no reflection or summary of the lesson was provided to the learners (this could be because the class ended before the teacher could arrive at that stage). I am of the view if a formal lesson plan was designed, teacher A could have most probably reached greater mileage in terms of covering content knowledge, could have used a more nuanced and appropriate teaching strategy and also could have used time more efficiently.

(d) Content knowledge on optics

Teacher A, before intervention on the optics section of the CAPS curriculum, scored 2/35 (6%) in a visible light test, which indicates that she had an under-developed content knowledge. This raises a similar concern to that of Venkat and Spaull (2015) that many South African science teachers have content knowledge below the grade taught. In the researcher's view, this is one of the main reasons why South African learners perform below standard in international tests such as TIMSS. This concern also speaks to the bigger picture of learners not being capacitated with the envisioned curriculum skill capital, which can also result in poor human development, particularly in science-related jobs.

4.2.3.2 Teacher A's views on practical (laboratory) work, inquiry learning, and the nature of science

(a) Inquiry learning in Teacher A's classroom

During the observed lessons, the teacher did not engage learners in inquiry learning. Learners were mostly passive during teacher-centred classroom activities. They were not afforded an opportunity to engage in the nature of science and to develop their science process skills such as interpreting data, making careful observations, constructing an argument, measuring, problem-solving and critical thinking, recording and communicating information – all of which might have dire consequences for them when transcending to the further education and training (FET) band. This view, according to the researcher, is problematic and concerning. Not engaging learners in inquiry activities can have severe consequences, such as making science unappealing to the learners.

This could be a reason why learners see science as boring, difficult and not exciting, and also explain why the sciences learners in FET are fewer in most cases as compared to other streams such as commerce and history-related subjects.

(b) Teacher A's responses in the UJ-DNA Barcoding questionnaire and Focus-group interview, prior to the DNA Barcoding intervention

Prior to the intervention of two days, where teachers engaged in DNA Barcoding at the University of Johannesburg, teachers were asked to complete a questionnaire (Refer to appendix M1). In the questionnaire, the teacher reflected that she is 2 out of 5 confident in handling laboratory equipment. She also indicated the following sentiments, '*I do not have a laboratory to use at school. The last time I was in a laboratory, it was when I was at university.'* When the teacher was asked how often she does practical work in terms of laboratory investigations with her learners her response was as follows: '*I hardly do practical work with my learners because I do not have a laboratory to use.'* This indicates that most of her learners do not benefit from the affordances of practical work and that they do not optimally develop skills that enable them to investigate or develop basic science process skills such as observations, communication skills, classification, inference of information from data or making predictions. This malpractice could perpetuate reasons why most of the students do not develop work-related skills required by most employers and in the 21st century world, for instance, critical thinking and analysing, to mention but two. Teacher A highlighted in the pre-questionnaire that she wants to learn more about DNA barcoding and how to use laboratory equipment. She was asked what her understanding of DNA Barcoding is, and her response was '*I do not know much, but I think it is the sequence of genes (how genes are arranged)*'. Again (like in the previous section on her knowledge of optics), Teacher A shows under-developed content knowledge. This could highlight the reasons why teachers should be engaged more often in science laboratories and be assisted with content knowledge.

When the teacher was asked what she understands of polymerase chain reaction (PCR), her response was '*I have no idea*'. When the teacher was further asked how she as a teacher can make the study of DNA relevant and interesting to learners, the teacher's response was '*conduct investigations with the learners*'. The responses of Teacher A indicated that the teacher was not confident in doing investigations with the learners due to lack of resources in her school, and a lack of agency to improvise. A reason why she engages in transmission-mode teaching might be due to the lack of confidence in handling laboratory equipment, as well as her under-developed content knowledge.

From her insights, one can conclude that the teacher has inadequate DNA content knowledge, and this requires attention. What is promising is that the teacher identified a need to learn about DNA and to learn more of investigations in order to provide her learners with more nuanced understandings of the nature of science.

(c) Teacher A's views of the nature of science

Teacher A has a partly informed view of the nature of science (VNOS). (Refer to appendix I2 for the completed VNOS questionnaire). For instance, in the VNOS questionnaire, the teacher was asked what an atom looks like, how certain scientists are of the nature of the atom, and what specific evidence she thinks scientists use to determine what an atom looks like. The response of Teacher A was 'The scientist uses models to explain how atoms look like'. This narrative is uniformed (UI) as it does not address how an atom looks like: for instance, she could have explained the atom in terms of being the smallest constituent unit of ordinary matter that constitutes a chemical element. Every atom is composed of a nucleus and one or more electrons are bound to the nucleus. The nucleus is made of one or more protons and a number of neutrons. This is required from a teacher to be able to pictorially or verbally provide insights to the learners on the structure of an atom. This view further fails to describe how scientists come to an understanding of the nature of an atom. The teacher from her response seems not to understand what an atom looks like. However, she uses popular jargon, such as 'uses models to explain how atoms look like'. The response failed to provide a timeline on the development of an atom, for instance, mention how John Dalton argued an atom to be and how the theory developed over the years by scientists such as Thomson, Ernest Rutherford, de Broglie, etc. in the build-up to how an atom is perceived today. This uninformed view might provide challenges for her in explaining holistically the basic science and the make-up of biotic and abiotic factors which are constructs in the senior phase curriculum.

Teacher A could not provide any answers which demonstrate an understanding of the tenets (nature) of science. For instance, the teacher was asked two Natural Sciences-related questions in the VNOS questionnaire. The questions were asked as follows: (a) some astronomers believe that the universe is expanding while others believe that it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data? And (b) the teacher was also asked a question about the differences and similarities between science and the arts. The teacher did not respond to the questions, or indicate if she had a nuanced understanding of the tenets of science, such as science is tentative (and subject to change), inferential, creative, etc.

4.2.3.3 Teacher A's views on Science and Society

(a) Portraying the role of science in society during lessons: evidence from the lesson observations using RTOP, lesson plan and interviews

During the class observation (Refer to appendix G2), I noticed that the teacher does not contextualise the lesson and does not address the learners' affective domain. The lesson was structured from textbook activities, and no effort was made to use other creative forms to provide a context for the learners. During the interview, the researcher probed to understand why Teacher A says science is boring. The response from the teacher was that science '*is boring to the learners and it is also boring to the teachers because it is only theory and we repeating the same thing day in day out. It is never exciting because the learners are not excited.*' This narrative is very alarming as I realised even during the classroom observations that the teacher does not emphasise the importance of science in the society in her classroom or in her activities. The learners might be bored because science and society have been separated; it is not made possible for them to link science to their realities or lived experiences. From my observation as a researcher, I could draw conclusions on what might be the reasons why Teacher A found it difficult to contextualise lessons. One of the reasons is that even though Teacher A understands the content of the textbook, she hardly uses her own narratives to connect science to society; she predominantly depends on the textbook and the curriculum plan is regarded as fixed. Science is portrayed as being in a silo far removed from the learners' everyday experiences.

(b) Teacher A's view on the nature of indigenous knowledge

Teacher A's understanding of indigenous knowledge is *'the deep knowledge and skills unique to a particular indigenous culture. This knowledge is passed on from one generation to another. It includes medical practices, production of food etc.'* This view demonstrates that the teacher has an understanding of indigenous knowledge. When

Teacher A was asked if practitioners of indigenous knowledge do experiments and tests to verify or validate IK, her response showed an informed understanding of indigenous knowledge. For instance, her response was '*yes, indigenous knowledge is based on human experiences. The practitioners of indigenous knowledge tried different methods which were replaced with other methods if they were unsuccessful. This was continued till success. If a method was not working, they tried a different method.*' She also understood that the Khoi-San used *Hoodia gordonii* as an appetite suppressant. The only aspect in which Teacher A showed a uniformed view was that she believed that indigenous knowledge stays the same, not recognising that it is a dynamic knowledge base that evolves. The data obtained from the pre-intervention VNOIK questionnaire suggests that Teacher A has a partially informed understanding of the tenets of indigenous knowledge (IK), and only needs pragmatic and professional development to facilitate such epistemological border-crossing in the science classroom. During classroom observations, there was no evidence of the integration of elements of indigenous knowledge or emphasis thereof in lessons. Even though the teacher had a partially informed view of indigenous knowledge, she struggled to include indigenous knowledge in the Natural Sciences curriculum. One of the many reasons for this is that Teacher A in her undergraduate qualification was not taught and assisted on how to integrate indigenous knowledge into the science curriculum (from the interview data); regardless of the fact that indigenous knowledge forms part of the curriculum. Le Grange (2019) refers to Aoki's (1999) use of the *curriculum-as-plan* and the *curriculum-as-lived*. Whereas indigenous knowledge is mentioned in the *curriculum-as-plan*, research shows that it often does not happen in the *curriculum-as-lived*. My interpretation is that Teacher A has an understanding of the role of indigenous knowledge in science, but struggles with the border crossing of the two knowledge systems. Hence the teacher could define indigenous knowledge in the questionnaire but could not integrate or use the tenets thereof to contextualise her lessons or sensitise the learners to the relevance of indigenous knowledge in the Natural Sciences. A partially informed view of indigenous knowledge did not necessarily imply application or transfer in Teachers A's classroom.

4.2.3.4 Teacher A's views on assessment/ assessment practices

The data shows that Teacher A 'teaches to the test', and that she does not engage in innovative assessment practices. Furthermore, her assessment only covers lower levels in Bloom's taxonomy, such as ‘knowledge’. During the classroom observations, her assessment, for example, provided learners with one multiple choice question on what the purpose of the food chain is. This was followed with a question on matching column A with B (matching descriptions of omnivores, insectivores, consumers and producers allocated a mark each). In question 3 the learners were provided with a case study involving a zebra, grass and lions, and were required to write down the information as a food chain, and that was followed with a question that required the learners to label the producer and consumers. In question 4, a follow-up question required the learners to answer what would happen when the zebra (in the context of question 3) died, and the question was assessed out of 2 marks.

From the observation assessment did not provide experience for the learners that will result in expected cognitive development objectives on age and grade level. As mentioned, only classwork on a lower cognitive level was given to the learners, without provision of homework. Lower-order cognitive questions are insufficient to provide learners with problem-solving and critical thinking skills, which are abilities required for the 21st-century and should be nurtured and emphasised on a grade and age level. According to CAPS, the assessment must be structured carefully to cover the content knowledge as well as science process skills. From the classroom observation and assessment provided to the learners, the sciences process skills did not become a focus in the assessment. The teacher asked questions and wrote the solutions on the board as the learners answered. The teacher's content knowledge of energy change is above par, and she is well articulated in the language of instruction. She could have used her skill to perhaps engage learners in dialogue and assessed their ability to respond to challenging questions. Very little attention was given to testing if learners were able to solve real-life problems or to offer a variety of solutions to problems regarding the given topic. This would have allowed the learners to engage as critical thinkers and critical reflectors.

4.2.3.5 Teacher A and Self-Directed Learning (SDL)

(a) Qualitative analysis of SDL

In terms of the revised Rogan and Grayson (2003) profile of implementation Teacher A is mapped at level 1. From the pre-intervention data, Teacher A does not indicate the agency to improve her teaching strategy, ‘chalk-and-talk’, during the observed lesson and interviews. For instance, the teacher is aware of structural challenges in her school, such as lack of resources. Based on those challenges, the teacher seldom fosters inquiry-based learning. The researcher's findings are that Teacher A struggled to improvise by using shoestring science approaches to facilitate inquiry-based learning. From the observed lesson, the teacher did not inspire learners to be self-directed in their learning, and this could be that the teacher at this stage has a naive understanding of SDL (Bailey, 2016 and Bosch, 2017).

That Teacher A voluntarily became a member of the A-Team professional development programme is regarded as the minimal indication of interest in her own professional development. The decision requires the teacher to be a self-directed learner and be able to identify her own professional development need(s). At this stage of reporting of the pre-intervention data, the teacher did not have any concrete learning goals identified. There is minimal evidence of SDL; the teacher indicates that she has professional development needs, but there are no concrete learning goals identified yet.

(b) Quantitative analysis of Teacher A's SDL, utilising the SDLI instrument

Teacher A completed an SDL questionnaire (Refer to appendix L2) in order to determine her views on her own self-directed learning skills. Teacher A scored 77 out of 100 in terms of the SDL instrument. In Table 4.4, her SDL is indicated in terms of the sub-four domains, as indicated in the Table below.

Table 4.4: SDL of Teacher A

Sub-domain in the profile of implementation	Questions	Score of Teacher A	Score of Teacher A reported as percentage (%)
Learning motivation	Q 1-6	26 / 30	86.66
Planning and implementing	Q 7-12	20 / 30	66.67
Self-monitoring	Q 13-16	14 / 20	70.00
Interpersonal communication	Q 17-20	17/ 20	85.00
TOTAL:		77/100	

This places her on level 3 (in contrast to the qualitative analysis, which suggests a level 1). Mentz and De Beer (2019) show that such a discrepancy often occurs between quantitative and qualitative SDL data. Very often, participants have naive understandings of SDL when they start to engage in the intervention. Teacher A's views align strongly with her being motivated to learn. In Table 4.4, she scored 26/30 in terms of learning motivation, which is reported as 87% learner motivation. Teacher A's response from the questionnaire showed a strong agreement in the following categories: she strongly hopes to be constantly improving and excelling in her learning. She also emphasised a strong sentiment that her successes and failures inspire her to continue learning. She also enjoys finding answers to questions. This narrative indicates that the teacher enjoys being self-directed in her learning. Teacher A furthermore indicated in the questionnaire that she knows which learning strategies are appropriate for her in reaching her learning goals. This indicates that the teacher feels strongly about being a life-long learner (which resonates with her teaching philosophy). In addition, she believes her interaction with others helps her plan for further learning. This is translated into efforts made by the teacher to attend almost all the interventions. She also applied for postgraduate studies.

It should also be emphasised that even though Teacher A is motivated to learn, she scored the lowest score in planning and implementation in terms of the four sub-domains. The Teacher scored the lowest score of 20/30 in the questionnaire amongst the other sub-domains. Even though the teacher scored herself 66%, she indicated she is not good in arranging and controlling her learning time, in this category she rated herself one (1), which is the lowest score in terms of lack of skill. This was evident in a lesson which she could not finish and reflect on. This response creates the expectation that she would probably embrace some of the challenges and successes in the pre-intervention and be able to correct some of the challenges after the intervention, and illustrate transformed teaching.

4.2.3.6 Teacher A's holistic wellbeing

(a) Wellbeing of Teacher A

Teacher A indicated that she has to cope with tight deadlines (pacesetters) that cause stress, and she needs to learn more about techniques of dealing with stress. When teacher A was interviewed, she mentioned that her job is stressful and that she sometimes struggles to cope with all the demands facing her.

(b) Professional development needs of Teacher A

Teacher A indicated that she needed to be assisted with the following curriculum topics: electricity grade 8, chemistry, and strategies to teach overcrowded classrooms (Refer to appendix N2). Since the intervention was designed to address the teacher‘s needs, some of Teacher A's professional development needs were addressed during the intervention and will be reported in the post-intervention section.

4.2.4 Post-intervention Data – Teacher A

Teacher A actively participated in most of the intervention activities. The only intervention she did not participate in was the short learning programme on indigenous knowledge organised by North-West University. I will now reflect on the post-intervention data in this section. Below we will follow a similar structure in terms of data obtained in terms of (a) classroom interaction (pedagogical orientation), science practical work (and nature of science), (c) science and society, and indigenous knowledge, (d) assessment, (e) self-directed learning (SDL), and (f) teacher’s wellbeing and teacher’s professional development.

4.2.4.1 Pedagogical orientation of Teacher A

Teacher A has a definite ‘active direct’ teaching pedagogical orientation (Ramnarain and Schuster, 2014). The teacher's pedagogical orientation did not change after the intervention. The teacher still used transmission mode as a dominant teaching strategy, which sees learners as *tabula rasa*. The teacher is still very dependent on the textbook and lecture style. Unfortunately, the teacher continued engaging the learners mostly in a teacher-centred approach that did not engage learners with the nature of science. The impact of the DNA barcoding work did not seem to have much of an effect in terms of being sensitive to centre-stage the , scientific method in the classroom. Despite being exposed to suitable teaching methodologies such as the Jigsaw method during the intervention, the teacher continued with transmission-mode approaches. For instance, writing notes and solutions on the board showed a 'parrot-like' teaching, which required learners to respond in a 'choir-like' approach.

(a) Lesson observation using Reformed Teaching Observation Protocol (RTOP) instrument

The teacher started the lesson by determining background knowledge on visible light and asked learners, 'Why do we see a rainbow?' The lesson was unfortunately still teacher-centred, despite an intervention on optics in which she participated as part of the research, with little learner interaction (Refer to appendix G4). However, learners are sitting in lecture-style format (rows; cinema style), making it difficult to do cooperative learning. Unfortunately, there was no evidence of either problem-based or project-based learning. The lesson observed was based on visible light (the same topic the teachers were assisted with during one of many interventions). What was observed with Teacher A was the 'wash-out' effect (Zeichner & Tabachnick, 1981), when teachers return to their predominant (prior) strategies in the 'coalface of the classroom'. Even though Teacher A was provided with a 'cognitive apprenticeship during the intervention' (Ramsaroop & Gravett, 2018), she continued with the transmission mode type of teaching. What exercised the researcher's mind during the observation was, why would Teacher A resort to transmission mode after being provided with the teaching skills and techniques to teach this exact topic (visible light)? This was further probed by why Teacher A did not use the Jigsaw method to curb the challenge of large student numbers in her classroom. What the researcher noticed is that Teacher A reverted to transmission mode because of the effect called the 'apprenticeship of observation' (Lortie, 1975).

This view provides reasons why Teacher A did not use the optics kit, PhET simulations, tablets and shoestring approaches that were provided during the interventions, to engage learners in an inquiry-based activity. This emphasises the conversation that teachers teach as they were taught (Lortie, 1975). This also makes sense of Teacher A's failure to use the Jigsaw method and problem-based learning in her classroom. None of the skills and approaches gathered during the intervention were evident during the post-intervention classroom observation. The teacher was still very dependent on the textbook and 'lecture style'. Teacher A is more aware of implementing cooperative learning approaches, but the learner interaction observed did not meet any of the elements that should characterise cooperative learning. Learners still answered questions in chorus format.

(b) Teaching and learning (Lesson plan); analysis of lesson plan

No lesson plan was prepared. Only the textbook was used during the observed post-intervention lesson to engage the learners on the rainbow colours and one activity consisting of lower-order questions. For instance, the learners were required to define the terms luminous, wavelength and frequency. The questions were followed by questions such as, where does the light come from, how does light travel, how do you see the light, name all colours in the visible spectrum, and name all the colours in order of increasing wavelength (refer to appendix G5). The teacher did not provide learners with a lesson that inspired inquiry minds or inspired learners to enjoy the fascinating nature of visible light. As in the pre-intervention lesson observed, transmission-mode teaching took place, with very little learner engagement. The lesson lacked structured objectives, and the teacher did not reflect on the lesson. From the lesson observation and exit interview, it became clear that no reflection in, for and on practice was done.

(c) Exit interview and discussing the recorded lesson using stimulated video recall

During the exit interview (refer to appendix K2) the teacher mentioned that systemic pressures coming from her seniors lead her in teaching the way she does (using transmission mode). For instance, when the teacher was asked, do you feel that there is a lot of pressure from parents and principals or school management to teach to the test to ensure good results?', her response was: '*Yes, they tell you to need to be done* *with this topic on this date then you start with this one at least the principal would be on my case if I do not produce results, they will be on my case, so you just need to teach to the test, and the kids give us the results that they need so there is no time to have fun in the classroom.'* The response was disheartening on two levels; from the teacher's response, her seniors accept the transmission mode of teaching as the preferred way to capacitate learners. Second, the teacher's actions do not prepare learners with the 21st century and self-directed learning skills needed in our complex society. This view indicates that the teacher was aware that she uses transmission mode teaching style. For instance, she mentioned that she is forced to teach to the test. Hence her pedagogical orientation did not change. (See the transcribed interview in the appendix K2.) She also mentioned the pacesetters (DoE) as a hindrance in using skills and techniques taught in the intervention. Teacher A felt frustrated by the work schedule's inflexibility and prescribed time frames. Her teaching is based on following the content provided on the work schedule. However, she also indicated that the intervention inspired her and that she feels more empowered for the challenging profession.

When the teacher was asked if the school set-up enables her to engage learners in problem-based learning, inquiry learning, cooperative learning that she learned from the intervention, her response was as follows: '*This school makes it impossible. We have fifty kids in the classroom so we cannot do group work we cannot arrange the tables, it asks for space, then we get over and done, and then we move on even when we have to do practical investigations of the classroom it becomes difficult because you cannot keep the learners at all the apparatus, there's a shortage of apparatus...'* (Later in this chapter, I provide a Cultural-Historical Activity Theory perspective on this information.)

(d) Content knowledge on optics

After the intervention (an optics workshop), Teacher A saw a percentage increase of 48% in her post-test. In her pre-test, she scored 2/35 (5.7%), and in the post-test, she scored 19/35 (54.3%). This indicates that the intervention assisted her in developing her content knowledge on visible light. This was also evident in her confidence in teaching visible light during a classroom observation. Statistically, the teacher benefited from the intervention in terms of increased subject knowledge and confidence in teaching the content, and this investment in the teacher's subject knowledge is one of the milestones of the study. It is disconcerting, however, that the activities and strategies (e.g., the PhET simulations) were not transferred to her classroom teaching.

(e) Evidence of pedagogical orientation from the portfolio

The teacher did not attend the SLP due to a funeral she had to attend in Kwa-Zulu Natal. She, therefore, did not submit a portfolio.

4.2.4.2 Teacher A's views on practical (laboratory) work, inquiry learning, and the nature of science

(a) Inquiry learning in Teacher A's classroom

No evidence of practical work or inquiry learning was provided or observed. What is disappointing is that there was no evidence that any of the resources provided to her (e.g., the optics kit, sponsored by the Fuchs Foundation) were used. Despite not having a laboratory, she was trained during the intervention in using shoestring-approaches. Teacher A's response from the Jigsaw method and science-on-a-shoestring questionnaire was '*a teacher does not need to use expensive materials to carry out investigations'*, and she also mentioned her highlight of that specific intervention as building spectroscopes using cheap and available resources (refer to Figure 3.5). A spectroscope has the affordances of facilitating the inquiry-based activities on the construct of visible light and the dispersion of colours into their different wavelengths and providing with the colours of the rainbow. Despite the teacher being capacitated with skills to build and use spectroscopes, no evidence of inquiry-based activity was observed. What is to be highlighted is that Teacher A, in the questionnaire, highlighted that the intervention addressed her professional development in terms of using science-on-a-shoestring approaches in under-resourced classrooms. Based on the teacher's feedback from the questionnaire, the researcher concludes that Teacher A did not use inquiry-based activity regardless of being sensitised with the knowledge and skills to do so.

Teacher A's responses regarding the value of shoestring approaches in fostering inquiry learning from the questionnaire were not congruent with evidence during the classroom observation. Another concern is that Teacher A did not engage learners in doing problem-based activities. When the teacher was asked to provide an example of how problem-based learning could be used to teach optics in the same questionnaire her response was as follows, *‘Give learners problems to solve using PhET simulations’,* but this was also not evident in the classroom observation. The teacher could have used PhET simulations to engage learners in an inquiry activity. According to Ledward and Hirata (2011), PhET simulations could assist in promoting 21st-century skills in place-based, project-based, or problem-based learning context. Teacher A was also provided with optic kits for her classroom. Regardless of resourcing the teacher with the methodological skills and equipment to facilitate inquiry activities, there was no evidence of transfer to the classroom. During an interview Teacher A raised her frustration on the lack of resources to do practical inquiries, and science being theory-laden. Teacher A, is aware of the importance of utilising inquiry-, laboratory-based approaches in teaching Natural Sciences, even though no transfer of these insights was seen in any of the observed lessons – despite the fact that most obstacles were removed for her during the intervention. (I will further discuss this in the CHAT section, later on in this chapter.).

(b) Teacher A's responses in the UJ DNA Barcoding questionnaire (and focus group interview afterwards)

In the post-questionnaire (Refer to appendix M2), Teacher A reflected that she is now 4 out of 5 confident in handling laboratory equipment after the intervention. She also indicated the following sentiments during the interview: ‘*I was feeling happy, I was excited to work with all the apparatus, and for me it was an experience. Once you like something, you are more interested in it. If we take it to the NS classroom, learners would be interested more in the subject because now they go to the classroom, we talk theory, and they do not know how to apply it in real life.’* She further emphasised the following in the post-questionnaire: ‘*after the experience of using laboratory equipment at the African Centre for DNA Barcoding (ACDB) I think I have gained a lot of lab skills.’* The teacher's experience at the African Centre for DNA Barcoding was a beautiful one. For instance, in the focus group interview Teacher A made the following remark ‘*it was fun, we learned new things. I cannot wait to go back to the classroom and share the information which I have learned*’.

An important remark made by Teacher A during the interview was ‘*I see that there is much more to be done in classroom. I've been robbing my learners, now I realise why*

I was not getting those good marks because my kids were not motivated enough. With the knowledge I gained in two days, if I can take that knowledge and pass it all to my kids, pass on the skills, my learners will be much more interested in the subject.' What remains surprising is that, despite comments in the post-questionnaire such as, '*I have learned to use different equipment, and I have gained much interest to do experiments in my class with my learners',* or comments such as '*This whole experience has enhanced my interest in doing practical work'*, the culture of not doing inquiry-based activities continued during the post-intervention classroom observation. There was little evidence of transformed teaching.

The data, therefore, points to the wash-out effect of newly acquired knowledge and skills in the classroom after the intervention. Regardless of the well-planned intervention, the teacher resorted back to the same old ways of teaching, and no learner practical skills were enhanced. Lortie (1975) refers to this effect as 'apprenticeship of observation'. This phenomenon provides a reason why Teacher A used predominantly chalk-and-talk, amongst many reasons, as this was how she was taught when she was still a learner. Another element is that, even though the intervention was meaningful to Teacher A, after the intervention, the teacher could still not understand what PCR meant. This highlights a big gap in this teacher's knowledge, which could not be adequately addressed by the two-day intervention at ACDB.

(c) Teacher A's views on the nature of science (VNOS)

Teacher A did not attend the short learning programme (SLP) on 18-19 March 2019. Amongst many activities that the teacher engaged in, a strong emphasis was based on activities that demonstrate the nature of science (NOS). Teachers were sensitised on the nature of science, such as that nature is real, observable and testable, tentative (science is subject to change and not absolute and certain), inferential (there is a clear distinction between observations made of nature and deductions or conclusions (inferences) made from observations to explain the causes).

However, Teacher A did attend the DNA Barcoding intervention, which aimed to achieve the same understanding of the processes of science.

After the intervention, in the VNOS questionnaire, Teacher A showed a more informed view on the nature of science. She developed a better understanding of the inferential and empirical nature of science. However, her views were not in sync with the classroom observations, as during the lesson, not a single element of the nature of science (tenets of science) was evident.

4.2.4.3 Teacher A's views on science and society

(a) Portraying the role of science in society during lessons: evidence from the lesson observations using RTOP, lesson plan and interviews

In the exit interview, Teacher A mentioned how indigenous knowledge could be integrated into a lesson and how this knowledge has affordances of making the lesson more interesting. However, no attempt to infuse indigenous knowledge into the lesson, or an attempt to contextualise the lesson using some of the indigenous knowledge applicable to the topic of optics, was evident. For instance, when one teaches visible light, it is possible to make a connection to rainbow colours. The rainbow is a very familiar natural phenomenon, and colours play a pivotal element in most indigenous knowledge systems. For instance, the Ndebele relate colours to the status or power of the homeowner, and paintings on the house could be indicating a period of prayer or the announcement of marriage. I am of the view that, if Teacher A addressed colour from an indigenous knowledge perspective, it would have centralised the affective domain.

During the classroom observations, Teacher A did not attempt to show the relevance of science in broader society and continued to marginalise the affective domain. The teacher missed an opportunity to make the lesson fun and exciting.

With the data collected and the classroom observation, the researcher holds the view that Teacher A finds it challenging to facilitate the epistemological border crossing between science and indigenous knowledge (and society). Despite an awareness of her learners experiencing science as uninspiring, there were minimal attempts by her to address the promotion of affective outcomes.

(b) Teacher A's view on the nature of indigenous knowledge

Teacher A still held a partially informed view of the nature of indigenous knowledge after the intervention, probably because she could not participate in the SLP on indigenous knowledge and this knowledge was also not centre-stated during her B.Ed. degree. Teacher A attended all the intervention activities except for the SLP on indigenous knowledge, due to a family funeral she had to attend to.

4.2.4.4 Teacher's views on assessment practices

(a) Reformed Teaching Observation Protocol (RTOP) and lesson plan

From the last lesson observed, it is clear that the teacher still 'teaches to the test', and lower-order questions in Bloom's taxonomy are still favoured. Teacher A did not attend the SLP and did not submit a portfolio for that reason. From the lesson observations, I could conclude that the teacher asks lower-order cognitive questions and does not engage in innovative assessment practices, e.g., peer assessment. She utilised ineffective assessment techniques. For example, after a teacher-centred lesson, the assessment opportunity entailed that learners, using their textbooks, had to write down answers to lower-level cognitive questions. The teacher then called upon individual learners to go and write down the answers on a whiteboard in front of the class. The researcher realised that much time is spent on very ineffective assessment procedures. While learners were writing answers on the whiteboard, other learners were talking to each other, or did homework of different subject(s). A significant limitation observed is the lack of assessment of affective and psychomotor outcomes.

(b) SLP Portfolio

Unfortunately, Teacher A did not submit a portfolio.

4.2.4.5 Teacher A's Self-Directed Learning (SDL)

(a) Qualitative analysis of SDL

In order to map Teacher A's development growth in the profile of implementation rubric, interviews and post-intervention data were used to observe if the teacher-facilitated self-directed skills among her learners. Evidence of enhanced self-directed learning is that, due to the motivational aspect of this intervention, Teacher A successfully registered for BEd (Honours) studies in the Natural Sciences in 2020. When prompted about this in the exit interview, she mentioned that this intervention made her realise that she needs to invest in her professional development. She identified several aspects that she needs training on, and identified personal learning goals, such as becoming more competent in teaching electricity topics. Teacher A displayed several of the qualities of a self-directed learner, e.g., her enthusiasm in terms of the intervention offerings. In the post-qualitative data Teacher A indicates evidence of SDL in terms of her learning goals. She could use resources during the intervention and use strategies to simulate inquiry-based activities. However, at the coal face of teaching, no transformative teaching was observed, critical reflection was not evident, and the teacher did not indicate agency to use science on a shoestring in an under-resourced classroom. According to the profile of implementation rubric, Teacher A is mapped on level 2 scale.

(b) Quantitative analysis of Teacher A's SDL, utilising the SDLI instrument

In order to map Teacher A's development growth, the SDLI instrument (Refer to appendix L3), profile of implementation rubric, interviews and the classroom observations were used. Teacher A's views in the pre- and post-intervention were compared as in Table 4.5.

Table 4.5: Pre- and Post-SDL views of Teacher A

Pre-SDL views				Post-SDL views			
Sub-domain in the profile of implementation	Questions	Score of Teacher A	Score of Teacher A reported in percentage (%).	Score of Teacher A	Score of Teacher A reported in percentage (%)	Change in SDL scores	Change in SDL reported in percentage (%)
Learning motivation	Q 1-6	26 / 30	86.67	25 / 30	83.33	-1	-3.3
Planning and implementing	Q 7-12	20 / 30	66.67	18 / 30	60.00	-2	-6.7
Self-monitoring	Q 13-16	14 / 20	70.00	13/ 20	65.00	-1	-5
Interpersonal communication	Q 17-20	17/ 20	85.00	15/ 20	75.00	-2	-10
TOTAL:		77/100		71/100		-6	-6.25

Even though Teacher A still values learning motivation in the four sub-domains of self-directed learning, her scores dropped from 26/30 to 25/30. This remained a domain Teacher A felt strong about. The same patterns are seen in terms of planning and implementation, in the pre-questionnaire, she rated herself 20/30 and in the post-test 18/30. Her scores were calculated by considering the post-intervention SDL data. Research indicates that when participants complete the pre-SDL instrument, most of the participants have naive understandings of SDL. Similar trends were seen in the studies of Bailey (2016) and Bosch (2017). After the intervention, the teacher was more sensitised in terms of what SDL entails. Hence post-data were used to map teacher professional development. In the post-quantitative data using SDL instrument, Teacher A scored 71 out of 100 (6 lower than in the pre-test). In terms of the revised Rogan & Grayson's rubric, both the qualitative and quantitative data indicate that Teacher A is at level 2 in terms of her SDL professional development.

The drop in the score in the SDLI (from 77 to 71), seems to indicate that Teacher A became less self-directed as the intervention unfolded. However, qualitative data provides a different picture. I concur with Mentz and De Beer (n.d., p 25) that ‘the utilisation of quantitative and qualitative methods could result in dichotomous data, and that CHAT holds many affordances to open this “black box”. I will further discuss this in the CHAT section in this chapter.

4.2.4.6 Teacher A's holistic wellbeing

(a) General wellbeing after the intervention

In an exit interview Teacher A mentioned how grateful she was that she attended the stress management intervention and that the intervention helped her in navigating the stressful nature of being a teacher. After the stress management workshop, presented by a registered psychologist, the teacher mentioned that she would be able to handle work stress more effectively in future. In the exit interview, even though she said she would be able to deal with stress better, she did mention that the pressure coming from her seniors is immense. This indicated that pressure and the nature of teaching is one of her many stressors, regardless of the technique and skills to deal with stress management, and this raise a concern.

(b) Professional development needs

After the visit to the African Center for DNA Barcoding, Teacher A identified goals for her own professional development (e.g., learning more about PCR and laboratory protocols). She has applied for registration in the Honours degree in 2020, fuelled by the realisation that she needs to invest in her own professional development and to be a more self-directed learner. Despite the pressure on Teacher A, it is commendable that she would like to pursue a BEd (Hons) in 2020. This means that she values her own professional development as a teacher. To this end, the teacher has been assisted with how to create parallel and series connection and how the relationships are related to Ohm’s law (see the Fuchs Foundation video provided on the DVD which accompanies this study). The teacher was also sensitised on how to use the cooperative learning Jigsaw method in facilitating group work. The only need that was not addressed of Teacher A was in terms of chemistry. We are of the view that if the teacher is self-directed in her learning, she will be able to seek a solution, and identify resources to assist her in her learning.

4.2.5 Synthesis: Using revised Rogan and Grayson's (2003) heuristic to assess teacher professional growth, and plotting learning/development during a longitudinal and systemic teacher development programme

Below I am using Rogan and Grayson's profile of implementation, with the addition of SDL. This assisted me to evaluate if Teacher A showed evidence of transformed teaching during the post-intervention. To map Teacher A's progress, I used Rogan’s (2004b:159) profile of implementation rubric. Below I provide Teacher A's progress during a longitudinal and systemic teacher development programme.

Table 4.6: Teacher A’s progress

Table 4.6: Teacher A's progress during teacher professional development that spanned from 2017-2019																									
A HEURISTIC TO MAP TEACHERS’ SKILLS ACCORDING TO THE ROGAN AND GREYSON PROFILE OF IMPLEMENTATION																									
PRE- (X) AND POST (0) INTERVENTION PROFILING HEURISTIC																									
	Classroom interaction					Practical work					Science and society					Assessment					Self-directed learning				
PARTICIPANT(S) IN TPD	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	**4**
TEACHER A	X	0				X 0						X 0				X	0					X	0		

4.3 PROFILE OF TEACHER B

4.3.1 Personal profile (biography) of Teacher B

Teacher B holds a BSc degree in chemistry and mathematics. The teacher aspires to be a circuit manager at the department of education and to assist teachers at the ‘coalface of teaching’. Teacher B is under the age of 35. At the time of reporting, he was registered as an honours student at North-West University. Teacher B is a novice teacher with three years of teaching experience.

4.3.2 School and classroom

The school that was observed is a quantile 1 school. The school is in an unfortunate state of a lack of resources. In a class, I observed the learners do not have chairs to sit on and have to move to the other classes to take or borrow chairs. Three learners share tables that are designed for two. The same applies to the chairs, and learners are expected to share with another learner. The classroom observed does not inspire learning, and is untidy.

4.3.3 Pre-intervention data: Teacher B

4.3.3.1 Pedagogical orientation of Teacher B

Teacher B used demonstrations followed by a more predominant 'chalk-and-talk' teaching style. During the teaching phase, the teacher taught the learners using learners' textbooks to make inferences. Learner engagement was almost non-existent; this is despite the fact that the teacher made efforts to ask learners questions. The teacher called the learners by names to respond when they did not voluntarily respond. When the learners decided to respond, I (researcher) noted that language is a barrier as some learners grappled with constructing their thoughts. This view also applied in question 13 of the Natural Sciences pre-questionnaire. When the teacher was asked which problems he experienced in teaching Natural Sciences, his response was '*the learners are struggling with the language of teaching (English*)'. The teacher mediated learning by using learner's home language and language of instruction together to facilitate teaching and learning. Teaching proceeded in transmission mode, and the lesson was underpinned by a theoretical understanding of the topic on circuits. The voices of the learners were 'silenced' by the continuous way of teaching. The view above to a large degree agrees with the data provided by the teacher in the Natural Sciences pre-questionnaire. When Teacher B was asked how he plans his Natural Sciences lessons in question 5 of the questionnaire, his response was '*I take the instrument like CAPS document and look at the skills learners have to learn. After I look at the previous knowledge, they have, and build from there…*'. Teacher B's perception of building on knowledge is informed by transferring knowledge to learners from the teacher's perspective.

(a) Lesson observation using the Reformed Teaching Observation Protocol (RTOP) instrument

The class consisted of 43 learners, with 22 females and 21 males. The lesson observed was a grade 8 class on the topic of electric circuits. The teacher started by requesting the learners to take out their notes, preceded by introducing the researcher. The lesson's objective was written on the chalkboard. The teacher made an effort to establish learners' background knowledge on electric circuits and usage of terms. The teacher explained the concepts 'system and 'electric circuit'. The objective of the lesson was to build a simple electric circuit. It should be made clear beforehand that the learners did not have resources to engage in building electric circuits. The teacher used shoestring approaches to provide learners with the understanding thereof. Before the teacher used the demonstrations, he explained components such as wires and batteries. Learners were shown pictures of these components and of how a circuit is connected. After the demonstration, the teacher used pictures to demonstrate a unimodal set-up of the circuit to explain how the connections worked. The teacher persisted in teaching in transmission mode fashion. The lesson did not activate and inspire inquiry minds. The lesson was followed by classwork, asking questions on lower-order cognitive levels that mainstreamed questions referring to 'what'. The assessment questions were written on the chalkboard, and no worksheet was provided to the learners, nor was homework provided to the learners. The teacher provided feedback on the classwork activity. The learners were instructed to write only the answer in their books.

(b) Teaching and learning: analysis of lesson plan

Teacher B did not prepare a lesson plan. Instead, he prepared a lesson from the textbook and demonstrations. Despite the absence of a lesson plan, the lesson remained semi-structured. For instance, the teacher began by introducing the topic to the learners. The lesson objectives were communicated with the learners. The teachers determined what prior knowledge learners held, even though most learners did not show much interest. Most parts of the teaching consisted of a chalk-and-talk approach. Learners were provided with an activity. The lesson lacked reflection and summary during the class observation.

(c) Content knowledge on optics

Teacher B scored 18 out of 35 in a visible light pre-test. This implied that the teacher had only 51% content knowledge of the optics test written. This raises a concern. What is disconcerting is that the CAPS themes informed the test and outcomes.

The question the research needs to ask is, will Teacher B be able to assist the learners to achieve mastery level on this specific content knowledge in his class?

4.3.3.2 Teacher B's views on practical (laboratory) work, inquiry learning, and the nature of science

(a) Inquiry learning in Teacher B's classroom

During the class observation, no inquiry-based activity or discussions were observed. This is despite the CAPS curriculum's mainstreaming of problem-based learning and cooperative learning skills and outcomes. The reason for Teacher B not to engage learners in cooperative learning and problem-based learning could be the fact that the teacher is not capacitated. The Natural Sciences Questionnaire indicates that Teacher B has a naive understanding of problem-based learning and cooperative learning. For instance, in question 9 of the questionnaire, the teacher was asked what his views are on using problem-based learning in the classroom. He was also required to provide an example. Teacher B's reply was '*problem-based learning help learners to work together and to use their prior knowledge*', and his example of problem-based learning provided was a case study. The response failed to indicate the crux of problem-based learning, which is to create an authentic problem the learners need to solve or investigate. The response of Teacher B was as follows: '*The learners can learn from each other in the language they understand.*' Even though the response highlighted one of the cooperative learning strands, which is positive interdependence, the response failed to capture other vital strands such as group processing, individual accountability, promotive interaction, interpersonal and social skills (Johnson & Johnson, 2002). Hence, I make the assertion that Teacher B has a naïve understanding of problem-based and cooperative learning which might create difficulties in creating an effective inquiry-based science classroom. In question 7 of the same questionnaire, the teacher was asked if it was possible for a teacher to facilitate work without a laboratory, and to provide reasons. The teacher's response was '*yes, the teacher can plan field trips*'; this view also provides evidence of naïve understanding of the inquiry. A field trip on its own is not practical work that necessarily promotes understanding of the tenets of science. Practical work or investigations start with a hypothesis, aims and objectives, followed by scientific methods, observation, analysis of data, and a conclusion. In the teacher's response no indication of these indicators was observed.

(b) Teacher B's responses in the UJ-DNA Barcoding questionnaire and focus-group interview, prior to the DNA Barcoding intervention

Unfortunately, Teacher B could not attend ACDB at UJ, and the researcher subscribed to the standard of ethics as outlined in the research certificate, and did not therefore pressurise Teacher B to attend.

(c) Teacher B's views of the nature of science

In the VNOS questionnaire, when Teacher B was asked, 'After scientist developed a theory, does the theory ever change? The teacher's response was that '*theory will only change if it is challenged by another theory or experiment that contradict the theory that needs to change. Through new experiments, theories can be changed based on new evidence*.' When the teacher was asked a follow-up question on why scientific theories are taught, no response was provided by Teacher B. From his response, it was evident that Teacher B understood that methods of science inform the existence of theories. This response also indicates that the teacher had an informed understanding that science is not static and builds on new insights supported by empirical data. The teacher's informed understandings of the nature of science could, to a large extent, be influenced by the fact that Teacher B is a qualified scientist majoring in chemistry (with a BSc degree in mathematics and chemistry). This is supported by his response when he was asked what an atom looks like. His response was '*an atom is a model used to describe the existence of matter. An atom as a model consists of electrons circulating around a nucleus that consists of negative protons and negatively charged neutrons.*' In question 3 of the same questionnaire, the teacher was asked how science and art are similar, and how are they different? The teacher stated that '*science is objective and based on facts, and art is subjective. Science and arts depend on observations.*' In question 6, when the teacher was asked the difference between scientific knowledge and opinion, he responded by saying ‘*scientific knowledge is based on truth and opinion can use emotions.*’ This understanding informs the teacher to have nuanced understandings of science.

4.3.3.3 Teacher B's views on Science and Society

(a) Portraying the role of science in society during lessons: evidence from the lesson observations using RTOP, lesson plan and interviews

There was no apparent link between science and society observed during the lesson. The teacher had an opportunity to bring science-in-society perspectives into the lesson. For instance, many learners are aware of resistors, which are readily available resources in many societies. The teacher had an opportunity of asking each learner to bring resistors from broken appliances and to use colour-coding methods to calculate the value of different resistors. This is a shoestring approach and does not require much financial resources. This could have been followed by asking learners to bring different connection wires from broken appliances, small light bulbs and batteries. These are resources that can be used to explain Ohm’s law, in circuit connection. This could also be extended by teaching the illegality of bad connections, and the learners could discuss the unethical aspects of these connections. These resources could also be used to demonstrate how electricity consumption is calculated from the relationship between current, voltage and power. For instance, to calculate electricity consumption per day, the learner will need to understand that power is the product of voltage and electricity, $P = VI$ and is measured in watts. The consumption of electricity is determined by following the two steps below. Step 1 calculates energy consumption by finding out how many watts each device uses per day, i.e., iron use 100-1800 watts. The second step is to multiply the appliance wattage by the number of hours. The answer in step 2 will give the number of watt-hours consumed per day. In terms of this example, the learners will be able to calculate how much electricity is consumed by iron devices in different households.

These are a few examples amongst many where science addresses issues concerning society. This can be the science the learners will remember and connect with but requires teachers to be agents of change. This, I claim, would make science interesting and relevant to many learners.

(b) Teacher B's view on the nature of indigenous knowledge

In question 11 of the Natural Sciences questionnaire, Teacher B's view on including indigenous knowledge in the teaching of Natural Sciences was as follows, '*it will help learners to see that science is not for only certain people, actually is for everyone*'. When the teacher was asked how a teacher can include indigenous knowledge in a science lesson, his response was, '*Story telling – learners will have to go back to the community and ask old people how did things in the past work, and compare how they are doing now*'. In the above response the teacher provides an appreciative view on indigenous knowledge as knowledge that stems from many generations. The teacher also provides a teaching strategy to integrate this IK into the curriculum. Teacher B also suggested that science will be made interesting through the integration of indigenous knowledge in Natural Sciences curriculum. This provides the basis that Teacher B had an understanding of how indigenous knowledge could be integrated into the curriculum. It is on this basis that I infer that Teacher B, according to his response, had informed views of indigenous knowledge.

4.3.3.4 Teacher B's views on assessment/assessment practices

No formal activity was provided to the learners, except three questions written on the chalkboard centralising the 'what' questions. For instance, the questions asked were the following: What is current? What is a circuit? and What is an instrument used to measure voltage called?

The learners were further instructed to write only the answers in their learner's books. This practice of assessing is flawed on many levels. On the first level, all the questions asked are on the lower cognitive levels of Bloom's Taxonomy. Emphasis was on remembering, which exhibits memory of previously learned content by recalling facts, concepts and answers. Secondly, the questions were not aligned to the objectives of the lesson, and lastly, no homework was provided. Homework is important to reinforce what was taught in class and also would have provided learners with an opportunity to go beyond the scope covered in class. This narrative provides insight that Teacher B's assessment practice is poor and does not centralise effective assessment strategies.

4.3.3.5 Teacher B and Self-Directed Learning (SDL)

(a) Qualitative analysis of SDL

Teacher B was mapped on level 1 on the revised Rogan and Grayson rubric for the SDL domain. There is minimal evidence of SDL. For instance, the teacher in the pre-intervention mentioned his professional development needs were practical worksheets that would engage learners, and classroom management. During the observation, no concrete evidence of any strategies to make the classroom stimulating or adequately managed emerged. No practical was done, and no practical worksheet was evident, although the teacher could have used freely available worksheets provided on the internet or the one provided by the DoE.

(b) Quantitative analysis of Teacher B's SDL, utilising the SDLI instrument (Cheng et al., 2010)

Teacher B’s SDL development was recorded using SDLI (see Table 4.7 below), in order to map the quantitative data of Teacher B. From the insights of SDLI data, a profile of implementation rubric was used to record the teacher’s rating. The rating was used to map the teacher's development programme as in Table 4.9 in the post-intervention data. Further down, Table 4.8 gives the SDLI instrument used to evaluate teachers view on SDL.

Table 4.7: SDL of Teacher B

Sub-domain in the profile of implementation	Questions	Score of Teacher B	Score of Teacher B reported in percentage (%).
Learning motivation	Q 1-6	28/ 30	93.33
Planning and implementing	Q 7-12	19 / 30	63.33
Self-monitoring	Q 13-16	14/ 20	70.00
Interpersonal communication	Q 17-20	18/ 20	90.00
TOTAL:		79/100	

Teacher B scored 79 out of 100 in the SDLI. His SDL is indicated in terms of the four sub- domains of the SDLI instrument, in the revised profile of implementation. Teacher B feels strongest about learning motivation, as he was indicated to be 93% motivated towards learning.

In contrast, Teacher B feels the least strong about his ability to plan and implement. An overall score across the four sub-domains was 79. According to the revised profile of implementation, Teacher B is scaled at level 3.

4.3.3.6 Teacher B's holistic wellbeing

(a) *Wellbeing of Teacher B*

Teacher B, like many teachers in the interview, mentioned that his workload is overwhelming.

(b) Professional development needs of Teacher B

- Dealing with stress
- Classroom management
- Practical worksheets
- Intermolecular forces.

4.3.4 Post-intervention Data – Teacher B

4.3.4.1 Pedagogical orientation of Teacher B

(a) Lesson observation using Reformed Teaching Observation Protocol (RTOP) instrument

In the post-intervention lesson elements of transformed teaching were observed. For instance, a teaching orientation that centred learners at the core of learning was observed. Learners were placed in groups of four, and each group received a jar full of beads. In the lesson, the learners were provided with posters and were required to draw three big circles labelled A, B and C and on the same circle to place the same colour of beads. This took place after the teacher introduced the topic on ecology and clarified the concepts on population, community and ecosystem with learners. The learners had to refer back to the terms and infer meaning to what the three circles represented individually. This was followed by the question – if the three circles are differently placed, and the beads represented species of animals, do the learners think that species in circle A and B form the same population? The learner was asked, based on the previous question, if the species that lived about 100 years ago still formed part of the population.

Later in the lesson, the learners were provided with a different poster and were required to draw big circles, labelled, and to put circle A, B and C inside D. The learners were asked to look at the terms again and to give meaning to what circle D represented. What was interesting about this lesson was that the content was contextualised to address the diverse learners' affective domain and to make the lesson interesting and inviting. Again, the lesson required the learners to be the ones navigating the process of learning. Teacher B in this lesson acted as a facilitator of learning.

(b)Teaching and learning; analysis of lesson plan

The lesson was well structured. There was a huge improvement in terms of the structure of the lesson plan, and I claim that the lesson plan enhanced teaching and learning. For instance, in the pre-intervention, the teacher did not indicate the lesson objectives and the skills the lesson aimed to impart to the learners. In the post-intervention, the lesson objectives, the specific aims, and science process skills aims were clearly demonstrated in the lesson. The classroom management was also better than in the pre-intervention lesson. The lesson plan constituted an activity with a memorandum. The learners were also given homework from their textbook (Spot on:11. At the end of the lesson, the teacher asked the learners to follow up questions. For instance, the learners were asked to (a) arrange the terms *species, community, population* and *ecosystem* in order from biggest to smallest, and (b) the learners had to give an example of a population and community from their school environment. What the teacher did well in the lesson plan was to contextualise the lesson and afford the learners a context-sensitive science lesson. After the lesson the teacher became a reflective practitioner, for instance he mentioned how the lesson could be improved. One of his suggestions was to consider using a video of wild life or arranging an educational tour to a park. Even though the lesson was structured well and the time needed for the lesson was indicated, the lesson failed to structure how the time would be divided during different lesson phases.

(c) Exit interview and discussing the recorded lesson using stimulated video recall

As explained earlier, the teacher showed an improvement in terms of his pedagogical orientation in the post-intervention data. There was evidence of improved structure in the lesson plan, and the teacher used engaging pedagogies such as contextualising the lesson by means of using beads and group work. In the exit interview, when the teacher was asked how he felt about the lesson after watching a short clip of the lesson recorded, his response was, *I think the lesson was not bad, I think I improved a little bit*', which was the case. Teacher B, in the post-intervention improved as already mentioned. When the teacher was asked how he experienced the intervention and what insights he could share, Teacher B reported that the teacher professional development intervention assisted him. It was encouraging to listen to the teacher in terms of how he sees himself developing professionally in the next five years and envisioning to have a master's degree then. When the teacher prompted him to reflect on his good and bad experiences during the programmes, his response was '*I really enjoyed the activities they were all fun and engaging. My frustrations were most of the strategies were time-consuming, and mostly I could not apply them in my classroom because most of them needed time to be perfected them*'**.** While the time factor was an important insight, Teacher B showed agency regardless of the challenges faced. He did not stop improving and applying what he learned from the intervention.

(d) Content knowledge on optics

Teacher B, scored 18 out 35 (51%) in a visible light pre-test; and, in the post-test score, 22 out of 35 (63%). This implies that Teacher B scored 12% improvement in the post-test. This also indicates that the intervention on optics scaffolded the teacher's content knowledge on the theme mentioned. I can claim that the intervention placed the teacher in a better position to provide learners with a more nuanced content knowledge on the construct of optics.

(e) Evidence of pedagogical orientation from the portfolio

Teacher B made a significant improvement in terms of his pedagogical content knowledge. In the pre-intervention, the teacher's pedagogy was predominantly teacher-centred and characterised by transmission mode that did not inspire the learners. In the portfolio Teacher B designed an inquiry-based lesson that required the learners to engage with the content on fermentation and later engaged the learners in investigating the chemical reaction in a traditional beer-making practice.

4.3.4.2 Teacher B's views on practical (laboratory) work, inquiry learning, and the nature of science

(a) Inquiry learning in Teacher B's classroom

Teacher B's lesson focused on two specific aims, namely knowing the subject content and making connections, and secondly, understanding the use of science and indigenous knowledge in everyday life. The learners mainly focused on the following science process skills: assessing and recalling information, comparing, sorting and classifying. For instance, the learner was provided with beans and illustrated the concepts of population and community, etc. (see the section on post-pedagogical orientation). The lesson placed learners to perform the activities in groups of four. The learners were provided with opportunities of learning from their peers, learners engaged in group processing, and interacted as they all had to do the task together. Learners were exposed to solving a problem by engaging in different options and using reasoning and communication skills to solve a problem as a collective.

(b) Teacher B's responses in the UJ DNA Barcoding questionnaire (and focus group interview afterwards)

Teacher B did not attend this intervention.

(c) Teacher B's views on the nature of Science (VNOS)

Even though the teacher demonstrated transformative teaching, the lesson did not demonstrate all the seven tenets of science, as highlighted by Lederman (1999:917). The teacher demonstrated science as empirical, for instance, learners had to learn the concepts of population, community and ecosystem through observation. They had also to learn that science involves human interpretation and creativity. The learners had to create and interpret the circles in order to understand what is meant by ecology, community and population. For the fact that the teacher used the method of science, I make a claim that the teacher has informed views on the nature of science.

4.3.4.3 Teacher B's views on science and society

(a) Portraying the role of science in society during lessons: evidence from the lesson observations using RTOP, lesson plan and interviews

Looking at the lesson plan provided in the portfolio, it is a clear distinction that the teacher focused on context-sensitive science. For instance, in the lesson plan, the teacher engaged the learners in a locally famous beer called ‘nkwapa’. Further, in the context of the lesson plan, he makes a note that ‘almost all learners know about this beer’, which makes the lesson context-based. In the lesson plan, the teacher listed the ingredients required to make the beer and the procedure thereof. For instance, the procedure was given as follows: ‘in a 20-litre bucket add (water must be warm and not hot), add bread to the bucket and grind it, add sorghum, yeast and sugar followed by stirring the mixture. Cover the mixtures with something to keep it warm for 24 hours. After 24 hours, separate the residue (drain)’. The teacher mentioned that he would do the beer with the learners as an activity. The beer-making covers curriculum themes such as fermentation and oxidation. This approach I claim affords learners with an opportunity to engage in scientific methods while framing the science in the familiar context of many learners, and this is what Gibbons (2000) refers to as mode 2 learning. In this particular lesson, the teacher emphasised science that is locally embedded. The focus was also placed on how the oxidation process causes the beer to be sour and the reason why people use potatoes as a base to neutralise the alcohol. By doing this, the teacher mainstreamed the affective domain of many learners.

(b) Teacher B's view on the nature of indigenous knowledge

From the two observed lessons (classroom observation and the portfolio) it does become evident that the teacher understands the value of the epistemological border crossing between science and indigenous knowledge. This approach holds affordance to address the affective domain of many learners. In another lesson observed, the teachers used beads (the use of beads in South Africa holds much cultural meaning for all learners). This I claim holds the affordances of reminding the learners of the content taught as learning was personalised and made relative and also fun.

4.3.4.4 Teacher's views on assessment/ assessment practices

(a) Reformed Teaching Observation Protocol (RTOP) and lesson plan

In the pre-observation, the teacher provided ineffective practices and did not stick to the recommended CAPS recommendations of at least two informal assessments per day. In the post-intervention, the teacher used a more informative and pragmatic assessment. Learners were involved in questioning and answering, and this opened a dialogue and created an inviting environment. In both, the lesson observed in the post-intervention classwork and homework was provided to the learners.

(b) SLP Portfolio

From the portfolio, the researcher could reach the following understanding. After the teacher had demonstrated the experiment and the learners were back in their groups, the learners continued their discussions in their small groups, where they were given questions that stimulated higher-order thinking skills. For example, three of the interesting questions that were asked were phrased as follows: (a) *What do you think will happen to the beer if sugar is not added?* This question probed the learners to understand that fermentation will not continue as the yeast lacks the sugar to feed it. (b) *What causes the beer to be sour?* This question required learners to understand oxidation – 'When ethanol is oxidised, it changes to acetic acid and water is produced + oxygen which produces ethanoic acid + water.' *What role do chopped potatoes play in sour beer?* Here the learners need to learn that the chopped potatoes inside the alcohol will absorb the acid, and this will reduce the sourness. The lesson displays improved lesson practices that centralise science as relevant and connect to the learners' experiences.

4.3.4.5 Teacher B's self-directed learning (SDL)

(a) Qualitative analysis of SDL

In the post-intervention, Teacher B experienced transformed teaching, and inquiry learning was evident. In the pre-intervention, Teacher B mentioned classroom management was one of his professional development needs. In the pre-intervention, the teacher's classroom was not organised and not inviting. In the post-intervention, the classroom space was inviting, and learners were engaged. The classroom atmosphere was positive, and the class was well managed. Learners engaged in group work. There is evidence from the professional development needs mentioned that classroom management was improved, The teacher indicated that he consulted with experienced teachers and read more about classroom management. There is clear evidence of SDL: appropriate strategies such as group work and inquiry learning were used and evident. However, there is no critical evidence of reflection. In the reflections, the teacher does not describe what happened, analyse why it happened, or theorise to improve his practice, and this cast doubt on whether the teacher will be able to test his theory in practice.

(b) Quantitative analysis of Teacher B's SDL, utilising the SDLI instrument (SDLI)

Table 4.8: Pre- and Post-SDL views of Teacher B

Pre-SDL views				Post-SDL views			
Sub-domain in the profile of implementation	Questions	Score of Teacher B	Score of Teacher B reported in percentage (%).	Score of Teacher B	Score of Teacher B reported in percentage (%)	Change in SDL scores	Change in SDL reported in percentage (%)
Learning motivation	Q 1-6	28 / 30	93.00	28/ 30	93.00	0	0.00
Planning and implementing	Q 7-12	19 / 30	63.34	20/ 30	66.67	1	3.33
Self-monitoring	Q 13-16	14 / 20	70.00	16/ 20	80.00	2	10.00
Interpersonal communication	Q 17-20	18/ 20	90.00	15/ 20	75.00	-3	-15.00
TOTAL:		79/100		79/100		0	1.67

This teacher, therefore, functions on level 3 in terms of SDL.

4.3.4.6 Teacher B's holistic wellbeing

(a) General wellbeing after the intervention

From the interview, the teacher mentioned that his work is stressing and there is no time to do other things of life beside preparing, assessing the learners and doing administration. Issues pertaining work-stress continued post-intervention.

(b) Professional development needs

The teacher required assistance with large classes, disruptive learners and time management intervention.

4.3.5 Synthesis: Using revised Rogan and Grayson's (2003) heuristic to assess teacher professional growth, and plotting their learning/ development during a longitudinal and systemic teacher development programme

Below I used the revised Rogan and Grayson's profile of implementation to map Teacher B's professional development during a longitudinal and systemic professional development as follows:

Table 4.9: Teacher B's progress

Table 4.9: Teacher B's progress during teacher professional development that spanned from 2017 to 2019																									
A HEURISTIC TO MAP TEACHERS SKILLS ACCORDING TO THE ROGAN AND GREYSON PROFILE OF IMPLEMENTATION																									
PRE- (X) AND POST (0) INTERVENTION PROFILING HEURISTIC																									
	Classroom interaction					Practical work					Science and society					Assessment					Self-directed learning				
PARTICIPANT(S) IN TPD	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
TEACHER B	0	X				0	X					0	X			X	0					X		0	

4.4 PROFILE OF TEACHER C

4.4.1 Personal profile (biography) of Teacher C

Teacher C holds a B.Ed. degree in Natural Sciences from North-West University. Teacher C is a neophyte teacher who is under the age of 30. Teacher C loves teaching and feels the proudest when her learners succeed academically.

4.4.2 School and classroom

Teacher C teaches in an urban school that has an under-resourced science laboratory, access to the internet and library. The school composition is primarily coloured and black learners with the minority being Indian learners. The classroom that Teacher C teaches in is a small mobile classroom without ventilation and overcrowding is a perennial concern.

4.4.3 Pre-intervention data: Teacher C

4.4.3.1 Pedagogical orientation of Teacher C

During the observation, Teacher C used transmission mode teaching combined with learner interaction through dialogues and mini-discussions. Teacher C is an excellent communicator and organised in her teaching. Even though Teacher C uses transmission mode for the most part of her teaching, her lesson is well structured, and the outcomes of the lesson are clear. She uses learner's textbooks, teacher's guide and used a few visuals from the textbook to illustrate microorganisms visually. Due to time constraints learners could not engage in a group as planned by Teacher C.

(a) Lesson observation using Reformed Teaching Observation Protocol (*RTOP*) instrument

The lesson began with Teacher C greeting the learners and introducing the researcher to learners. The lesson observed was a grade 8 lesson based on microorganisms, with a particular focus on types of microbes such as harmful and useful microorganisms. The teacher used the CAPS document and introduced the lesson by explaining the objectives and simplifying terms to be used during the lesson. To a large extent, the lesson made sense and included limited examples of real-life application. The learners did activities coming straight from the textbook. The learner activities were meaningful, but more formal thought needed to be demonstrated with regard to the learning process and learners' engagement with content. The teacher also needed to demonstrate teacher autonomy by providing learners with creative activities. The teacher has good content knowledge, and teaching strategies need to be improved to centre stage learner-centred learning approach. The teacher understood the context of the learners taught, leading to a relatively successful lesson.

(b) Teaching and learning (lesson plan); analysis of lesson plan

No formal lesson plan was presented during the lesson observation. The teacher prepared the activities of the learners from the textbook. The lesson's objectives were made clear to the learners, and the terms were also simplified for the learners.

(c) Content knowledge on optics

Teacher C, before intervention on the optics, scored 8/35 (23%) in a visible light test, which indicates she had below-average content knowledge on the topic assessed. This result is very concerning as the teacher is expected to scaffold learners across the zone of proximal learner development in terms of visible light content knowledge in grade 8. With such a score, this raises questions about the teacher's ability to cognitively stimulate and assist her learners on the topic of visible light as its part of the curriculum she needs to teach.

4.4.3.2 Teacher C's views on practical (laboratory) work, inquiry learning, and the nature of science

(a) Inquiry learning in Teacher C's classroom

From the lesson observation, it became clear that the lesson was not entailing what an inquiry lesson is, and science was not portrayed to be *empirical,* tentative, inferential, creative, social and cultural, and no methods of science (such as hypothesis formulation, or analysis of data) was observed during the lesson. The lesson was derived from a content transferring lesson. Issues of resources are a concern at Teacher C's school. In a Natural Sciences pre-questionnaire, the teacher was asked if she would be able to facilitate practical work without a laboratory, and her response was '*yes, although this will not benefit the learners optimally. The educator can demonstrate, and the learners observe, take notes and answer questions'.* From the questionnaire, only her understanding of science process skills was observed. In a Jigsaw and shoestring questionnaire, Teacher C was asked if she has used shoestring approaches in her classroom before, and her response was *'no'.* A follow-up question asked the teacher if she would use shoestring approaches in an under-resourced classroom. Her response was ‘*yes, they are easily available resources and does not place strain on learners, to be careful in damaging expensive equipment resulting in being care-free when assembling the device’.* Furthermore, in the same questionnaire when the teacher was asked What does it mean when we refer to teachers as an agent of change?, her response was ‘*As a teacher, I am responsible to bring about positive change in my classroom regardless of having resources or not’.* From the above responses, the researcher concluded that Teacher C will be able to improvise in her Natural Sciences and use shoestring approaches, resulting in Teacher C being an agent of change. Also, Teacher C agreed that the intervention(s) addressed her potential development and her remarks were *‘a shift in mindset was made, and positive thinking was enhanced to be an agent of change’.* From the responses, it does prompt the researcher to think that Teacher C will be an agent of change and more shoestring inquiry-based teaching will be observed during the post-observation.

(b) Teacher C's responses in the UJ-DNA Barcoding questionnaire and Focus-group interview, prior to the DNA Barcoding intervention

Teacher C could not attend the UJ-DNA barcoding due to family responsibilities.

(c) Teacher C's views of the nature of science

Although the teacher demonstrated an informed view, or a partially informed view, in some of the items in the questionnaire, the predominant responses were classified as being uninformed views. In question 2 of the VNOS questionnaire, the teacher was asked how does an atom look, how certain are scientists about the nature of the atom, and what specific evidence she thinks scientists use to determine what an atom looks like. The response of Teacher C was ‘*an atom has protons and neutrons. Scientists are fairly certain about the nature of the atom since many theories were made and tested to be positive.*’

This response failed to provide a true reflection of what an atom looks like. For instance, the atom consists of negatively charged electrons, positively charged protons and neutrally charged neutrons. The electrons are the one circulating the nucleus of the atom. Secondly, the protons and the neutrons are found inside the nucleus of an atom. Her response further failed to capture the descriptive transition and periods of different theories that described what an atom looked like to date. She also did not provide details on how scientists determined what an atom looks like. In question 1, Teacher C was asked: ‘After the scientists have developed theory (e.g., atomic theory), does the theory ever change?’ And if she believed that the theories do change, she was also asked to explain why we bother to teach scientific theories. Her response was: *‘Theories are constantly proven and accepted or rejected based on new evidence that comes forth with changing times. We teach theories to have a baseline or foundation to compare new knowledge that arises.*’

This view is informed (I) as it does address the use of theories and why we teach scientific theories. Her view further acknowledged that theories could be challenged and changed based on constant scientific discoveries. In question 5, when the teacher was asked if there is a difference between scientific knowledge and opinion, and if she can illustrate her response by example, her response was as follows: *‘yes, scientific knowledge is based on tested and proven theories, whereas scientific opinion leads to knowledge if tested and proved* ‘.

This response is uninformed as scientific knowledge is objective while opinion is subjective. In Question 7 participants were asked, (a) Some astronomers believe that the universe is expanding while others believe that it is shrinking; still, others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data? and (b) the teacher was also asked a question about the differences and similarities between science and the arts. The teacher did not respond to the questions, and Teacher C missed an opportunity to demonstrate her understanding of these tenets of science. If the teacher had a nuanced understanding of the principles of science, such as science is tentative (and subjected to change), inferential, creative etc., the teacher could have answered the questions and substantiated her argument. The issue of time was not a factor as the teacher was given ample time to complete the questionnaire. Besides, the teacher was advised to submit when she had completed the questionnaire.

4.4.3.3 Teacher C's views on Science and Society

(a) Portraying the role of science in society during lessons: evidence from the lesson observations using RTOP, lesson plan and interviews

When Teacher C was asked how she contextualises her Natural Sciences lesson in the VNOS questionnaire, she did not respond to the question. During the class observation, a lesson on hygiene was taught and Teacher C did not contextualise the lesson, nor did she address the role of science in society. For instance, the issue of hygiene is a big concern in most communities. The teacher could have taken the leverage of relating bad hygiene to harmful microorganisms, or given learners an investigation activity to learn more of these microorganisms from their communities framework. (This will in all probability change in the post-Covid-19 era!) Teacher C was resourced with foldscope microscopes during the intervention (see Figure 3.13), and she thus had the apparatus to facilitate a hands-on inquiry lesson on microorganisms and hygiene. This would have provided a strong science and society focus on the lesson.

(b) Teacher C's view on the nature of indigenous knowledge

In the VNOIK questionnaire, Teacher C's understanding of indigenous knowledge was '*knowledge that stems from various cultures (is raw, untested knowledge); it is different since it is passed on from one generation to the next. It is not tested based on a theory*'. Teacher C's view was informed; she understood that indigenous knowledge is informed by culture and is transferred from one generation to the other. She also made a critical remark that indigenous knowledge is different to western knowledge that is verified through theories.

In question 2 she acknowledged that practitioners of indigenous knowledge, e.g., elders, herbalists and traditional healers, observe nature to generate this knowledge by doing experiments and tests to verify this knowledge. In the questionnaire, she commented that indigenous knowledge holders '*look/observe the properties of the plant and based on that they administer it for a specific ailment. They closely monitor the results and administer something different. I suppose it works (tested) through trial and error*'. This view is informed as the teacher was able to show that indigenous knowledge is *empirical*; and that nature is real, partly or generally tested and observed. The universe is orderly and partly predictable (Bohensky & Maru, 2011; Le Grange, 2007; Ogunniyi, 2004; Agrawal, 1995).

In question 4, Teacher C was asked if indigenous knowledge is transferred from one generation to the next over many decades and centuries, and if this knowledge stays the same or does change over time. Her response was '*it changes over time because environmental and climate changes occur which compels nature to change. Certain plants adapt, and therefore the properties used changes too*'. This response is informed. Teacher C managed to demonstrate that indigenous knowledge is *resilient yet tentative* (indigenous knowledge has withstood the test of time, but is continually changing with tradition; it is fluid and transformative, linked to people's experiences. In most of the questions from the VNOIK questionnaire Teacher C demonstrated more informed response.

4.4.3.4 Teacher C's views on assessment/ assessment practices

From the classroom observation, Teacher C asks learners questions and waits for a response from the learners. If the learners do not respond, she provides learners with the answers without providing rigorous dialogue to engage the learners. Later on, during the lesson as she teaches, she asked learners questions and asked learners to complete the task given in the textbook. The assessment style of the teacher did not capacitate the learners with 21st-century skills such as problem-solving and critical thinking skills. Very little attention was also given to test if learners can solve real-life problems. It cast doubt that the learners were capacitated and assessed for critical thinking skills.

4.4.3.5 Teacher C and Self-Directed Learning (SDL)

(a) Qualitative analysis of SDL

In the revised Rogan and Grayson rubric, Teacher C is on level 1. The teacher shows slight characteristics of SDL. For example, even when Teacher C does not know how to use shoestring science approaches, she has agreed to utilise the strategy because the strategy centralised using cheap and readily available resources. She also indicated an understanding of being an agent of change as bringing positive change in the classroom irrespective of the class being resourced or not. This is despite the teacher not engaging learners in inquiry-based learning due to lack of resources. Teacher C identified managing administration and being organised as her learning goals. It will be interesting to observe during the post-intervention if the teacher would have addressed her learning goals and if the teacher is a SDL, using shoestring approaches to facilitate learner-centred teaching.

(b) Quantitative analysis of SDL

The SDLI (Cheng et al., 2010) was used below to determine the teacher's views on SDL pre-intervention. Teacher’s views are recorded below in Table 4.10 as follows.

Table 4.10: SDL views of Teacher C

Sub-domain in the profile of implementation	Questions	Score of Teacher C	Score of Teacher C reported in percentage (%).
Learning motivation	Q 1-6	26/ 30	86.67
Planning and implementing	Q 7-12	19/ 30	63.34
Self-monitoring	Q 13-16	14/ 20	70
Interpersonal communication	Q 17-20	16/ 20	80
TOTAL		75/100	

In terms of the four sub-domains, Teacher C strongly views learning motivation as one of the sub-domains she resonates with the most. In the questionnaire, Teacher C also indicated that she knows what she needs to learn, and she hopes to improve and excel in her learning constantly. In Figure 4.10, Teacher C, in terms of learning motivation, scored 26/30, which translates to mean Teacher C is 86.67% motivated to learn.

In disparity to the interpretation above, Teacher C views planning and implementation as the sub-domain she resonates with the least. In the questionnaire, she also agreed that she is not good at arranging and controlling her learning time. In terms of Figure 4.10, Teacher C scored the lowest score of 19/30 amongst the other sub-domains.

In the SDLI pre-questionnaire Teacher C scored 75 out of 100. In relation to the revised Rogan and Grayson’s rubric, Teacher C was scaled at level 3, in terms of being SDL.

4.4.3.6 Teacher C's holistic wellbeing

(a) Wellbeing of Teacher C

In the stress management questionnaire, Teacher C made it explicit that she often felt stressed. She also indicated that the curriculum demands and pressure with pace-setters, finances, family and friends are the aspects that caused her most stress, in that order. She also indicated that one of her biggest problems is feeling inadequate (in terms of training) for the demands of teaching. Her concern was that the curriculum demand and administration made her feel overwhelmed. One of the stress symptoms indicated in the questionnaire was exhaustion. While working, she felt angry and overtired. She also did not take any leave in the past 12 months. She felt like her workload had increased in the past two years. What is worrisome in the questionnaire is that administration, teaching new subjects and increased student numbers resurfaced as her most significant concerns. It should be noted that the administration also 'float-up' as her professional development needs in the pre-intervention data. Lack of funds/resources/support to do the job, given responsibilities without the authority to make decisions and feeling isolated in curriculum decisions are some factors related to her work stress. In an informal discussion with Teacher C, she mentioned that these demands made her consider changing her field of work. This view is related to her response in the questionnaire when she was asked where she saw herself in the next five years from now. Her response was, '*working for another establishment in a promoted post*'. When Teacher C was asked, what were the two things which would make a significant difference in addressing her concerns, her response was '*Learning to plan things in advance and having proper resources as well as being mentored through a curriculum area.'* She also commented that the stress management workshop was excellent and commented that she would be able to implement some procedures or techniques to reduce stress. She also regarded the workshop as already having been a stepping stone to assist her coping with stress.

(b) Professional development needs of Teacher C

Teacher C indicated that she needs to be assisted with the following teacher professional development needs:

- Study strategies for learners
- How to manage stress
- Motivate learners in sciences
- Human skeletal system
- Evolution (fossils; relative dating and radiometric dating)

- Plant and animal tissues (simplify it for teachers in order to facilitate better teaching to the learners)
- Being organised and how to manage administration.

4.4.4 Post-intervention Data – Teacher C

4.4.4.1 Pedagogical orientation of Teacher C

Due to workload and other responsibilities, Teacher C became busy, and this resulted in decreased participation in the intervention, in comparison to the first six months of the intervention. Teacher C saw some improvement in most of the activities and during the classroom observation. Teacher C's pedagogical orientation slightly changed from transmission mode to more inquiry-based learning, and elements of effective group work were observable. In the Natural Sciences questionnaire (Refer to appendices F2 and F3 for pre and post questionnaire)., when the teacher was asked whether she will use PhET simulations in her classroom, her response was as follows '*I would formulate a problem or outcomes to reach. Guide learners on using the PhET, group them and let them self-discover the content. Have an interactive class discussion thereafter.'* The teacher used the textbook along with other resources such as PhET simulations to stimulate learning. The teacher used demonstrations to promote some inquiry learning. The teacher engaged learners with problem-based learning, and the activity encouraged learners to think deeply. There is some evidence that Teacher C will be an agent of change and will be more resourceful and use more inquiry-based methods, for instance, in the Natural Science questionnaire Teacher C commented by saying *'Loved the whole science on a shoestring idea; Innovative!'*

(a) Lesson observation using Reformed Teaching Observation Protocol (RTOP) instrument

The class observed was grade 9, and the lesson taught was on the visible construct. The seating arrangement was traditional rows, and the class consisted of more than 40 learners. The class is a mobile classroom without ventilation, and it is difficult to move around. The lesson began by the teacher greeting the learners and communicating the topic and the lesson objectives. This was followed by baseline questions on reflection and refraction. The classroom walls were decorated with the posters provided to the teacher during the intervention, and this created a more inviting learning climate. The lesson had been planned thoroughly. CAPS aims were broken down into clear lesson objectives (and or key questions were identified). Teaching and learning activities made perfect sense with the learning activities progressing from lower to higher levels of cognition. An assessment had been perfectly aligned with teaching and learning. Activities were planned to enhance the quality of teaching, learning, and assessment. The teacher continued with a demonstration of how light passes through different material, and the learners had to make predictions before the demonstration. The learners were also asked why there is a duplicate image of a person in the mirror. As the lesson proceeded, the teacher requested the learners to discuss and complete a worksheet on reflection and refraction. The teacher displayed good content knowledge and pedagogical content knowledge. There was engaged discussion amongst the learners, and the teacher walked around and assisted learners who were struggling. The lesson was engaging, and most of the learners responded positively. In an informal discussion with the teacher, she made me aware that she planned to use PhET simulation on the same topic the following day. Due to time constraints, the lesson finished while the teacher was giving feedback and homework to the learners.

(b) Teaching and learning; analysis of lesson plan

The lesson was well planned and structured. Appropriate teaching strategies were used to make the new content clear to the learners. There was an effective integration of resources to ensure that teaching and learning in a specific context was achieved. The learning activities were appropriate and relevant and captured the essence of the objectives. The teaching and learning phase demonstrated excellent skills by the teacher to teach specific content using applicable and creative explanations, analogies, and activities aimed at the appropriate level. Communication between learners was promoted. Assessment perfectly aligned with the lesson objectives and promoted learning effectively (excellent PCK and GPK). Effective use of appropriate assessment strategies (types, tools, agents, methods) was shown. The lesson plan demonstrated how the consolidation phase would result in new knowledge and skills (perfectly aligned with lesson objectives). Activities were also attached to the lesson plan. Teacher C paid a lot of consideration to the planning of the lesson.

(c) Exit interview and discussing the recorded lesson using stimulated video recall

Due to time constraints, Teacher C had to attend another class, and an arrangement was made to conduct another interview at a later stage. An interview with Teacher C became impossible after several arrangements and attempts. The common reason given was a busy schedule, the administration that needs to be sorted, and finalisation of continuous assessment. Due to the ethical principles that I subscribed to in this research, I had to comply.

(d) Content knowledge on optics

Teacher C saw a percentage increase of 31% in the optics test. In the pre-test Teacher C scored 8/35 (23%) and in the post-test 19/35 (54%). The teacher benefited from the intervention in terms of increased subject knowledge**.** What was impressive was that the lesson that was observed was the same topic that was dealt with during the teacher professional development intervention. In the Natural Sciences post-questionnaire, Teacher C made the following comment '*interesting section, had no stable knowledge on optics. Today I learnt a few things regarding reflection and refraction*.'

(e) Evidence of pedagogical orientation from the portfolio

The lesson submitted in the portfolio was also on visible light, and particularly on the transfer of light. The lesson plan began with lesson objectives and the content to be discussed with the learners. In the introduction, the teacher started the lesson by posing a series of questions to trigger prior knowledge regarding reflection and refraction. She also planned to ask the question 'How did the San or the Khoi spearfish near a riverbank? How can you apply reflection and refraction to spearfishing?' In the lesson plan, the teacher included learner activities that required group work. For instance, the educator planned to divide the learners into pairs and have them moved to the computer lab where they would engage with the PhET simulations. The learners would be given a worksheet with instructions for interacting with the virtual simulations and completing their worksheets. The lesson plan also had elements of problem-based learning. For instance, under learner activities, the learners would receive a hand-out of guiding questions, which would enable them to understand the concept of refraction and reflection better. At the time of the observation, the teacher mentioned that the school was under-resourced, and the teacher was provided with a tablet do demonstrate PhET simulation inquiry activities.

4.4.4.2 Teacher C's views on practical (laboratory) work, inquiry learning, and the nature of science

(a) Inquiry learning in Teacher C's classroom

There has been a difference in the pre-observation and the post-observation. In the pre-observation, Teacher C was completely teacher-centred. After the intervention, there was evidence that Teacher C has changed her teaching approach. Her teaching strategy centred learners in inquiry-based learning. During the lesson, I observed Teacher C engaged learners in both problem-based learning and group work, as mentioned earlier. The lesson consisted of demonstrations followed by a worksheet that required learners to find answers to the problems themselves. The post-observation favoured more of an inquiry approach as compared in the pre-observation.

(b) Teacher C's responses in the UJ DNA Barcoding questionnaire (and focus group interview afterwards)

Teacher C did not attend the intervention at the University of Johannesburg on DNA Barcoding due to family responsibilities.

(c) Teacher C's Views on the nature of Science (VNOS)

Teacher C did attend the SLP on the indigenous knowledge but did not submit her post-questionnaire on VNOS. I, therefore, had to assess the teacher’s understanding of the nature of science from the lesson plan and classroom observation. Teacher C engaged learners in the science process skills such as observing. In the lesson observed, the learners had to make structured observations on how light moves in different material, and in the portfolio lesson plan the teacher indicated that the learners would see the visual simulation on bending light during the PHET simulations. This is the most basic skill in science. The learners will be using their five senses, and this will help them make predictions. Observing is also essential in learning other science process skills. Learners were also engaged in communicating their views and findings in the post-lesson observation. In the portfolio, the learners were expected to provide feedback after doing an inquiry activity. Learners were provided with an opportunity to predict before they could engage with the activity. Prediction is an educated guess that provides learners with an opportunity to be cognitively stimulated. These inferences show that Teacher C‘s views on the nature of science were enhanced. Amongst many tenets of science, Teacher C has demonstrated that science is empirical and inferential.

4.4.4.3 Teacher C's views on Science and Society

(a) Portraying the role of science in society during lessons: evidence from the lesson observations using RTOP, lesson plan and interviews

When Teacher C was asked how she contextualises her Natural Sciences lesson in the VNOS questionnaire, she did not respond to the question. During the class observation, a lesson on hygiene was taught and Teacher C did not contextualise the lesson, nor did she address the role of science in society. For instance, the issue of hygiene is a big concern in most communities. The teacher could have taken the leverage of relating bad hygiene to harmful microorganisms, or given learners an investigation activity to learn more of these microorganisms from their communities. (This will in all probability change post-Covid-19.) Teacher C was resourced with foldscope microscopes during the intervention and she thus had the apparatus to facilitate a hands-on inquiry lesson on microorganisms and hygiene. This would have provided a strong science and society focus on the lesson.

(b) Teacher C's view on the nature of indigenous knowledge

In the VNOIK questionnaire (Refer to appendix H2)., Teacher C’s understanding of indigenous knowledge was ‘*knowledge that stems from various cultures (is raw, untested knowledge); it is different since it is passed on from one generation to the next. It is not tested based on a theory*’. Teacher C’s view was informed; she understood that indigenous knowledge is informed by culture and is transferred from one generation to the other. She also made a critical remark that indigenous knowledge is different to western knowledge that is verified through theories.

In question 2 she acknowledged that practitioners of indigenous knowledge, e.g. elders, herbalists and traditional healers, observe nature to generate this knowledge by doing experiments and tests to verify this knowledge. In the questionnaire, she commented that indigenous knowledge holders ‘*look/observe the properties of the plant and based on that they administer it for a specific ailment. They closely monitor the results and administer something different. I suppose it works (tested) through trial* *and error*'. This view is informed as the teacher was able to show that indigenous knowledge is *empirical*; and that nature is real, partly or generally tested and observed. The universe is orderly and partly predictable (Bohensky & Maru, 2011; Le Grange, 2007; Ogunniyi, 2004; Agrawal, 1995).

In question 4, Teacher C was asked if indigenous knowledge is transferred from one generation to the next over many decades and centuries, and if this knowledge stays the same or does change over time. Her response was '*it changes over time because environmental and climate changes occur which compels nature to change. Certain plants adapt, and therefore the properties used changes too*'. This response is informed. Teacher C managed to demonstrate that indigenous knowledge is *resilient yet tentative* (indigenous knowledge has withstood the test of time, but is continually changing with tradition; it is fluid and transformative, linked to people's experiences. In most of the questions from the VNOIK questionnaire Teacher C demonstrated more informed response.

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(a) Qualitative analysis of SDL

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In terms of the four sub-domains, Teacher C strongly views learning motivation as one of the sub-domains she resonates with the most. In the questionnaire, Teacher C also indicated that she knows what she needs to learn, and she hopes to improve and excel in her learning constantly. In Figure 4.10, Teacher C, in terms of learning motivation, scored 26/30, which translates to mean Teacher C is 86.67% motivated to learn.

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4.4.4.6 Teacher C's holistic wellbeing

(a) Wellbeing of Teacher C

In the stress management questionnaire (Refer to appendix N3)., Teacher C made it explicit that she often felt stressed. She also indicated that the curriculum demands and pressure with pace-setters, finances, family and friends are the aspects that caused her most stress, in that order. She also indicated that one of her biggest problems is feeling inadequate (in terms of training) for the demands of teaching. Her concern was that the curriculum demand and administration made her feel overwhelmed. One of the stress symptoms indicated in the questionnaire was exhaustion. While working, she felt angry and overtired. She also did not take any leave in the past 12 months. She felt like her workload had increased in the past two years. What is worrisome in the questionnaire is that administration, teaching new subjects and increased student numbers resurfaced as her most significant concerns. It should be noted that the administration also 'float-up' as her professional development needs in the pre-intervention data. Lack of funds/resources/support to do the job, given responsibilities without the authority to make decisions and feeling isolated in curriculum decisions are some factors related to her work stress. In an informal discussion with Teacher C, she mentioned that these demands made her consider changing her field of work. This view is related to her response in the questionnaire when she was asked where she saw herself in the next five years from now. Her response was, '*working for another establishment in a promoted post*'. When Teacher C was asked, what were the two things which would make a significant difference in addressing her concerns, her response was '*Learning to plan things in advance and having proper resources as well as being mentored through a curriculum area.'* She also commented that the stress management workshop was excellent and commented that she would be able to implement some procedures or techniques to reduce stress. She also regarded the workshop as already having been a stepping stone to assist her coping with stress.

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Teacher C indicated that she needs to be assisted with the following teacher professional development needs:

- Study strategies for learners
- How to manage stress
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- Human skeletal system
- Evolution (fossils; relative dating and radiometric dating)
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- Being organised and how to manage administration.

4.4.5 Post-intervention Data – Teacher C

4.4.5.1 Pedagogical orientation of Teacher C

Due to workload and other responsibilities, Teacher C became busy, and this resulted in decreased participation in the intervention, in comparison to the first six months of the intervention. Teacher C saw some improvement in most of the activities and during the classroom observation. Teacher C‘s pedagogical orientation slightly changed from transmission mode to more inquiry-based learning, and elements of effective group work were observable. In the Natural Sciences questionnaire, when the teacher was asked whether she will use PhET simulations in her classroom, her response was as follows ‘*I would formulate a problem or outcomes to reach. Guide learners on using the PhET, group them and let them self-discover the content. Have an interactive class discussion thereafter.’* The teacher used the textbook along with other resources such as PhET simulations to stimulate learning. The teacher used demonstrations to promote some inquiry learning. The teacher engaged learners with problem-based learning, and the activity encouraged learners to think deeply. There is some evidence that Teacher C will be an agent of change and will be more resourceful and use more inquiry-based methods, for instance, in the Natural Science questionnaire Teacher C commented by saying *‘Loved the whole science on a shoestring idea; Innovative!’*

(a) Lesson observation using Reformed Teaching Observation Protocol (RTOP) instrument

The class observed was grade 9, and the lesson taught was on the visible construct. The seating arrangement was traditional rows, and the class consisted of more than 40 learners. The class is a mobile classroom without ventilation, and it is difficult to move around. The lesson began by the teacher greeting the learners and communicating the topic and the lesson objectives. This was followed by baseline questions on reflection and refraction. The classroom walls were decorated with the posters provided to the teacher during the intervention, and this created a more inviting learning climate. The lesson had been planned thoroughly. CAPS aims were broken down into clear lesson objectives (and or key questions were identified). Teaching and learning activities made perfect sense with the learning activities progressing from lower to higher levels of cognition. An assessment had been perfectly aligned with teaching and learning. Activities were planned to enhance the quality of teaching, learning, and assessment. The teacher continued with a demonstration of how light passes through different material, and the learners had to make predictions before the demonstration. The learners were also asked why there is a duplicate image of a person in the mirror. As the lesson proceeded, the teacher requested the learners to discuss and complete a worksheet on reflection and refraction. The teacher displayed good content knowledge and pedagogical content knowledge. There was engaged discussion amongst the learners, and the teacher walked around and assisted learners who were struggling. The lesson was engaging, and most of the learners responded positively. In an informal discussion with the teacher, she made me aware that she planned to use PhET simulation on the same topic the following day. Due to time constraints, the lesson finished while the teacher was giving feedback and homework to the learners.

(b) Teaching and learning; analysis of lesson plan

The lesson was well planned and structured. Appropriate teaching strategies were used to make the new content clear to the learners. There was an effective integration of resources to ensure that teaching and learning in a specific context was achieved. The learning activities were appropriate and relevant and captured the essence of the objectives. The teaching and learning phase demonstrated excellent skills by the teacher to teach specific content using applicable and creative explanations, analogies, and activities aimed at the appropriate level. Communication between learners was promoted. Assessment perfectly aligned with the lesson objectives and promoted learning effectively (excellent PCK and GPK). Effective use of appropriate assessment strategies (types, tools, agents, methods) was shown. The lesson plan demonstrated how the consolidation phase would result in new knowledge and skills (perfectly aligned with lesson objectives). Activities were also attached to the lesson plan. Teacher C paid a lot of consideration to the planning of the lesson.

(c) Exit interview and discussing the recorded lesson using stimulated video recall

Due to time constraints, Teacher C had to attend another class, and an arrangement was made to conduct another interview at a later stage. An interview with Teacher C became impossible after several arrangements and attempts. The common reason given was a busy schedule, the administration that needs to be sorted, and finalisation of continuous assessment. Due to the ethical principles that I subscribed to in this research, I had to comply.

(d) Content knowledge on optics

Teacher C saw a percentage increase of 31% in the optics test. In the pre-test Teacher C scored 8/35 (23%) and in the post-test 19/35 (54%). The teacher benefited from the intervention in terms of increased subject knowledge**.** What was impressive was that the lesson that was observed was the same topic that was dealt with during the teacher professional development intervention. In the Natural Sciences post-questionnaire, Teacher C made the following comment '*interesting section, had no stable knowledge on optics. Today I learnt a few things regarding reflection and refraction*.'

(e) Evidence of pedagogical orientation from the portfolio

The lesson submitted in the portfolio was also on visible light, and particularly on the transfer of light. The lesson plan began with lesson objectives and the content to be discussed with the learners. In the introduction, the teacher started the lesson by posing a series of questions to trigger prior knowledge regarding reflection and refraction. She also planned to ask the question 'How did the San or the Khoi spearfish near a riverbank? How can you apply reflection and refraction to spearfishing?' In the lesson plan, the teacher included learner activities that required group work. For instance, the educator planned to divide the learners into pairs and have them moved to the computer lab where they would engage with the PhET simulations. The learners would be given a worksheet with instructions for interacting with the virtual simulations and completing their worksheets. The lesson plan also had elements of problem-based learning. For instance, under learner activities, the learners would receive a hand-out of guiding questions, which would enable them to understand the concept of refraction and reflection better. At the time of the observation, the teacher mentioned that the school was under-resourced, and the teacher was provided with a tablet do demonstrate PhET simulation inquiry activities.

4.4.5.2 Teacher C's views on practical (laboratory) work, inquiry learning, and the nature of science

(a) Inquiry learning in Teacher C's classroom

There has been a difference in the pre-observation and the post-observation. In the pre-observation, Teacher C was completely teacher-centred. After the intervention, there was evidence that Teacher C has changed her teaching approach. Her teaching strategy centred learners in inquiry-based learning. During the lesson, I observed Teacher C engaged learners in both problem-based learning and group work, as mentioned earlier. The lesson consisted of demonstrations followed by a worksheet that required learners to find answers to the problems themselves. The post-observation favoured more of an inquiry approach as compared in the pre-observation.

(b) Teacher C's responses in the UJ DNA Barcoding questionnaire (and focus group interview afterwards)

Teacher C did not attend the intervention at the University of Johannesburg on DNA Barcoding due to family responsibilities.

(c) Teacher C's Views on the nature of science (VNOS)

Teacher C did attend the SLP on the indigenous knowledge but did not submit her post-questionnaire on VNOS. I, therefore, had to assess the teacher’s understanding of the nature of science from the lesson plan and classroom observation. Teacher C engaged learners in the science process skills such as observing. In the lesson observed, the learners had to make structured observations on how light moves in different material, and in the portfolio lesson plan the teacher indicated that the learners would see the visual simulation on bending light during the PHET simulations. This is the most basic skill in science. The learners will be using their five senses, and this will help them make predictions. Observing is also essential in learning other science process skills. Learners were also engaged in communicating their views and findings in the post-lesson observation. In the portfolio, the learners were expected to provide feedback after doing an inquiry activity. Learners were provided with an opportunity to predict before they could engage with the activity. Prediction is an educated guess that provides learners with an opportunity to be cognitively stimulated. These inferences show that Teacher C‘s views on the nature of science were enhanced. Amongst many tenets of science, Teacher C has demonstrated that science is empirical and inferential.

4.4.5.3 Teacher C's views on science and society

(a) Portraying the role of science in society during lessons: evidence from the lesson observations using RTOP, lesson plan and interviews

During the lesson observation, teacher C did not sufficiently link science content to a broader society. This is despite her response in question 4 of the Natural Sciences post-questionnaire that contextualising science means ‘*teaching knowledge and making it as relevant as possible to learners’ daily lives*’. What is positive, though, is that in the pre-questionnaire Teacher C did not respond to how she will contextualise science and post-intervention; she understands how she will contextualise her lesson.

(b) Teacher C's view on the nature of indigenous knowledge

Teacher C did not complete the post-VNOIK questionnaire. Teacher C was sensitised during the SLP on how to integrate indigenous knowledge in her lesson. In the portfolio assignment Teacher C indicated that she will start her lesson by asking learners how the Khoisan spearfished near a riverbank. This was followed with a question on how refraction and reflection could be applied to spearfishing. It was interesting that the lesson addressed context-sensitive science in making learners think. This was the only section in the lesson plan that addressed indigenous knowledge. It should also be made clear that the two-days workshop is too superficial to bring a complete change in how indigenous knowledge should be integrated into the science classroom.

4.4.5.4 Teacher's views on assessment/assessment practices

(a) Reformed Teaching Observation Protocol (RTOP) and lesson plan

Teacher C’s assessment practise improved in the post-intervention. As compared to asking learners questions and waiting for responses, Teacher C in the post-intervention provided learners with the assessment that is targeting both the lower-order cognition and higher-order question, which was not evident in the pre-intervention. The only flaw was that the activities are directly taken from the textbooks. No creativity in terms of assessment was explored or implemented.

(b) SLP Portfolio

In the portfolio, the teacher's assessment practice is observed as creative. For instance, it included PhET simulations. These technologies are reported as useful to engage learners in inquiry-based learning. In the portfolio, the learners are provided with two tables to complete with instructions. In the two tables, the learners need to determine the reflected angle and refracted angle where the medium is air-to-water. The learners are also required to draw the rays as observed from the simulation after passing light into the water at different incident angles. The only value given in the experiment is the angle between 5° and 85° that the learner needs to fill in in the incident angle column; the learners have to repeat the same procedures using different material such as air and glass and water and glass. At the end of the lesson, the learners had to compare the different reflected and refracted angles. The lesson is placed in such a way that it assesses both lower-order questions such as drawing and comparing at higher-order cognitive.

4.4.5.5 Teacher C's Self-Directed Learning (SDL)

(a) Qualitative analysis of SDL

In terms of the qualitative data, Teacher C moved from level 1 to level 2 in terms of the revised Rogan and Grayson's rubric. After Teacher C saw her poor optics test results (pre-intervention), she made an effort to increase her knowledge on optics, and this resulted in an increase of 31% in her post-intervention optics test. During the observation, it should be highlighted that Teacher C showed characteristics of SDL. In the pre-intervention, she knew what an agent of change meant. In the post-intervention, she displayed the agency. In her portfolio, she demonstrated how PhET simulations could be used to facilitate inquiry lessons and used a creative assessment plan. In the classroom interaction, her pedagogical orientation changed from direct action to inquiry-based teaching. These changes in the post-intervention all happened because the teacher had to set her goal to improve her learning to more transformative teaching, and that required the teacher to be an agent of change.

(b) Quantitative analysis of Teacher C's SDL, utilising the SDLI instrument (SDLI)

In the section below the researcher used SDLI (Cheng et al., 2010) to determine if Teacher C's view on SDL has changed (see table 4.11).

Table 4.11: Pre- and Post-SDL views of Teacher C

Pre-SDL views				Post-SDL views			
Sub-domain in the profile of implementation	Questions	Score of Teacher C	Score of Teacher C reported in percentage (%).	Score of Teacher C	Score of Teacher C reported in percentage (%)	Change in SDL scores	Change in SDL reported in percentage (%)
Learning motivation	Q 1-6	26 / 30	86.67	24/ 30	80.00	-2	-6.67
Planning and implementing	Q 7-12	19 / 30	63.34	17/ 30	56.67	-2	-6.67
Self-monitoring	Q 13-16	14 / 20	70.00	14/ 20	70.00	0	0
Interpersonal communication	Q 17-20	16/ 20	80.00	15/ 20	75	-1	-5
TOTAL		75/100		70/100		-5	-18.34

In Table 4.11 Teacher C scored 70 out of 100. This, according to the revised Rogan and Grayson's heuristics, mapped the teacher at level 2. In the pre-intervention Teacher C was mapped at level 3. As mentioned earlier, scholars such as Bailey (2016) and Bosch (2017) recommended that post-intervention data are more reliable than the pre-intervention data. The teacher's views in terms of the four sub-domains did not change. Teacher C's view was still strongly aligned with learning motivation.

Her view on planning and implementing remain the least of the four sub-domains. In both sub-domains, Teacher C reported a decline of 6.97, indicating that even though her views compared to the other four did not change, her SDL in terms of the two dropped significantly compared to the pre-intervention data. Teacher C in the post-data indicated agency and also set her personal, professional development needs such as: 'Keen to know more on shoestring approaches'.

4.4.5.6 Teacher C's holistic wellbeing

(a) General wellbeing after the intervention

Since no post-interview could be established, the researcher could not further probe into her wellbeing. In the professional development needs survey, Teacher C indicated that she still needs to be assisted with personal, professional development (time management, stress reduction). It does become apparent that even though the stress management workshop sensitised Teacher C on stress management techniques, at the coal face of teaching, Teacher C still feels overwhelmed and needs more assistance with wellbeing intervention and techniques.

(b) Professional development needs

In the Natural Sciences post-intervention Teacher C identified the following professional developmental needs:

- Knowledge on optics 'I have limited knowledge on optics.'
- Laboratory skills 'definitely require lab skills. Did not get enough exposure.'
- Problem-based learning approaches: 'Have touched on it, but would like to know more. How can I implement PBL in my classroom.'
- Cooperative learning techniques: 'require assistance.'
- Simulations and ICT'S: 'require assistance.'
- Science on a shoestring approaches: 'keen to know more.'
- Reflection: 'overall, good learning opportunity. Require more opportunities.'
- Her other needs are reflected in the appendix O2

4.4.6 Synthesis: Using revised Rogan and Grayson's (2003) heuristic to assess teacher professional growth, and plotting their learning/ development during a longitudinal and systemic teacher development programme

Below I used revised Rogan and Grayson's profile of implementation to map Teacher C's professional development during a longitudinal and systemic professional development as follows:

Table 4.12: Teacher C's progress

Table 4.12: Teacher C's progress during teacher professional development that spanned from 2017 to 2019																									
A HEURISTIC TO MAP TEACHERS SKILLS ACCORDING TO THE ROGAN AND GREYSON PROFILE OF IMPLEMENTATION																									
PRE- (X) AND POST- (0) INTERVENTION PROFILING HEURISTIC																									
	Classroom interaction					Practical work					Science and society					Assessment					Self-directed learning				
PARTICIPANT(S) IN TPD	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
TEACHER C		X	0			X	0				X 0						X	0					X 0		

4.5 PROFILE OF TEACHER D

4.5.1 Personal profile (biography) of Teacher D

Teacher D holds a BEd degree in Mathematics and Physical Sciences from the University of the Witwatersrand, commonly known as 'Wits University'. The school that Teacher D teaches at is in the location (formerly known as township schools) and embodies structural challenges similar to those of many South African 'township' schools. Teacher D is an ambitious teacher, teaching Mathematics, Physical Sciences and Natural Sciences. He is under the age of 30. With the intervention platform provided, Teacher D was inspired to apply for B.Ed. honours in Mathematics education 2019. At the time of reporting, Teacher D was an active honours student at North-West University, refer to appendix S7.

4.5.2 School and classroom

The school experiences structural challenges similar to those of many quintile 1 schools, such as under-resourced classrooms and overcrowding. The observed lesson semi-inspired inquiry minds and group work. Demonstration and learner-centred teaching approaches were favoured. The class was converted into dual space, with elements of a mini-laboratory and a classroom. The class consisted of a few science posters that aimed at sensitising learners to the fact that when entering the classroom, they are entering a different scientific epistemological space.

4.5.3 Pre-intervention data: Teacher D

4.5.3.1 Pedagogical orientation of Teacher D

Teacher D's pedagogical orientation can best be described as using guided demonstrations to promote a limited form of inquiry learning. The teacher used a textbook along with his written notes on the chalkboard to demonstrate an experiment on velocity using the ticker timer experiment. This insight is not supported by data emanating from the Natural Sciences pre-questionnaire, in question 4 in particular. When the teacher was asked how he plans for a Natural Sciences lesson, his response was '*textbook, internet and PowerPoint*'. For this specific observation, the internet and PowerPoint were not used. Due to limited resources, the teacher divided the class into four stations consisting of at least 10 learners per station sharing one ticker timer apparatus. North-West University donated four ticker timer apparatuses to Teacher D's school. The teacher stood in front of the class and demonstrated the experiment. The learners followed suit and assembled the ticker timer as per instructions. Due to a large number of learners in a group, some learners were pseudo-involved in the observation and discussions process. In the same questionnaire, Teacher D was asked in question 7 if it is possible to facilitate practical work without a laboratory. His response was '*yes, but it is difficult for learners to understand*'. The findings during the observation indicated that learners found it challenging to comprehend the constructs of displacement and velocity during the demonstrations. This is despite the teacher's pedagogical orientation centre-staging elements of inquiry learning. Some of the aspects of inquiry elements were learner engagement and co-operative interaction, a variety of responses coming from different groups.

(a) Lesson observation using Reformed Teaching Observation Protocol (RTOP) instrument

From the RTOP instrument, recordings of the following observations were made. The subject and grade observed was a grade 10 physical sciences lesson. The lesson was on mechanics with a particular focus on the ticker timer experiment on velocity. The seating arrangement was two parallel rows, with about five chairs per row. The lesson started with instructions to assemble the ticker timer, and teacher instructional strategies did not respect students' prior knowledge and preconceptions inherent therein. As earlier explained, Teacher D used a guided demonstration to facilitate teaching and learning. The positive aspect of the lesson design and implementation was to regard learners as members of a learning community. The learners were discussing amongst themselves the concepts of displacement, average velocity, constant velocity, and scalar and vector quantities. The lesson also captured fundamental concepts of the subjects, as mentioned in the above sentence.

(b) Teaching and learning; analysis of lesson plan

Even though the lesson captured some of the elements constituting a lesson plan, the lesson plan remained flawed and superficial. The lesson plan lacked time allocation, date of the lesson, time management within the lesson, learning outcomes or objectives, prior knowledge of the learners, application exercises or homework, assessment and assessment strategies. The only evident construct of the lesson plan was a summary of the lesson and reflection, learner involvement, core knowledge, instructions and conclusion.

(c) Content knowledge on optics

Teacher D scored 12/35 (34%) in a visible light pre-test (Refer to appendix J1); this score suggests that the teacher had under-developed content knowledge of optics. One of many significant concerns is that Teacher D did not understand why light bends as it travels from air into the water. This knowledge is imperative as it forms the baseline for teaching geometrical optics in grade 11. This raises concerns, as it implies that Teacher D, according to the CAPS standard, has a level 2 understanding of the content tested, which is a score between 30 and 39.

4.5.3.2 Teacher D's views on practical (laboratory) work, inquiry learning, and the nature of science

(a) Inquiry learning in Teacher D's classroom

The findings emanate from the data recorded using the RTOP instrument. Even though the lesson demonstrated elements of the inquiry-based approach, it only focused on observations, measuring different displacements on the ticker timer and explaining what is meant by constant velocity and making an inference to explain the concept of average velocity. The teacher did not begin with a question that prompts curiosity and a sense of wonder; nor did he encourage in-depth thinking. No activity was provided to learners to demonstrate their understanding of concepts under the investigation. The learners were not allowed an opportunity to engage in problem-solving, critical thinking, recording of data (even though the learners measured different displacements during the experiment). The learners had a chance to communicate their data using tables and graphs, but that did not come to light. The teacher missed an opportunity to provide learners with the skills to write a scientific report.

(b) Teacher D's responses in the UJ-DNA barcoding questionnaire and focus-group interview, prior to the DNA Barcoding intervention

In the questionnaire, the teacher reflected that he is at level 4 (out of 5) in handling laboratory equipment. In the same question, he claimed to be confident in '*working with lab equipment'.* When the teacher was asked how often he does practical work in terms of laboratory investigations with his learners, his response was as follows: '*once in a month (2-3 times in a term). The school does not have the equipment to do practical work.*' This response is concurrent with classroom observation. Teacher D was confident with handling the ticker timer's apparatus, and the school is not well resourced with laboratory equipment as stated. This further indicates that even when the teacher is confident in handling and using laboratory equipment, due to the systemic lack of resources, most learners might not be capacitated with laboratory science skills. It will be interesting to document whether the teacher will be using science on the shoestring approaches in the post-data. In question 4, Teacher D's understanding of DNA barcoding is 'short barcoding that identifies species'. The teacher's response is to a large extent in sync with the DNA barcoding definition. DNA barcoding is defined as a method of identifying organisms based on a short, standardised fragment of genomic DNA. The teacher did not understand what polymerase chain reaction meant before the intervention in question 5. In question 6, when the teacher was asked how he could make the study of DNA relevant and interesting to the learners, e.g how to contextualise DNA technology so that learners understand how it is used in everyday life, his response was '*using PhET simulation to show how learners DNA barcoding work. Engage learners with the use of tablet to play around with simulation*'. This response indicates a willingness to be an agent of change, and further indicates that the teacher understands the meaning of contextualising science. A similar understanding of agency is derived from the Natural Sciences questionnaire, where the teacher indicated that he would use mirrors to contextualise the lesson on the topic of optics.

(c) Teacher D's views of the nature of science

Teacher D did not complete a VNOS questionnaire. From the basis of the lesson observed, the following inferences were made. The teacher demonstrated some elements that indicated that science is empirical. For instance, he demonstrated that science is observable and testable, from the experiment conducted by the learners. The learners were afforded an opportunity to observe and test the concept of velocity. The teacher demonstrated that science uses the reductionist approach. Complex phenomena such as mechanics were broken down into simpler concepts of displacement and velocity. These terms are used in mechanics to provide a conceptual understanding of concepts such as acceleration, force, impulse and are used in many applications that centralise themes in mechanics. The part-to-the-whole method was used, and if learners understood the concept of constant velocity, they might more easily grasp that the change in velocity is the definition of acceleration. Methods were superficially integrated into the lesson. The teacher sensitised learners to the concept that velocity can be confirmed experimentally. It should be highlighted that some tenets of science were pseudo-demonstrated. The teacher in his lesson did not show science as *tentative, inferential, creative and theory-laden*. It is from the lesson observation that I make the basis that Teacher D has a superficial understanding of the tenets of science.

4.5.3.3 Teacher D's views on Science and Society

(a) Portraying the role of science in society during lessons: evidence from the lesson observations using RTOP, lesson plan and interviews

During the class observation, Teacher D did not contextualise his lesson, despite having the understanding to contextualise science in the Natural Science and DNA barcoding questionnaire. From the observation, the lesson observed was completely CAPS compliant and failed to make a societal link (science-and-society approach) or better address the learner's affective domain by making the lesson interesting and attractive. The concept of velocity has endless meaning in society, for instance in the uses of Global Positioning Systems (GPS) devices, and could also have been related to the concept of speed (the speedometer in the car).

(b) Teacher D's view on the nature of indigenous knowledge

No elements of indigenous knowledge emanated from the teaching. This indicates that little transformative teaching took place in terms of IK-contextualisation of the curriculum. This is despite the teacher's comment in the Natural Sciences questionnaire, that 'learners will start enjoying science when fusing it with indigenous knowledge'. Gibson (2000) refers to this phenomenon as mode 2 learning or context-sensitive science and mentions that it holds affordances to address the learner's affective domain, which is mostly marginalised in the science classrooms (De Beer & Peterson, 2011).

4.5.3.4 Teacher D's views on assessment/assessment practices

From the lesson plan and the classroom observation, the teacher did not provide the learners with any form of assessment opportunities. No homework or class activity was made available in the lesson, nor did the experiment result in any form of assessment opportunity. This resulted in poor teaching practice, as no evidence was made to evaluate learners' understanding and challenges of content that was taught. This is regardless of the CAPS recommendation that learners should be given at least two problem-solving exercises every day as far as possible (CAPS, 2008).

4.5.3.5 Teacher D and Self-Directed Learning (SDL)

(a) Qualitative analysis of SDL

Based on the qualitative data, Teacher D showed limited self-directed learning and would function on level 1 in the revised Rogan and Grayson heuristic.

(b) Quantitative analysis of Teacher D's SDL, utilising the SDLI instrument

SDLI was used to analyse data in the four sub-domains, as indicated in Table 4.13. Teacher D scored 79 out of 100, and the sub-domain score is provided below.

Table 4.13: SDL of Teacher D

Sub-domain in the profile of implementation	Questions	Score of Teacher D	Score of Teacher D reported in percentage (%).
Learning motivation	Q 1-6	27 / 30	90.66
Planning and implementing	Q 7-12	21 / 30	70.00
Self-monitoring	Q 13-16	15 / 20	75.00
Interpersonal communication	Q 17-20	16 / 20	85.00
TOTAL:		79/100	

In terms of the four sub-domains, Teacher D feels very strong in terms of learner motivation. Teacher D scored 27/30, which translated in him being 90.66% motivated to learn. Thus, I claim that teacher D joined the intervention because he is eager to learn. For instance, in the Natural Sciences pre-questionnaire, when the teacher was asked what his expectations for this intervention were, his response was, '*Learn from my team on how they teach in their classroom*'. In the same questionnaire, he also stated that *'improve my incorporation of ICT, indigenous knowledge in my science teaching*'. The teacher scored the lowest score in the self-monitoring sub-domain. He scored 15/20, which translates in Teacher D having a view that he is 75% confident in self-monitoring. Even though this has been the lowest score of Teacher D, this is still interpreted as a relatively good score for self-monitoring. It provides an idea that the teacher can monitor himself and his work. Since Teacher D is intending to enrol for B.Ed. honours, it will be interesting to see if there is any change in the teacher's view of learning motivation and self-monitoring in the post-intervention data.

4.5.3.6 Teacher D's holistic wellbeing

(a) Wellbeing of Teacher D

The teacher indicated that his work is straining him, particularly the administration work that does not seem to end. He further stated that most of the time he is frustrated and feeling overwhelmed by tight deadlines and large classes. Unfortunately, Teacher D did not attend the stress management workshop.

(b) Professional development needs of Teacher D

Teacher D indicated that he needed to be assisted with bursaries to enrol for post-graduate studies. He also stated that he needs assistance with strategies to teach overcrowded classrooms and to deal with tedious administration. Since the intervention was designed to address the teacher's needs, the researcher will organise a person in the admission and bursary office to provide the teacher with essential information.

4.5.4 Post-intervention Data – Teacher D

4.5.4.1 Pedagogical orientation of Teacher D

Unfortunately**,** Teacher D did not provide the researcher with an opportunity to observe his post-intervention teaching. In two instances, the researcher went to the school upon invitation to observe the teacher, without success. Regardless of the arrangements made between the teacher and the researcher, the teacher did not feel ready to be observed, and on the second occasion had to attend a SADTU meeting. Due to the ethical guidelines, the researcher had to abide by the regulation and respect the teacher‘s decision. Another attempt was negotiated by the researcher, but the teacher did not respond to the researcher‘s call or to WhatsApp texts. The teacher did attend the SLP and did submit his portfolio. The researcher drew from the insights of the lessons to make inferences of the teacher's pedagogical orientation. It should also be made clear that the teacher did attend the DNA barcoding, but could participate in the interview since he had to leave immediately after the intervention. The teacher did submit the DNA barcoding questionnaire, Natural Sciences post-questionnaire, Self-directed learning instrument and did write the optics post-test.

From the lesson provided in the portfolio, the elements of inquiry-based approach are similar to the ones in the pre-intervention data. The teacher still arranges the learners in groups and learners discuss terms. For instance, in the lesson submitted, the learners had to define the terms *wavelength, amplitude, crest* and *troughs* using their textbooks. Even though the lesson had elements of inquiry and cooperative learning, only learner interaction was promoted. The teacher's pedagogical orientation did not change after the intervention. What emanates from this lesson was that Teacher D felt confident with learner-centred learning approaches, but unfortunately, the group work did not inspire positive interdependence, individual and group accountability, interpersonal and small group skills and group processing, which are characteristics of cooperative learning. When Teacher D was asked in question 6 if the workshop had changed his views on cooperative learning methods in the Natural Sciences classroom, his response was, '*cooperative learning enables learners to grasp concepts for life*'. This view indicates that Teacher D has an informed view of cooperative learning. Even though the teacher engaged the learners in group work, the lesson lacked the elements constituting cooperative learning. The lesson further did not emerge learners in problem-based learning.

(a) Lesson observation using Reformed Teaching Observation Protocol (RTOP) instrument

No lesson was observed using the RTOP instrument due to the unavailability of the teacher, as mentioned in section 4.2.3.

(b) Teaching and learning; analysis of lesson plan

The lesson plan lacked change in terms of improvement. The lesson missed the essential components that constitute the generic constructs of a lesson plan. For instance, time allocation was not indicated. This is a concern as this indicates a superficial understanding of planning. The date of the lesson was omitted. The prior learning of learners on the construct of waves was not considered, and learners were not stimulated or sensitised on the topic taught. The lesson did not indicate which learning outcome(s) or objective(s) will be achieved. What is disconcerting is that no classwork activity or homework was designed for the learners. This further indicates that assessment was not considered during and after the lesson. The structure of the lesson remains similar to that noted in the pre-intervention.

(c) Exit interview and discussing the recorded lesson using stimulated video recall

Due to the ethical reason mentioned in section 4.2.3, the interview with Teacher D was not conducted.

(d) Content knowledge on optics

Teacher D scored 14/35 (40%) in a visible light post-test (Refer to appendix J2, suggesting that the teacher still has under-developed content knowledge of optics after the intervention. As compared to the pre-test, Teacher D in post-test understood that light bends as it travels from air into water. This finding indicates that even after the intervention, the teacher did not make significant progress in developing his content knowledge on the construct of optics. What becomes a huge concern is that Teacher D also teaches Physical Sciences in grade 10. These results suggest that learners might not draw significant 'millage' in terms of understanding the topic under investigation if the content knowledge of the teacher is not improved.

4.5.4.2 Teacher D's views on practical (laboratory) work, inquiry learning, and the nature of science

(a) Inquiry learning in Teacher D's classroom

The findings emanate from the data recorded from the lesson plan. The lesson did not demonstrate elements of inquiry-based learning. The lesson only focused on observations similar to the lesson observed in the pre-intervention. This could be because the lesson was CAPS fixed. In the Physical Sciences CAPS (p.26), the learners are required to perform a practical demonstration. The learners are required to observe the motion of a single pulse travelling on a long, soft spring or a heavy rope. Teacher D followed the prescribed curriculum, and the researcher provided an appreciative view and also a critical stance on the lesson and inquiry learning. The lesson had only background information on the definition of transverse and longitudinal waves. In the lesson, a rope, slinky and PhET simulations are mentioned. The lesson did not indicate how the apparatus was going to be used. The learners, after playing with the apparatus, are required to pay particular attention to the wave and direction of propagation and what type of angle is formed. The lesson that was supposed to be inquiry-based did not pose questions, problems or scenarios to prompt learners to be problem solvers or to unlock inquisitive minds. Even though group work was emphasised, it was only used to help learners define the concepts of wavelength, amplitude, crest and troughs from the learner's textbook. The teacher missed an opportunity to afford learners a chance to practise other science process skills such as measuring, sorting and classifying, predicting or communicating findings. The only science process skill that was superficially practised was to observe the rope going up and down, and on the PhET simulation. This view agrees with the Teacher D's response to question 8 in the Natural Sciences post-intervention questionnaire. When Teacher D was asked to provide an example of how he would use problem-based learning, his response was as follows '*Use PhET simulation in the classroom and ask learners to give feedback about what they are observing*'. This is a clear indication that Teacher D has an under-developed understanding of what problem-based learning entails. Even after Teacher D followed the pace-setter by the DoE (appreciative view), the lesson remained uninspiring and did not remind the learners that they are doing science (critical view). This is despite the teacher having been capacitated to use inquiry strategies during the intervention.

(b) Teacher D's responses in the UJ DNA Barcoding questionnaire (and focus group interview afterwards)

After the intervention Teacher D saw an increased level of confidence in doing laboratory work. Teacher D was 5 out of 5 confident as compared to 4 out of 5 in the pre-intervention. He further made the following comment, *'I was exposed to exciting new lab equipment, and the team emphasized safety at all times'*. When the teacher was asked how he experienced the laboratory engagement and how did the laboratory inquiry assist him in his professional development, his response was '*to engage with chemicals, it helped me in that I must get more of my learners involved in a lab work is a vital part of science*'. This view suggests twofold insights that the intervention assisted the teacher to be more inquiry inclined in his lessons and also the teacher realised that he was not involving his learners in more inquiry-based, investigation-based lessons. This impression suggests that the teacher was sensitised to use more inquiry-based approaches. Unfortunately, the transfer in the post-intervention remained pseudo-inquiry-based as the only science process skills were dealt with.

In question 3, the teacher indicated aspects of the training that were challenging were '*steps of mixing the chemicals. Outline not very clear (of mixing), some materials were* *very new to work with*'. This view indicates that, even when the teacher reported a general feeling of excitement after the intervention, the experience was also uncomfortable and exposed the teacher to new techniques. This experience is termed 'prolepsis'. The teacher was exposed out of his depth in order to foster new learning and cognitive growth. To substantiate this argument, in pre-intervention the teacher did not understand what is meant by a polymerase chain reaction, and in the post-intervention Teacher D defined polymerase chain reaction as 'It is used in biology to analyse a single copy or more copies of DNA to generate thousands of copies', which reveals a more nuanced understanding of the concept.

(c) Teacher D's Views on the nature of science (VNOS)

Teacher D's views on the nature of science are improved in the post-intervention. In the Natural Sciences post-questionnaire, Teacher D indicated that science practicals should be made relevant to learners, in verbatim '*science practical and method of science should be linked to learners' experiences, in my class I'm going to ask the learners to make their own equipment's to test a particular topic by using science methods*'. This view indicates that teacher D is aware of the nature of science and further provides a context of how he will ascertain that his learners benefit practical skills. During the lesson observation, there was no link between science and society. This, despite the intervention, centralised contextualising science lesson and promoting teaching that addresses the affective domain of the learners taught.

4.5.4.3 Teacher D's views on science and society

(a) Portraying the role of science in society during lessons: evidence from the lesson observations using RTOP, lesson plan and interviews

In the post-questionnaire, when Teacher D was asked how he can contextualise science teaching, his response was '*I will try to link the knowledge that the learner understands first, by also showing that science is based on our different day to day life'.* In the lesson analysed Teacher D did not attempt to contextualise the lesson on waves. For instance, the teacher could have introduced the lesson by looking at the science of radio use. The radio uses amplitude modulation (AM) and frequency modulation (FM), and most learners are accustomed or are familiar with radio. The teacher would have had an opportunity to clarify the relationship between the amplitude and the frequency. This I contest will be the science that learners will remember as it would have centralised science that is relative to learners' experiences. In the lesson analysed, teacher D did not attempt to contextualise the lesson. This is despite the effort made during the intervention.

(b) Teacher D's view on the nature of indigenous knowledge

Even though Teacher D attended the SLP on indigenous knowledge, no elements of this knowledge became apparent in the lesson analysed.

4.5.4.5 Teacher's views on assessment/ assessment practices

The teacher's assessment practices did not change post-intervention. The teacher focuses on group assessment, where learners define definitions in groups on lower order cognition**.**

(a) Reformed Teaching Observation Protocol (RTOP) and lesson plan

From the lesson plan and the classroom observation, the teacher did not provide the learners with any form of assessment opportunities. No homework was given, and class activity that provided formative assessment opportunities was absent. This resulted in poor teaching practice, as no evidence was made to evaluate learners' understanding and the challenges of content that was taught. This is regardless of the CAPS recommendation that learners should at least be given two problem-solving exercises every day as far as possible (CAPS, 2008).

(b) SLP Portfolio

From the portfolio and the lesson plans analysed, the teacher's pedagogical orientation did not change. The overall analysis indicates that the teacher does not understand problem-based learning, and fails to facilitate the border-crossing between science, society and indigenous knowledge.

4.5.4.6 Teacher D's Self-Directed Learning (SDL)

(a) Qualitative analysis of SDL

Teacher D is at level 2 in terms of Rogan and Grayson's heuristic in terms of the SDL domain. In the post-intervention he showed minimal evidence of SDL. Even though the teacher used innovative strategies such as PhET simulations, the understanding of problem-based learning remained a matter of concern in the pre-and post-intervention. Teacher D indicated elements of SDL, like identifying resources. The teacher used ICTs and shoestring approaches (ropes to simulate waves), but because his understanding of problem-based learning as group work failed the intention of the lessons in the pre- and post-intervention. Another aspect is that in the pre-intervention phase the teacher indicated that he wanted to enrol for postgraduate studies.

(b) Quantitative analysis of Teacher D's SDL, utilising the SDLI instrument

Teacher D in the post-questionnaire scored 69 out of 100 in SDLI. In Table 4.14 his SDL is indicated in terms of the four sub-domains of the Cheng instrument.

Table 4.14: Pre- and Post-SDL of Teacher D

Pre-SDL views				Post-SDL views			
Sub-domain in the profile of implementation	Questions	Score of Teacher D	Score of Teacher D reported in percentage (%).	Score of Teacher D	Score of Teacher D reported in percentage (%)	Change in SDL scores	Change in SDL reported in percentage (%)
Learning motivation	Q 1-6	27 / 30	90.00	22 / 30	73.34	-5	-16.67
Planning and implementing	Q 7-12	21 / 30	70.00	17/ 30	56.67	-4	-13.34
Self-monitoring	Q 13-16	15 / 20	75.00	14/ 20	70.00	-1	-5
Interpersonal communication	Q 17-20	16 / 20	80.00	16/ 20	80.00	0	0
TOTAL:		79/100		69/100		-10	-35.01

In the pre-intervention, the teacher felt most strongly about learning motivation. Out of the four sub-domains, he also felt least strong about learning and planning. In the post-intervention Teacher D felt most strongly about interpersonal communication and least strong in the same sub-domain planning and implementation. Bailey (2016), Bosch (2017) and Mentz and De Beer (2019) indicate that during the pre-intervention, the teachers had naïve views about SDL. It is important to emphasise that Teacher D in the pre-intervention was scaled at level 3 in terms of Rogan and Grayson's revised profile of implementation for the quantitative SDL domain, and in the post-data he was at level 2.

4.5.4.7 Teacher D's holistic wellbeing

(a) General wellbeing after the intervention

Teacher D feels frustrated by undisciplined learners and administrative pressure, which are stressors in his life.

(b) Professional development needs

Teacher D was inspired to do post-graduate studies, and during reporting, he was already enrolled to do B.Ed. honours in mathematics education.

4.5.5 Synthesis: Using revised Rogan and Grayson's (2003) heuristic to assess teacher professional growth, and plotting their learning/development during a longitudinal and systemic teacher development programme

Below I used revised Rogan and Grayson's profile of implementation to map Teacher D's professional development during a longitudinal and systemic professional development as follows:

Table 4.15: Teacher D's progress

Table 4.15: Teacher D's progress during teacher professional development that spanned from 2017-2019																									
A HEURSITIC TO MAP TEACHERS SKILLS ACCORDING TO THE ROGAN AND GREYSON PROFILE OF IMPLEMENTATION																									
PRE- (X) AND POST (0) INTERVENTION PROFILING HEURISTIC																									
	Classroom interaction					Practical work					Science and society					Assessment					Self-directed learning				
PARTICIPANT(S) IN TPD	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
TEACHER D		X 0				X	0					X 0					X 0					X	0		

4.6 PROFILE OF TEACHER E

4.6.1 Personal profile (biography) of Teacher E

Teacher E holds a BEd degree in Natural Sciences from North-West University. Through the platforms provided in the 'A-Team' professional development programme, he was going to apply for a B.Ed. Honours degree in Natural Sciences for the 2020 intake. At this stage of reporting, Teacher E in an interview mentioned that due to circumstances he will only apply for the B.Ed. Honours programme in 2021. In a conversation with Teacher E during post-classroom observation, he mentioned that the efforts made by the university inspired him and he intends to study further until he obtains a PhD. Teacher E said he has three years' experience of teaching Natural Sciences grade 7-9 and Life Sciences Grade 10-12. Teacher E is a novice teacher who is under the age of 30. His teaching philosophy is to be the best teacher every day.

4.6.2 School and classroom

The school that Teacher E works at is similar to many township schools in South Africa. The school constitutes 100% black learners and staff members. Like many township schools, the school mentioned above falls under quantile 1, with most learners coming from low-income families. The lessons that I have observed were for a class consisting of 35 learners (19 boys and 16 girls). When the researcher went to observe Teacher E during the pre-and-post, he noted that many learners were roaming around the school. When the teacher was asked why most of the learners were outside during class periods, he responded that the school faces a challenge of discipline and gangsterism. What I also observed is that the school is under-resourced and most chairs and tables are either broken or lacking in numbers, and most learners have to share a chair, for instance. Another observation is that the classrooms do not inspire inquiring minds, and no posters were found on the walls. This is disappointing, as all teachers in the project were provided with posters funded by the Fuchs Foundation, as well as teaching resources and laboratory apparatus (and even tablets).

4.6.3 Pre-intervention data: Teacher E

4.6.3.1 Pedagogical orientation of Teacher E

During the pre-intervention observation, Teacher E, for the most part, used ‘active direct’ teaching that involved direct exposition of the science content. His teaching was predominantly focused on learners memorising content knowledge for outcome and examination purposes. Even though the teacher did not directly teach using a textbook in his hand, he wrote notes on the chalkboard and instructed learners to copy the notes for one period and then explained the notes in the following period. What was surprising is that engagement between the teacher and the learners was predominantly teacher-centred, and the only space where the learners had the autonomy to respond was through answering of questions in ‘chorus’ format. This is despite the CAPS curriculum emphasising that the curriculum should mainstream learner-centred approaches (the intended curriculum), but what I observed was the realised curriculum which centre-staged a teacher who transferred knowledge to the learners.

(a) Lesson observation using Reformed Teaching Observation Protocol (RTOP) instrument

The lesson that I observed was on excretion in human beings, with emphasis on the kidneys. Knowing that later on in the intervention we were going to engage teachers in a short learning programme on indigenous knowledge, I was curious at the start of the lesson whether the teacher was going to address indigenous knowledge as a means of contextualising the lesson. Apart from many muthi medicines that are used for kidney diseases, e.g., *Lessertia frutescens* (=*Sutherlandia frutescens*), the 'cancer bush' (Van Wyk & Gericke, 2018), there is always the concern that the excessive use of such medicines (which contain alkaloids and other active ingredients) could harm the liver and kidneys. Teacher E was mostly engaged in parrot-like teaching which assumed that learners enter the classroom as *tabula rasa*, and the 'sage on the stage' should unpack curriculum themes to them. Unfortunately, no contextualisation was done. During the observed lesson, Teacher E read the notes from the chalkboard for the learners and further explained the notes. A factor that might have contributed to this is that Teacher E did not have a projector and limited resources. However, the Fuchs Foundation donated resources such as posters, to mention but a few, but there was no sign of these resources during the visit. The teacher, while teaching, asked questions by calling the learners by their names for a response. During the observation, there was no evidence of inquiry learning due to the predominant nature of lecture style. No activity or homework was given to the learners.

(b) Teaching and learning (lesson plan); analysis of lesson plan

No formal lesson plan was presented during the lesson observation. The teacher wrote notes on the chalkboard and read them to the learners. The lesson lacked formal lesson objectives and/or pertinent questions; for instance, the lesson did not demonstrate relevance or connections with real-life application. During the teaching and learning phase, Teacher E displayed excellent content knowledge on the topic of excretion in humans but did not show the skill to teach specific content by using particular analogies, models, or activities aimed at addressing the topic. For instance, shoestring activities could be done, e.g. plastic straws could be used to demonstrate the function of the nephron. The body of the lesson consisted of transmission-mode approaches (no learner-centred pedagogies were used).

(c) Content knowledge on optics

Teacher E, before intervention on optics, scored 18/35 (51%) in a visible light test, which indicates that he had an average level of content knowledge in terms of optics. This raises concern since Teacher E only shows 51% of content coverage of visible light in the test. To provide learners with a good understanding of Natural Sciences, a teacher needs to have above-average content knowledge in the grade taught, particularly if the teacher predominantly depends on transmission mode. This could qualify the speculation that the reason the teacher wrote the notes on the board and the learners had to copy the notes is because the teacher might not have a nuanced understanding of the content knowledge.

4.6.3.2 Teacher E's views on practical (laboratory) work, inquiry learning, and the nature of science

(a) Inquiry learning in Teacher E's classroom

During the observed lesson, the teacher did not engage learners in inquiry-based activities. Learners were mostly passive during a teacher-centred classroom set up. The learners were not allowed to celebrate the nature of science; for instance, at no stage of the lesson did I observe science being portrayed as *empirical, tentative,* or *creative.* What became dominant in Teacher E‘s classroom was a theory-laden type of a lesson, which did not inspire 21st-century inquiry minds. Even though the lesson was *theory-laden,* which is one of the tenets of science, it lacked the use of models and analogies to make science fun, exciting and addressing the affective domain for the learners. Even though the issue of resources is a challenge at Teacher E’s school, if the teacher had been self-directed and had agency, he could have still made the lesson interesting and based on inquiry learning. For instance, the teacher could have started his lessons with appropriate key terms to be used in the lesson, for example small intestines, large intestine, oesophagus, kidneys, filters, ureter, bladder, to mention a few.

This would have been followed by the learners using a shoestring approach to model what happens to the substance at the kidney level, assisted by the teacher as a facilitator. Below I suggest a shoestring approach the teacher could have considered: in the diagram the teacher could have used two balloons, a filter, cardboard and could have engaged learners to design their own kidney model as in the figure below. Alternatively, the students could have designed the model of their choice.

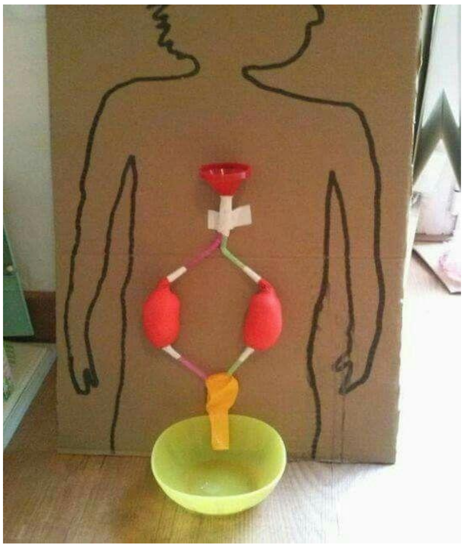

Figure 4.1: Using shoestring modelling to demonstrate filtration and selective reabsorption

This could have been followed by letting the learners work in groups and assigning each group with deeper thinking questions to investigate. For instance, one group could have been assigned responsibility to find out what problems low pressure imposes on the kidneys, whilst another group would try to understand what effect alcohol and caffeine have on the kidney, in that order. This would have been followed by different groups explaining their findings to each other. This, I suggest, would have been an inquiring learning strategy that emphasised active learning and began with posing questions or problem learners needed to respond to.

From the classroom observation I did make sense of why Teacher E uses a 'chalk–and-talk' approach. When Teacher E was asked in the Natural Sciences questionnaire how he plans his lessons, his response was as follows: '*I plan Natural Sciences lessons by using the CAPS document to instruct me which topics or content I should teach. I use the textbook, teacher's guide, and the curriculum pacesetter to plan for my lesson*'. From this view and the classroom observation, I can conclude that the teacher is 'chalk-and-talk' driven and only focuses on the cognitive domain of the learners without considering how the affective domain could provide learners with an opportunity to enjoy the content, and the lesson lacked creativity.

(b) Teacher E's responses in the UJ-DNA Barcoding questionnaire and Focus-group interview, prior to the DNA Barcoding intervention

In the questionnaire, the teacher reflected that he is 4 out of 5 confident in handling laboratory equipment. This implied that Teacher E is 80% confident in his skills and ability to handle laboratory apparatus, and is confident performing laboratory protocols. This provides some sort of confidence that Teacher E will engage his learners in inquiry-based activities in the post-intervention observations and his general science teaching. In question 2 of the questionnaire, Teacher E was asked how often he does practical work with his learners. His response was '*not so often because there are limited resources at work, so it is very difficult to do lab investigations'.* This emphasises the earlier argument that Teacher E is not accustomed to inquiry-based teaching. At his stage of reporting, the researcher was prompted to hypothesise that in the post-intervention, Teacher E will have the agency of using inquiry-based activities since most of the obstacles would have been removed for him during the intervention. For instance, the intervention was conceptualised to assist the teacher with resources and skills to do inquiry-based activities in the under-resourced classroom. The questionnaire indicates that Teacher E has a superficial knowledge of DNA. For instance, when Teacher E was asked for his understanding of 'DNA Barcoding' and polymerase chain reaction (PCR) in questions 4 and 5, his response was as follows. 'DNA Barcoding is the findings of DNA of a certain specimen' and 'I don't understand much about PCR'. Alarming, as DNA is a key construct in the CAPS curriculum.

(c) Teacher E's views of the nature of science

Teacher E has a partly informed view of the nature of science (VNOS). For instance, in the VNOS questionnaire (Question 5), the teacher was asked the following question: 'Scientists perform experiments/investigations to solve problems. Other than the planning and design of these experiments/investigations, do scientists use their creativity and imagination during and after data collection? Please explain your answer and provide an example if appropriate. The response of Teacher E was as follows: '*No, because most scientists have to adhere to the scientific method, use statistics and data, and carefully measure their results*'. The reason why this view is partially informed is that creativity is amongst the tenets of science. Observations and experiments are not the only sources of scientific knowledge. Human creativity and imagination also play a role. Another indication that Teacher E has a partially informed view stems from Question 1 of the VNOS questionnaire. Teacher E was asked, 'after scientists have developed a theory (e.g. atomic theory), does the theory ever change? If you believe that theories do not change, explain why we bother to teach scientific theories. Defend your answer with examples.' The response of Teacher E was as follows *'The theory does not change. We bother teaching scientific theories to lay foundation of new science concepts; example matter →small→ particle→sub-atomic particles to ever small particles'*. This view is really surprising as theories can change based on new scientific insights.

In question 2, the teacher also provided a partially informed view; for instance, when the teacher was asked what an atom looks like. 'How certain are scientists about the nature of the atom? What specific evidence do you think scientists use to determine what an atom looks like?' The response of the teacher was as follows: *'on a zone called the nucleus in the centre we find protons and neutrons and around electrons. I personally think it is difficult for a scientist to be certain about the nature of the atom'*. The first sentence provides what an atom looks like. The lack in his response was to answer the question of how certain are the scientists about the nature of an atom. The teacher failed to give an account to describe the development of an atom (timeline) which provides the basis that the theory of an atom has been subjective for many years.

From the classroom observation, it was also evident that Teacher E has uninformed views on the nature of science. This was illustrated by how the teacher used transmission mode teaching strategies that only focused on theory and neglected that science is *empirical, tentative, inferential, creative, social and cultural*, and no coverage of the methods of science was observed during the lesson.

4.6.3.3 Teacher E's views on Science and Society

(a) Portraying the role of science in society during lessons: evidence from the lesson observations using RTOP, lesson plan and interviews

During the class observation, I noticed that the teacher did not contextualise the lesson and did not stimulate the learners' interest (the affective domain). What was surprising is that Teacher E did not link science and society. The teacher was teaching about kidney failure, which falls under the topic of human excretion. In his teaching he did not mention how the indigenous people of South Africa used indigenous plants to treat the kidney failure, nor did he portray the role of science in society, e.g. improving the quality of life of people with kidney diseases (e.g. dialysis and modern treatments for kidney ailments). Since the teacher did not give learners a classroom activity or homework, the teacher further missed an opportunity to provide learners with an opportunity to investigate the role which science plays in society, for instance how indigenous people used plants and other resources to curb or cure kidney failures.

(b) Teacher E's view on the nature of indigenous knowledge

Teacher E’s understanding of indigenous knowledge was that *‘Indigenous knowledge is the knowledge that is used by a certain group of people or community and the knowledge can only be learned by members of the community only’*. Furthermore, Teacher E sees indigenous knowledge as static, and states that *‘IK stays the same, as people do not see the need for change as they are satisfied with the way of doing’*. This is an uniformed view and could possibly be influenced by the fact that Teacher E was not trained by the University during his undergraduate studies on the construct of indigenous knowledge, although indigenous knowledge is identified as one of the principles underpinning the South African school curriculum. This could also be argued why teacher E did not integrate indigenous knowledge in his classroom.

When teacher E was asked if practitioners of indigenous knowledge do experiments and tests to verify or validate IK, his response showed an uninformed view of indigenous knowledge. His response was *‘No, especially the traditional healers, they base their knowledge on their instinct and beliefs’*.

4.6.3.4 Teacher E's views on assessment/assessment practices

From the classroom observation Teacher E uses transmission mode as a way to assess the learners. For example, the teacher as the protagonist remains the main focus during teaching and learning. The teacher stood in front of the learners, and he posed questions to the learners. The learners responded to the teacher, with anticipation of getting feedback whether the answer was correct or not. During the observation, I also noted that the teacher did not have an assessment plan, and most of his questions were not structured and only aimed at the lower order cognition of Bloom‘s taxonomy. No evidence of assessment of the affective and the psychomotor domain was provided. The observation showed that Teacher E used transmission mode to ‘teach to the test’, and that he did not engage in innovative assessment practices. There was no sign of meaningful assessment activity to encourage and promote learning. The assessment style of the teacher did not capacitate the learners with 21st-century skills such as problem-solving and critical thinking skills. Very little attention was also given to testing whether learners can solve real-life problems or are able to come up with a variety of solutions to problems or solutions to address kidney failures. This would have allowed the learners to engage as critical thinkers and become more reflective on the topic.

4.6.3.5 Teacher E and self-directed learning (SDL)

(a) Qualitative analysis of SDL

Based on the qualitative data, the teacher in terms of the revised Rogan and Grayson heuristic is mapped at level 1 for SDL. Even though Teacher E identified his professional development needs as teaching methods and ways of addressing the affective domain (learner interest), from the observation there was minimal evidence of SDL. While the teacher has identified his learning goals, there was no agency to improve during the observation.

(b) Quantitative analysis of Teacher E utilising the SDLI instrument

Teacher E scored 91 out of 100 in the SDLI. In Table 4.16 his SDL is indicated in terms of the four sub-domains of the SDLI.

Table 4.16: SDL of Teacher E

Sub-domain in the profile of implementation	Questions	Score of Teacher E	Score of Teacher E reported in percentage (%).
Learning motivation	Q 1-6	28 / 30	93.34
Planning and implementing	Q 7-12	27 / 30	90.00
Self-monitoring	Q 13-16	18 / 20	90.00
Interpersonal communication	Q 17-20	18 / 20	90.00
TOTAL:		91/100	

Teacher E’s response from the questionnaire showed a strong agreement with the following aspects of self-directed learning: Regardless of the results or effectiveness of his learning, he still likes learning. He strongly hopes to improve and excel in his learning constantly. He enjoys finding answers to questions. Whether in the clinical practicum, classroom or on his own, he can follow his plan of learning. He can connect new knowledge with his own personal experiences. His interaction with others helps him plan for further learning. Lastly, he is able to communicate messages effectively in writing. Based on the data in Table 4.16, the teacher seems to operate on level 4 in terms of self-directed learning.

What is contrary from the SDLI and his professional development need is that Teacher E needs assistance and support in terms of administration and management skills, whilst in the SDLI this teacher scored 90% in terms of his views on planning and implementing. Teacher E indicated a neutral response when asked whether he knows what he needs to learn. He also had a neutral thought and feeling with regard to evaluating his own learning outcomes. In terms of the quantitative construct of SDL in the revised Rogan and Grayson heuristic Teacher E is scaled at level 4 of SDL, which is contrary to the qualitative assessment.

4.6.3.6 Teacher E's holistic wellbeing

Teacher E specified that his profession is pressure intense and he has to cope with continuous tight deadlines, such as marking, and has to deal with challenges in his school, such as disruptive behaviour and discipline of the learners which contribute negatively towards his stress.

4.6.3.7 Professional development needs of Teacher E

Teacher E needs assistance in terms of disruptive behaviour & discipline, and Classroom management

4.6.4 Post-intervention Data – Teacher E

4.6.4.1 Pedagogical orientation of Teacher E

Teacher E’s pedagogical orientation did not change at all after the intervention. Teacher E’s teaching continued to centre-stage transmission mode type of teaching. His teaching style resembled ‘content-information sessions’ and reading notes from the chalkboard and the learners responding in a chorus format. This is despite Teacher

E‘s absolute agreement to use cooperative learning (CL) and problem-based learning in future, as reflected in the Natural Sciences post-questionnaire. No inquiry-based learning or elements thereof became apparent during the classroom observation, even though the intervention mainstreamed inquiry-based learning and research, promoting it as one of the superlative approaches to learning science (Abd-El-Khalick et al., 2004).

(a) Lesson observation using Reformed Teaching Observation Protocol (RTOP) instrument

The post-intervention class I observed was a grade 11 lesson on diabetes. The arrangement of the classroom is a column-based configuration that complements teacher-based instruction and teaching. The teacher began the lesson by providing background understanding on the topic of diabetes for about five minutes. As the lesson continued, the teacher kept explaining the notes written on the board about the topic as guided by the CAPS curriculum. Inopportunely, the teacher continued with transmission-based teaching that required the learners just to imprint the knowledge exactly from the transmitter (teacher) to the listener (learners). This resulted in some learners losing interest and doing a mathematics assignment. The classroom and the lesson did not inspire science culture that reflected investigations or demonstrations of the tenets of science. No posters were present in the classroom despite the fact that the teacher was provided with such resources. No problem was solved during the lesson and the learners were not provided with a class or homework on the topic taught. Teacher E lost an opportunity to engage the learners in inquiry-based activity, despite the resources and strategies provided and used during the intervention. The ‘wash-out’ effect was observed during the lesson observation.

(b) Teaching and learning (Lesson plan); analysis of lesson plan

No lesson plan was prepared. Only the notes on the chalk-board were used during the observation. Even though Teacher E has on knowledge of the subject matter, poor planning resulted in an uninspiring lesson, and the curriculum outcomes were not achieved. However, the Teaching and Learning phase used skill to teach specific content by using particular explanations, analogies, models, or activities. Learner activities were aligned with lesson objectives. Assessment was aligned with lesson objectives to promote learning effectively.

(b) Exit interview and discussing the recorded lesson using stimulated video recall

During the exit interview, the teacher mentioned that the system and pressures from his superiors leads him to teach using transmission mode. He also said that the pacesetters push teachers to complete the curriculum fast, and it is straining him. When the teacher was asked if the transmission mode is working for him and do students pass, his response was '*they do pass, but not the way you expect, only few of them do pass. Learners have many methods to learn; actually, some can learn by chalk and writing, some can learn while listening, some they can learn by seeing the pictures or videos. Method of chalk and talk sometimes it disadvantages other learners... in school, we do not have those computers and projectors...*' The above sentiments from the teacher provide three concerns: first, the teacher is aware that he is using transmission mode and that he disadvantages some learners; second, the systemic pressure coming from his seniors forcing him to teach the way he teaches, and thirdly, frustration that comes with the teaching profession. These results are disconcerting. Despite the fact that the teacher was capacitated with engaging pedagogies, at the coalface of teaching he fell back on his traditional type of teaching that marginalises the learners from being at the centre stage of teaching and learning. That is the reason why many schools with low-quality education become a poverty trap for most South African learners (Spaull, 2015). It is frustrating to see that the system predominantly fails some of the learners in Teacher E's class. The researcher is in sync with Jansen's view that 'a black child born to poor parents in a deeply rural area while attending a dysfunctional school on average has little to no chance of escaping a life of poverty despite the education received.' (Jansen, 2019:360). Even though the school of Teacher E is not in a rural area, a similar sentiment holds.

When the teacher was asked if there is any strategy or method that he enjoyed or implemented in his classroom from the intervention, he said '*like the Jigsaw methods I also introduced that method actually and it worked. And another method you can introduce is puppets also that method is perfect and I enjoyed it. But the reason why we cannot always use these methods is because of time constraints. If we have to apply these methods we will have to make extra classes, and sometimes in extra classes, learners don't come.*' This issue refers to an over-packed curriculum that does not provide the teachers with teaching autonomy. Even though the teacher enjoyed the Jigsaw method, there is small likelihood that he might regularly implement the strategy due to the packed curriculum.

When the teacher was asked how often he does practical work in the Natural Sciences, his response was '*Aah not that quite often, we do practical work when it is necessary when it is a formal task because we short resources, so we cannot do practical work often. We do them when it is a must, like it's a formal task. You find out the resources are not there, and you must go and ask in other schools.*' When the teacher was asked if he succeeds in getting resources from other schools, his response was *'Ja, few of them you do get them, but not all some you will have to buy them or improvise'*. Issues of resources remain a massive challenge in most poor schools. The intervention at least capacitated the teacher to be an agent of change and trained him to use shoestring approaches. Unfortunately, no inquiry activity was observed in the post-observation, and none of the resources given to the teacher were used in his classes observed.

(c) Content knowledge on optics

Teacher E saw a percentage increase of 12% in the optics test. In the pre-test Teacher E scored 18/35 (51%) and in the post-test 22/35 (63%). Statistically, the teacher benefited from the intervention in terms of increased subject knowledge**.** Teacher E moved from an adequate achievement to substantial achievement in terms of the CAPS scale of achievement. This indicates that the intervention assisted Teacher E in developing a more nuanced understanding of visible light content knowledge. Even though Teacher E did not make any significant improvement in the multiple-choice questions and filling the missing words section (Question 1), he did see a considerable improvement in the comprehension section (Question 2). Teacher E did gain a better understanding of drawing symmetrical objects, how electromagnetic energy differs from visible light, and how to use a magnification lens to start a fire.

4.6.4.2 Teacher E's views on practical (laboratory) work, inquiry learning, and the nature of science

Even though Teacher E attended the SLP, he could not submit the portfolio. His reason was that pressure of work made it impossible for him to submit.

(a) Inquiry learning in Teacher E's classroom

No evidence of practical work or inquiry learning was recorded during the observation; nor were elements of inquiry-based activities evident. This is despite Teacher E's view in an interview that *'learners must be given more practical work sessions, they must get used to doing practical's, not just theory only…'* In an attempt to understand why Teacher E only uses transmission mode teaching, in an interview he was asked if doing practicals in Life Sciences was important, and his response was: *'Yes and university was more theoretical'.* From his response the researcher posed a follow-up question to probe what Teacher E implied by his response. The follow-up question was centred on understanding if Teacher E felt that the university did not equip him well as a teacher to facilitate inquiry-based activities and if that is the reason why he uses transmission mode as his default teaching strategy. He answered affirmatively and stated that the university training did not prepare him to facilitate inquiry learning in the school laboratory effectively. This view of Teacher E cemented one of perhaps many reasons why he used 'active direct' teaching orientation. In the same interview Teacher E mentioned resources as another limitation in engaging learners in inquiry-based activities. His exact words were *'the thing is we do not have enough apparatus at our school, and sometimes it is difficult to do other practicals'*. Even though that is the case (from the researcher's observation), Teacher E was capacitated with skills and resources to be utilised in under-resourced classrooms and sensitised to be more inquiry based in his teaching approach, during the two-year long professional development intervention. To show that the teacher was sensitised in shoestring approach, in the Natural Sciences post-questionnaire, Teacher E made the following remark when asked how he made use of shoestring approaches in his classroom: *'Actually I never thought that I can use cheap materials to teach other topics. I depended on using those expensive materials'*. He further added that the workshop *'taught me on how to use other resources around us to replace that we did not have in order to solve some problems'*. Beside the teacher being capacitated with shoestring approaches, Teacher E was provided with a tablet and capacitated to use PhET simulations in which most activities also centre stage inquiry-based approaches. Teacher E was afforded many platforms to assist him on his teacher professional development in terms of using an inquiry-based approach. Through the classroom observation, the researcher can conclude that the teacher is comfortable with using 'chalk-and-talk' procedures. The views above further emphasise the lack of agency of the teacher to be self-directed.

(b) Teacher E's responses in the UJ DNA Barcoding questionnaire (and focus group interview afterwards)

In the post-questionnaire, Teacher E reflected that he is now 5 out of 5 confident in handling laboratory equipment and performing laboratory protocols. He also made the following remark: '*I have handled laboratory equipment very well and many times*'. This comment alludes to the verity that Teacher E was sensitised to use laboratory equipment and also made comfortable to use it. In question 2, Teacher E was asked about his experience of DNA Barcoding, and how the laboratory inquiry assisted him in his professional development. His response was inspiring, namely: *'It assisted me in terms of how to extract DNA and very lot about DNA'*. In a focus group interview Teacher E expressed the following sentiments, *'I never knew the analysis of the DNA actually, so now I can see that anything that is living, it can be plants or animal, they have the DNA that we can classify them with'*. This response is on the one hand very inspiring, but also very disconcerting, as it shows a previous lack of understanding of the most basic CAPS content, namely that 'DNA (or Deoxyribonucleic Acid) carries the genetic code for cell specialisation and cell functioning and DNA packages, as genes, determine what an organism will look like and how it will function…' This response was pertinent to be recorded, as it highlights some elements of the teacher's professional development. For instance, Teacher E, according to the CAPS curriculum, is required to assist the learners to perform a simple process to extract DNA and examine the threads, and to understand DNA 'fingerprinting'/DNA profiling: (case study only).

Teacher E's interview response cast a doubt that he was able to perform the investigations mentioned above as stipulated in the CAPS curriculum before the intervention. The following response from Teacher E further supports this argument: *'I did not know how to extract the DNA; I just saw it in the book, I did not know how they extract it or by engaging in the DNA…'* When the teacher was asked about his experience at the African Centre for DNA Barcoding (ACDB) his response was surprising, namely, *'from my experience of Life Sciences, I did not think with DNA there are a lot of things there, because I used to think of it more with paternity test, but* *now I realise there is more to it.'* According to Teacher E in the focus group interview, he never did any practical work at a university level relating to DNA. He stated that *'actually we only had practicals about chemicals but I did not have practicals about genetics'*. It is on this basis that I make an argument that this intervention was important in assisting Teacher E in his professional development. In question 5 Teacher E was asked if he planned to do more practical work (in terms of lab investigations) with his learners in future. His response was *'Yes, learners will understand more when we do things theoretically and practically'*. In an interview Teacher E gave an indication that he really enjoyed the intervention. For instance in one of the interview snippets he said *'I've learned a lot, and it was really fun, it was actually exciting, and I've acquired so much knowledge, some of the things I did not know about them but now at least I know.'* Although Teacher E enjoyed the intervention, the 'wash-out' effect remained evident during the classroom observation, and he resorted back to transmission mode teaching. It should also be emphasised that the two days of intervention was insufficient to address Teacher E's professional development in terms of DNA technology and inquiry learning.

(c) Teacher E's Views on the nature of science (VNOS)

Teacher E attended the short learning programme (SLP) on 18-19 March 2019. Amongst many activities, Teacher E engaged in the Kirby-Bauer technique for testing the anti-microbial activity of *muthi* plants and using an optics kit to develop an inquiry-based activity. The objectives of the activities were to demonstrate that science is: empirical, tentative, inferential, creative, subjective, social and cultural, reductionist, etc. Since Teacher E did not submit the VNOS questionnaire, I had to rely on the lessons I observed to develop an understanding of Teacher E's views on the nature of science. During the observation, the teacher's lesson failed to a large extent to demonstrate science as: observable and testable, subject to change and not absolute and certain, or that there is a clear distinction between observations made of nature and deductions or conclusions (inferences) made from observations to explain the causes. Teacher E failed to demonstrate that science is creative. For instance, his lesson did not demonstrate human creativity and imagination; the lesson remained theory laden. As mentioned before, Teacher E stands in front of the class and reads the notes on the chalkboard.

4.6.4.3 Teacher E's views on science and society

(a) Portraying the role of science in society during lessons: evidence from the lesson observations using RTOP, lesson plan and interviews

During the lesson observation, no elements of contextualising science by either infusing indigenous knowledge or making science relevant to the broader society were observed. In the exit interview, it became clear that time remained the biggest constraint for Teacher E to integrate science, indigenous knowledge and society. Hence Teacher E only covers what the pacesetter demands. Diabetes is a crisis in many societies, and sometimes men are mocked for erectile dysfunction that comes with the sickness. Teacher E had an opportunity to link diabetes with societal views as a way of introducing the topic, or perhaps could have provided a few minutes for learner dialogue on this particular subject. Teacher E was provided with the 'People's Plants' resources book (a book by Van Wyk & Gericke, 2018, published by Briza). This book refers to 16 plants which were traditionally used to treat diabetes, for instance, *Hoodia currorri,* which is used to treat diabetes and hypertension amongst many illnesses, or *Momordica balsamina,* which is a herb that is also used to treat diabetes in South Africa and Malawi. In my opinion, Teacher E could have engaged the learners in ethnobiological knowledge index (EKI) and Species Popularity Index (SPI) research, utilising the Matrix Method developed by De Beer and Van Wyk (2011). Teacher E was capacitated to use the Matrix Method during the SLP. The teacher could have used this method to engage learners in an ethnobotanical survey, to identify which plants or herbs were traditionally used for the treatment of diabetes in their environments. This would have addressed science that speaks back to the society, which Gibbson (2000) refers to as context-sensitive science or mode 2 learning.

(b) Teacher E's view on the nature of indigenous knowledge

Teacher E still held a partially informed view of the nature of indigenous knowledge after the intervention. During the SLP intervention Teacher E engaged in the soap-making process. Before the soap-making activity, there was a lecture on how several plants have traditionally been used to make soap, and how it facilitated the saponification process (Van Wyk & Gericke, 2018:277). It was also emphasised how soap-making is, therefore, a lovely activity to use in the classroom, to illustrate indigenous knowledge and its links to the CAPS curriculum. In an exit interview when

Teacher E was asked if he ever had a chance to infuse indigenous knowledge in his science lessons, his response was as follows: *'so far I had never had a chance'*; in a follow-up question the teacher referred to a lack of time as a constraint. When the teacher was asked if, provided that he had enough time, he would contextualise his lessons by infusing indigenous knowledge, his response was *'I can do it, I can do it, I can do it if I can get like those materials and I have enough time; because to link indigenous knowledge with science, sometimes it requires time. Sometimes you must go outside the classroom and do those things. Now the system does not give us enough time actually, like everything you must do it fast and that is why those slow learners they don't catch up fast, and you must go extra miles'*.

4.6.4.4 Teacher's views on assessment/assessment practices

(a) Reformed Teaching Observation Protocol (RTOP) and lesson plan

From the observation, there was no form of formal assessment provided to the learners, nor was any assessment plan conceptualised. The only formative assessment was through superficial questioning (lower-level questions on Bloom's taxonomy) during the teaching phase, which required learners to answer in a 'chorus' form.

4.6.4.5 Teacher E's Self-Directed Learning (SDL)

(a) Qualitative analysis of SDL

Evidence of enhanced self-directed learning is that, due to the motivational aspect of this intervention, Teacher E is motivated to study further until PhD level (as communicated during an interview). Teacher E was further inspired to register for B.Ed. (Honours) in the Natural Sciences in 2020. The teacher has identified his learning goal to improve his human capital. Whilst that is the case, Teacher E did not improve in the other four domains in the revised Rogan and Grayson's rubric. The teacher also failed to inspire his learners with SDL skills. In the pre-test the teacher identified learning strategies as his professional development need, in the post-intervention the teacher was still teaching in the same way, using transmission mode as the main teaching strategy. This insight indicates that Teacher E lacked agency to improve in his pedagogical orientation. According to the rubric teacher E is scaled at level 2. The teacher formulated learning goals, but there is limited evidence that learning resources or learning strategies were identified.

(b) Quantitative analysis of Teacher E utilising the SDLI instrument (SDLI)

Teacher E scored 85 out of 100 in the post-SDLI. In Table 4.17 his SDL is indicated in terms of the four sub-domains of SDLI.

Table 4.17: SDL of Teacher E, after the intervention

Pre-SDL views				Post-SDL views			
Sub-domain in the profile of implementation	Questions	Score of Teacher E	Score of Teacher E reported in percentage	Score of Teacher E	Score of Teacher E reported in percentage (%)	Change in SDL scores	Change in SDL reported in percentage (%)
Learning motivation	Q 1-6	28/ 30	93.34	26/ 30	87	-2	-16.67
Planning and implementing	Q 7-12	27/ 30	90	24/ 30	80	-3	-13.34
Self-monitoring	Q 13-16	18/ 20	90	17/ 20	85	-1	-5
Interpersonal communication	Q 17-20	18 / 20	90	18/ 20	90	0	0
TOTAL		91/100		85/100		6	-35.01

In the pre-SDLI the teacher showed a strong view towards learning motivation, and aspired to study until PhD level. In the post-SDLI he shifted to having a strong view on interpersonal communication, whilst in the pre-planning and implementation, self-monitoring and interpersonal communication were both rated at 90%. In the post-SDLI planning and implementing came out as the sub-domain scored the lowest amongst others. Post-intervention the teacher still view himself as being very self-directed in his learning. According to the revised heuristic Teacher E quantitatively moved from level 4, to level 3. This is despite him not making improvement in the other four domains in the revised profile of implementation.

4.6.4.6 Teacher E's holistic wellbeing

(a) General wellbeing after the intervention

In an exit interview Teacher E mentioned how stressful and frustrating his work is due to the pressure coming from his superiors. Teacher E did attend the stress management intervention workshop. It should be stated that the stress management intervention was to sensitise teachers on techniques to be used when they are stressed. The intervention did not include counselling and other psychological platforms. It is important to note that the one-day stress management workshop was not adequate to deal with each and every teacher‘s profile, but instead provided a generic view and approach on how to deal with pressure and stress. It is therefore important that the schools provide teachers with this service. From the interview the researcher could pick up the frustrations of Teacher E and concerns when it gets to his personal wellbeing.

(b) Professional development needs

One of many professional development needs identified by Teacher E was to study further and to be a head of department (HOD). He further indicated he needed to be assisted and trained in the following topics:

- Assessment
- Infusion of technology into teaching
- Personal professional development (time management, stress reduction)
- Differentiated instruction
- Classroom leadership
- Self-directed strategies and
- Conflict resolution

4.6.5 Synthesis: Using revised Rogan and Grayson's (2003) heuristic to assess teacher professional growth, and plotting their learning/ development during a longitudinal and systemic teacher development programme

Below I used revised Rogan and Grayson's profile of implementation to map Teacher E's professional development during a longitudinal and systemic professional development as follows

Table 4.18: Teacher E's progress

Table 4.18: Teacher E's progress during teacher professional development that spanned from 2017 to 2019																									
A HEURSITIC TO MAP TEACHERS SKILLS ACCORDING TO THE ROGAN AND GREYSON PROFILE OF IMPLEMENTATION																									
PRE- (X) AND POST (0) INTERVENTION PROFILING HEURISTIC																									
	Classroom interaction					Practical work					Science and society					Assessment					Self-directed learning				
PARTICIPANT(S) IN TPD	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
TEACHER E		X 0				X 0						X 0					X 0					X	0		

In Chapter 5 (contributions of the study), I will discuss the difference in the quantitative and qualitative SDL data, and how CHAT could provide a lens to get clarity on this apparent 'black box' (Mentz & De Beer, 2019).

4.7 PROFILE OF TEACHER F

With this last profile (Teacher F), I will be only providing a birds-eye view on the data emanating from the pre- and post-intervention and plot the teacher's professional development on the revised Rogan and Grayson profile of implementation in Table 4.18. The reason is that I have reached data saturation, with the same general trends emerging. The thick descriptions provided for the other five teachers informed the decision.

4.7.1 Personal profile (biography) of Teacher F

Teacher F is a neophyte teacher who is under the age of 35. The teacher is a source of inspiration to many learners around the area of the school. In his spare time, teacher F teaches young people mathematics and science. At the time of reporting the teacher is enrolled for an LLB degree at the University of South Africa (UNISA). He is inspired to be an agent of change and to be the voice of the marginalised groups in the South African educational system.

4.7.2 School and classroom

Teacher F's school resembles many Q1 schools in South Africa. Over-crowding and lack of resources is cause for concern. The school is based in a Coloured, Indian and Black community. The constituents of the school are predominantly from the above-mentioned demographics.

4.7.3 Pre-intervention data: Teacher F

4.7.3.1 Pedagogical orientation of Teacher F

(a) Lesson observation using Reformed Teaching Observation Protocol (RTOP) instrument

During the lesson observation, the teacher indicated a great sense of confidence, and the learners were engaged. The teacher provided the researchers with three of the learners' books. The class that was observed was a grade 8 class on the topic of photosynthesis and respiration. The teacher began recapping on the topic, which was introduced a day before the observation. The lesson was followed by marking the homework that was provided to learners. The teacher stood in front of the learners, read homework questions, and the learners provided the teacher with the answers. In the second period, the teacher monitored the learners' books and signed the homework completed. The class ended with the teacher announcing the lesson will be completed the following day, and the learners had to come prepared.

(b) Teaching and learning; analysis of lesson plan

The teacher did not prepare a lesson plan. He used the CAPS document and the learners' textbook. This, despite the teacher mentioning in the Natural Science pre-questionnaire in question 5 that he uses lesson plans. Based on good content knowledge, the lesson was structured and focused on recapping the importance of the sun as a source of light and heat. The construct of heat and light was related to the process of photosynthesis. The teacher explained how plants use carbon dioxide from the air and water from the soil. The teacher also explained how the oxygen gas is released into the air as a by-product.

(c) Content knowledge on optics

In the pre-test Teacher F scored 9 out of 35 and indicated an understanding of 26% of the content tested. This indicates that Teacher F had undeveloped content knowledge on the topic of optics.

4.7.3.2 Teacher F's views on practical (laboratory) work, inquiry learning, and the nature of science

(a) Inquiry learning in Teacher F's classroom

The lesson observed was semi-inquiry structured. During the observation, the learners were the ones answering homework questions to the teacher, and the learners displayed active involvement. During the recapping stage, the teacher presented facts based on his subject knowledge, and this failed the intent of recapping, as learners were pseudo-involved.

(b) Teacher F's responses in the UJ-DNA Barcoding questionnaire and focus-group interview, prior to the DNA barcoding intervention

On a Likert scale Teacher F was 3/5 confident in handling laboratory equipment, with five (5) representing very confident and one (1) not confident at all. Teacher F also made the following comment *'Not exposed to such at the school level. The calibre of science is not well inculcated.*' In question 2 when the teacher was asked how often he does practicals in terms of investigations with his learners, his response was: '*I do conduct practicals, but limitations are large groups and limited resources*'. It will be interesting to evaluate post-intervention if shoestring approaches and the Jigsaw method will assist the teacher with issues of resources and large groups. Teacher F's expectations of the two-day training at the ACDB was captured as '*get to know the processes involved and illicit confidence of working in a lab*'. This was part of the intervention's objective, to assist the teacher in laboratory skills by immersing teachers with real scientists. This, I claim, will enhance the teacher's views on the nature of science. Teacher F in question 4 of the questionnaire, did not understand what is meant by the term DNA Barcoding. His understanding of polymerase chain reaction (PCR) in question 5 of the questionnaire was '*it has to do with DNA and its sequencing*.' This is a naïve understanding of PCR. It will be interesting to note if, after the intervention, the teacher will understand PCR as a method used in molecular biology to produce millions to billions of copies of a specific DNA sample. In question 6 the teacher was asked how he will make the study of DNA relevant and interesting to his learners. His response was as follows: '*It is part of their everyday lives (in crime science medical processes). It is also infused in the curriculum.*' The response understood the importance of contextualising the curriculum and making it relative to everyday life context. It will be interesting to observe if the teacher in the post-intervention will have a more nuanced understanding of the nature of science and if he will be contextualising the curriculum themes.

(c) Teacher F's views of the nature of science

Teacher F did not complete the VNOS questionnaire and from the lesson observed, the researcher could not conclude on this aspect.

4.7.3.3 Teacher F's views on Science and Society

(a) Portraying the role of science in society during lessons: evidence from the lesson observations using RTOP, lesson plan and interviews

The aspect of science and society was not well addressed during the observation; the only example made was that all the green plants contain a pigment named chlorophyll. This is despite chlorophyll also being found in algae and cyanobacteria. This, according to the researcher, can create a perception that chlorophyll is only found in healthy plants. For example, a harmful algal bloom comprises organisms that can lower oxygen levels in natural waters, killing marine species. From the DNA Barcoding questionnaire, the teacher had an understanding of science and society. For instance, when he was asked how he would make DNA Barcoding relevant to the learners, his response was '*It is part of their everyday lives (in crime science/ medical processes). It is also infused in the curriculum*'. This view provides an impression that the teacher understands that ‘science should speak to society’. . Even though the teacher saw the importance and the link between science and society during the observation, this was not made evident.

(b) Teacher F's view on the nature of indigenous knowledge

The teacher in the Natural Sciences pre-questionnaire had a partially informed view of indigenous knowledge. The teacher was asked how he could include indigenous knowledge in a science lesson. His response was ‘*How our parents used to device ways and came up with solutions to most health issues.*’ This view does recognise that IK offers another way of solving health issues, but does not say how this knowledge will be used in the classroom.

4.7.3.4 Teacher F's views on assessment/assessment practices

From the learners' books observed, it was clear that class and homework activities emanated from the learner’s textbook. The activities were not creative, as they were taken straight from the learner’s textbooks, and mostly focused on lower-order questions such as recalling and naming.

4.7.3.5 Teacher F and Self-Directed Learning (SDL)

(a) Qualitative analysis of SDL

In terms of the qualitative data, Teacher F is mapped at level 2. In the Natural Sciences questionnaire, Teacher F acknowledges that his school does not have resources to engage learners in authentic laboratory protocols and he is looking forward to learning how to ‘*use little resources at our disposal for many purposes in a classroom set-up*’ (see question 14 in the questionnaire). This is despite the teacher mentioning that the environment and the set-up at his school are not conducive to facilitate practical work without a laboratory.

(b) Quantitative analysis of Teacher F's SDL, utilising the SDLI instrument (Cheng et al., 2010)

Table 4.16: SDL of Teacher F

Sub-domain in the profile of implementation	Questions	Score of Teacher F	Score of Teacher F reported in percentage (%).
Learning motivation	Q 1-6	24/ 30	80.00
Planning and implementing	Q 7-12	21/ 30	70.00
Self-monitoring	Q 13-16	15 / 20	75.00
Interpersonal communication	Q 17-20	16/ 20	80.00
TOTAL		76/100	

The quantitative data shows that Teacher F functions on level 3.

4.7.3.6 Teacher F's holistic wellbeing

(a) Wellbeing of Teacher F

Teacher F indicated that the teaching profession is overwhelming, and often he is faced with stressors such as straining administration, disruptive learners, and having to make learners pass.

(b) Professional development needs of Teacher F

The teacher indicated that he is interested in continuing his professional development by enrolling for post-graduate studies in science education.

4.7.4 Post-intervention Data – Teacher F

4.7.4.1 Pedagogical orientation of Teacher F

(a) Lesson observation using Reformed Teaching Observation Protocol (RTOP) instrument

During the post-intervention lesson observation, the teacher was busy with administrative issues, amongst others, signing learner‘s book. In the second period, the teacher gave the learners an activity from the textbook as he had to attend to an urgent request from the principal's office. Some of the learners were busy with the task, while others were engaging in matters outside the scope of the task. The researcher asked for another appointment due to the fact that meaningful data could not be collected. It became impossible to book another opportunity to observe Teacher F's classroom.

(b) Teaching and learning; analysis of lesson plan

No lesson plan was provided; the learners did the activity from the textbook,

(c) Exit interview and discussing the recorded lesson using stimulated video recall

Due to ethical reasons, this objective could not be achieved. (I had to honour the teacher's apparent unwillingness for me to make another appointment.) It should also be made clear that the teacher later reached out to continue with the data collection, but due to the time constraints imposed by the submission of the thesis and the lock down regulation, this could not materialise

(d) Content knowledge on optics

In the pre-test Teacher F scored 9/35 (26%), and in the post-test 18/35 (51%), thus an improvement of 25%. This score indicates that the intervention was positive and aided the teacher in terms of the content knowledge on optics.

4.2.4.2 Teacher F's views on practical (laboratory) work, inquiry learning, and the nature of science

(a) Inquiry learning in Teacher F's classroom

No inquiry learning was captured. The learners had to do the activity from the textbook. It should also be emphasised that the teacher was capacitated with problem-based learning and cooperative learning strategy, i.e the Jigsaw method. This was a good opportunity for the teacher to engage learners in these strategies.

(b) Teacher F's responses in the UJ DNA barcoding questionnaire (and focus group interview afterwards)

Teacher F indicated professional growth in the post-questionnaire. For instance, in the pre-questionnaire, he rated himself 3/5 confident in terms of laboratory skills. In the post-questionnaire, the teacher rated himself 4/5, followed by the comment '*after very hands-on and informative lectures and sessions, I have learned a lot*'. When the teacher was asked about his experience of the laboratory engagement, he made the following comments: '*Build my confidence in handling the apparatus and elicited my interest in working in a science lab*'. The laboratory appeared to create cognitive dissonance for the teacher (Festinger, 1962). Even though the teacher indicated that he was scaffolded and assisted to be more confident in laboratory skills. In question 3 he also mentioned the most challenging aspect of the training was '*the extraction and perperting process* '. This experience provided the teacher with 'pedagogical laboratory' (Ramsaroop & Gravett, 2018) and 'cognitive apprenticeship' during the lecturing session. When the teacher was asked which aspect(s) he particularly enjoyed and why, his response was '*Everything about the presentations and demonstration*'. A very important insight was derived from question 5 of the post-questionnaire. The teacher was asked if he planned to do more practical work in terms of lab investigations with the learners in future. His response was '*Definitely!!! I am more confident*'.

(c) Teacher F's Views on the nature of science (VNOS)

The teacher did not submit the VNOS questionnaire, and I had to triangulate the data obtained through the interviews, Natural Sciences questionnaire, the insights from DNA Barcoding and the focus group interview to make inferences. In the pre-questionnaire, the data indicated that the teacher seldomly engages the learners in practical work, and this showed that the teacher did not engage the learners in the methods of science, largely due to the predominant transmission mode teaching strategy. From the basis that the teacher was more confident in laboratory protocols post-intervention, and the insights of the focus group interview that the teacher was sensitised on the nature of science, this did not translate into transformative teaching during the lesson observation. The teacher mentioned reasons for not engaging learners in science investigations and practical work as *'large numbers of learners,* *more space need and internet connection'* being considered as a limitation in implementing strategies introduced during the workshop in the Natural Sciences post-questionnaire. A similar view was made by the teacher in the focus group interview, namely that '*with our learners we are dealing with larger groups maybe it is another factor that we need to take into consideration. How do you control a class of 55 learners who are doing science and you are one facilitator*'. What was disconcerting during the observations is that Teacher F had a large number of classes that he had to teach. This was also another limitation that might result in the teacher falling back on transmission mode and not engaging learners in practicals or demonstrating the nature of science effectively.

4.2.4.3 Teacher F's views on science and society

(a) Portraying the role of science in society during lessons: evidence from the lesson observations using RTOP, lesson plan and interviews

From the Natural Sciences post-questionnaire in question 10, the teacher mentioned that the workshop on the use of shoestring approaches changed his view on his profesional development. His comment was '*it is helpful in a sense that I understood the shoestring methods* '. When he was asked how will he use shoestring approaches in question 11, his response was *'when you teach the pH scales acid, base etc. The learners can come with substances they use in their everyday life*'. In the DNA Barcoding questionnaire, the teacher emphasised that the teaching of DNA should be linked to learners' everyday life and include issues on crime science (forensic science) and medical processes. This view indicates that the teacher understands the relevance between science and society, but this was not evident from the leson observed, no link between science and society was made.

(b) Teacher F's view on the nature of indigenous knowledge

The teacher attended the SLP on indigenous knowledge but did not submit the data instrument, and during lessons observed no link of contextualising science by using IK was established.

4.2.4.4 Teacher F's views on assessment/ assessment practices

(a) Reformed Teaching Observation Protocol (RTOP) and lesson plan

The teacher’s assessment practices involved using activities straight from the textbook.

(b) SLP Portfolio

The teacher attended the SLP but did not submit the portfolio

4.2.4.5 Teacher F's Self-Directed Learning (SDL)

(a) Qualitative analysis of SDL

In terms of the revised Rogan and Greyson rubric the teacher remained at level 2.

(b) Quantitative analysis of Teacher F's SDL, utilising the SDLI instrument (SDLI)

Teacher F in the SDLI pre-questionnaire scored 73 out of a 100. In relation to the revised Rogan and Grayson's rubric Teacher F was scaled at level 2 (with only three points difference) in the post-intervention data (see Table 4.17).

Table 4.17: Pre and Post SDL of Teacher F

Pre-SDL views				Post-SDL views			
Sub-domain in the profile of implementation	Questions	Score of Teacher F	Score of Teacher F reported in percentage	Score of Teacher F	Score of Teacher F reported in percentage (%)	Change in SDL scores	Change in SDL reported in percentage (%)
Learning motivation	Q 1-6	24/ 30	80.00	25/ 30	83.34	1	3.34
Planning and implementing	Q 7-12	21/ 30	70.00	19/ 30	63.34	-2	-6.67
Self-monitoring	Q 13-16	15 / 20	75.00	13/ 20	65.00	-2	-10
Interpersonal communication	Q 17-20	16/ 20	80.00	16/ 20	80.00	0	0
TOTAL		76/100		73/100		-3	-13.33

The teacher's view remained strongly inclined to learning motivation as compared to the other three domains. Even though the teacher remained in the same sub-domain as in the pre-intervention, in the post-intervention Teacher, F saw an increase of one point in this sub-domain, moving from a score of 24/30 to a score of 25/30. On the other hand, the teacher saw a decrease in score in the sub-domain planning and implementation. Even though this remained the sub-domain Teacher F felt less strong about pre and post-intervention, the teacher dropped in score from 21/30 to a score of 19/30. This indicates that teacher after the intervention, his views remained inclined in these two domains only. Using the revised Rogan and Grayson heuristics, Teacher F dropped from level 3 to level 2 post-intervention.

4.2.4.6 Teacher F's holistic wellbeing

(a) General wellbeing after the intervention

In the needs survey completed by the teacher, stress reduction remained a topic of interest in the post-intervention.

(b) Professional development needs

In the needs survey completed question, Teacher F indicated discipline management and time management as his professional development needs in 2019.

4.7.5 Synthesis: Using revised Rogan and Grayson's (2003) heuristic to assess teacher professional growth, and plotting their learning/development during a longitudinal and systemic teacher development programme

Below I used revised Rogan and Grayson's profile of implementation to map Teacher F's professional development during a longitudinal and systemic professional development as follows:

Table 4.17: Teacher F's progress

Table 4.17: Teacher F's progress during teacher professional development that spanned from 2017-2019																									
A HEURiSTIC TO MAP TEACHER'S SKILLS ACCORDING TO THE ROGAN AND GREYSON PROFILE OF IMPLEMENTATION																									
PRE- (X) AND POST (0) INTERVENTION PROFILING HEURISTIC																									
	Classroom interaction					Practical work					Science and society					Assessment					Self-directed learning				
PARTICIPANT(S) IN TPD	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
TEACHER F		0 X					0 X					0 x					0 x						0 x		

4.8 RESEARCHER'S AUTO-ETHNOGRAPHY

Since the transcription of the auto-ethnography is lengthy, the transcription is made available in appendix Q1. The auto-ethnography was used to supplement the data and the findings that emerged from the profiles. From the auto-ethnography, the researcher used Saldaña's (2015), code-to-theory model to categorise codes into sub-themes. Relevant relationships were identified and chosen as codes (see Table 4.19). The codes were short phrases which were then grouped into sub-themes, as can be seen in Table 4.19. The sub-themes from the auto-ethnography and the profiles were grouped into themes.

Table 4.19: Summary of the codes and subthemes that emerged from the auto-ethnography

Code	Subtheme
The intervention created a safe learning space (a supportive community of practice).	The intervention created a supportive Community of Practice that facilitated teachers; learning.
A community of practice (CoP) should also create informal and social opportunities where informal learning can happen.	
A CoP should be built on mutual respect.	
The teachers should buy into the CoP.	
Teachers feel exposed (importance of creating a safe space in the CoP).	
Values + appreciation to underpin CoP.	
DoE should be involved, i.e stakeholders.	
Teachers invested time in the CoP. Designers should, therefore, ensure that teachers gain benefit from it.	
Utilising technology to keep teachers active/involved in CoP.	
The intervention focused on teachers‘ real needs.	
In such interventions, teachers should be involved in the planning.	
(Using technology) ICT’s.	
Teacher’s subject knowledge improved.	
The teachers should buy into the CoP.	
Specialists should be involved in the CoP.	
Pressure from school on teachers could erode transformed teaching.	Time pressures on teachers is a limitation to transformed teaching; more systemic interventions are needed.
Teachers revert to old styles of teaching.	
Department of Education was not involved in this intervention.	
Admin burden on teachers.	
Responsibilities of the researcher in terms of post-graduate studies + SDL project + lecturer resulted in limited time.	Teachers’ not always assisting with the data collection, yet the researcher needs to work within the parameters of the ethical protocol.
The pressure of such research on the researcher.	

Teachers taking on the roles of scientists getting a better understanding of the nature of science.	Immersion of teachers in real authentic lab activities are needed, yet it is not a guarantee for classroom transfer.
Affective outcomes reached (teachers were excited about the intervention).	
Teachers revert back to chalk-and-talk.	
Under-resourced classrooms, 26 years after democracy, make lab work difficult.	
Holistic and diverse professional development programme based on teachers' needs.	Evidence of SDL, teachers wanting to improve their qualifications/ growing professionally.
Evidence of SDL (teachers wanting to improve their qualification).	
Holistic + diverse professional development programme based on teachers' needs.	

4.9 THE THEMES THAT EMERGED FROM THE AUTO-ETHNOGRAPHY AND THE PROFILES

From the teacher profiles and auto-ethnography subthemes, the following themes emerged. The themes will be used to assist the researcher to understand the data better and to respond to the research questions in chapter 5. In this section, I outline the themes as follows:

- **Theme 1**

The intervention helped teachers to develop more nuanced understandings of the nature of science, yet little evidence of transfer and acknowledgement of the tenets of science (transformed teaching) were observed in the post-intervention classroom.

- **Theme 2**

The intervention assisted teachers to develop more nuanced understandings of the nature of indigenous knowledge, yet little evidence of transfer of such indigenous knowledge (transformed teaching) was observed in the post-intervention classroom.

- **Theme 3**

Despite the fact that teachers showed greater sensitivity towards contextualising curriculum themes through indigenous knowledge, the majority of them have challenges to implement contextualised problem-based learning (PBL) in the Natural Sciences classroom.

- **Theme 4**

Evidence exists of nascent self-directed learning, but this does not yet direct transformed teaching practices or the development of teacher agency.

- **Theme 5**

Despite teachers' enthusiasm about frugal science and PhET simulations, very little transfer took place in the classroom, and little evidence of the use of science-on-a-shoestring approaches or ICT approaches was observed.

- **Theme 6**

Despite experiencing 'the world of a scientist' at the ACDB at UJ, none of the teachers portrayed such tenets of science in the post-intervention classroom, probably because of their lack of knowledge and skills of laboratory protocols.

- **Theme 7**

A longitudinal professional development programme, fostering a supportive community of practice, could enhance teacher learning but should involve all stakeholders during the planning phase.

4.10 SECOND STAGE DATA ANALYSIS: USING CHAT TO LOOK INTO THE THEMES

Now I am going to try and shed light on the above data and findings, by using third-generation Cultural-Historical Activity Theory, as can be seen in Figure 4.1 below.

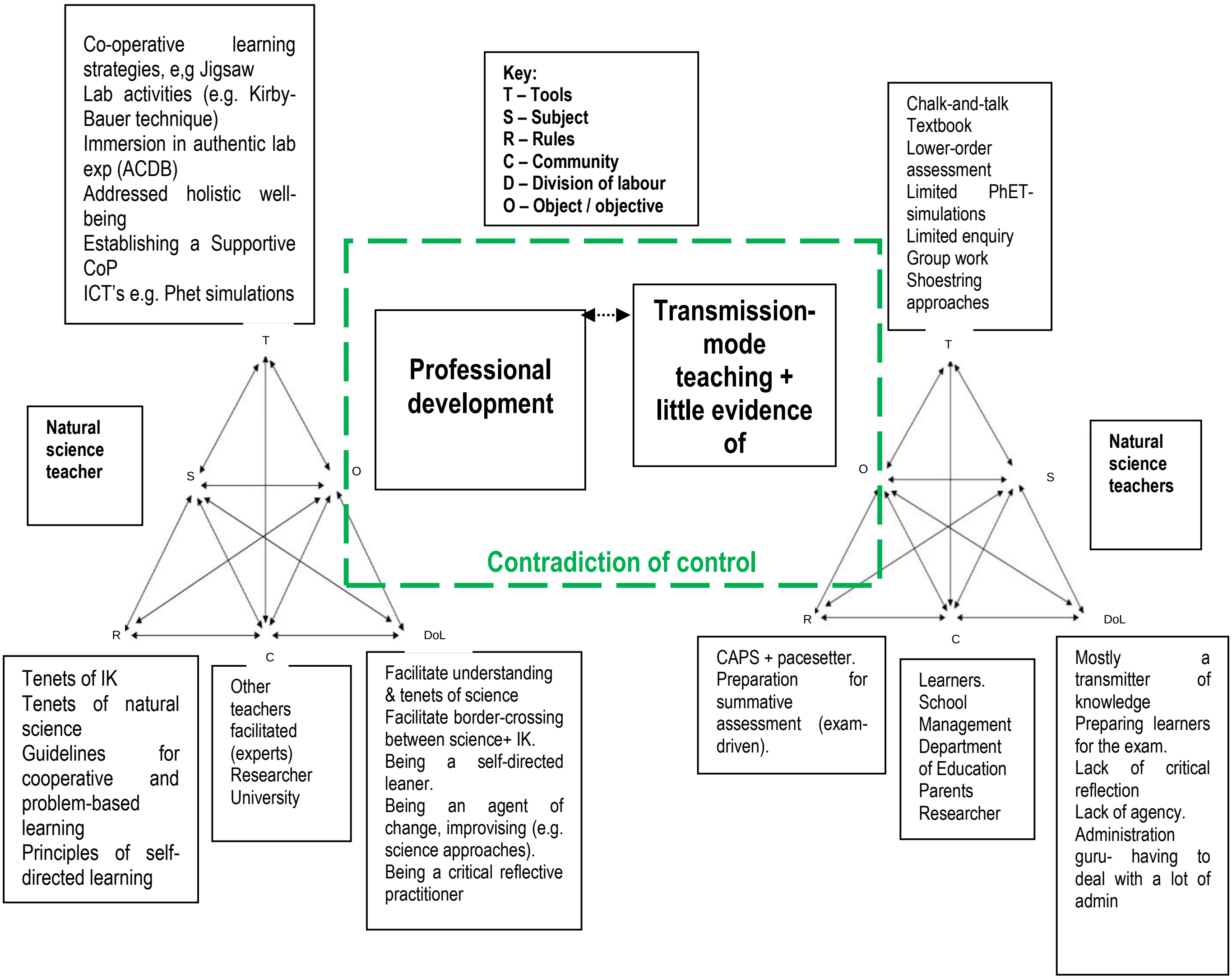

Figure 4.1: Using the third-generation Cultural-Historical Activity Theory (CHAT) in a conventional way: Comparing the Natural Sciences teacher as the subject, and his/her learning and professional development (the object) in two juxtaposed activity systems, namely the intervention (on the left), and in the post-intervention classroom (activity system on the right). Adapted from Engeström (1987) and De Beer and Mentz (2017:9).

I am going to juxtapose the two activity systems, which are the focus of my study. On the left-hand side, I am going to look into the two-year Natural Sciences teachers intervention with the 'A-Team' teachers. On the right-hand side, instead of looking at six different activity systems (namely the six classrooms of the teachers that I profiled), I am going to compile a 'general classroom', informed by the data obtained in all these six classes; due to the similar patterns that emerged from the data. The themes were used as ‘filters’ to get a more nuanced understanding of the data and what contradictions emerged in the post- intervention, at the ‘coalface of teaching’. The purpose of using CHAT in this particular fashion is to find out what are the tensions that led to the ‘contraction of control’ (McNeil, 2013) in terms of the objects in the activity systems. In Figure 4.1 it can be seen that the objects of the two activity systems are not aligned – a situation that McNeil refers to as a ‘contradiction of control’. Whereas the intervention envisaged an ‘object’ of professional development that would lead to transformed classroom teaching, emphasising the tenets of science and indigenous knowledge, amongst others, little of this was transferred to the classroom (as can be seen in the activity system on the right), and the object that materialised was transmission mode teaching and preparing learners for summative assessment opportunities. Please refer to Figure 4.1 for keys used in the activity systems. In section 4.10 I analyse the themes using Cultural Historical Theory.

4.11 THE SIX FILTERS TO BE ANALYSED

4.11.1 Lack of transfer of the nature of science (tenets of science)

The tools utilised during the intervention (the activity system on the left) were inquiry learning approaches (e.g. the Kirby-Bauer laboratory protocol, and the ACDB lab work), with the intention of providing teachers with more nuanced understandings of the nature (tenets) of science. The intention was that it would lead to transformed teaching in the post-intervention classroom as well, e.g. open-ended inquiry. However, the data shows that tools such as ‘chalk-and-talk’ approaches, lower-level Bloom questioning, and over-dependence on textbooks continued to dominate the post-intervention classroom, not providing learners with nuanced understandings of the nature of science. This lack of transformed teaching thus results in a contradiction of control between the two activity systems. CHAT provides insight into this. ‘Chalk-and-talk’ is seen as a better way of preparing learners for the examination. Pressure comes from school principals, who would like to see good results in their schools, as well as from parents, and teachers tend to revert to transmission-mode approaches, at the expense of inquiry learning. The same applies to cooperative learning approaches. Teachers knew how to use the Jigsaw method, but this was not evident in the post-intervention classroom. A reason provided for this, is that teachers feel that rules in the activity system, such as the ‘pace-setters’ of the Department of Basic Education, and the full curriculum, make it difficult to use pedagogies such as lab work or cooperative learning, as these are seen as being more time intensive (than for example lectures). The contradiction of control in the object is that of ‘chalk-and-talk’, regardless of the intervention objectives and the sterling effort made to scaffold the teacher learning across their zone of proximal development. The tension between the subject and the object is also subscribed to the apprenticeship of observation, as the teachers reverted back to what they know, which is ‘chalk-and-talk’. It becomes clear that it is difficult to break old habits. CHAT therefore highlights tensions between the different ‘nodes’ in the activity systems. One such tension exits between the rules (pacesetters and the summative assessment), and the object, as most teachers believe that inquiry approaches take time, due to the pace set for teaching, hence teachers opt for transmission mode. This implies that the structural challenges such as the congested curriculum continue to limit teachers trying to engage learners in a science that prides itself in the light of the nature of science. A tension between the division of labour and the tools and object, is that the teacher is burdened by lots of administrative tasks, which results in teachers not having sufficient time to plan for laboratory activities. A common tension that occurred is between tools and the object. Most schools do not have resources such as well-equipped laboratories and apparatus to engage learners in inquiry learning. Insights emerging from the focus group, from a few different teachers, were: *‘I realise that most of the time in our school levels, we are not exposing these learners to practicals; you can’t do theory without practical work’.* Another teacher said: *‘We need to do more practicals, sometimes you see something interesting on the internet but you cannot bring it to the classroom because there are no resources.*

Another tension is between the division of labour and the object of transformed teaching. From the portfolios that the teachers submitted, there was a lack of critical reflection. Unfortunately, many South African teachers are not critical reflective practitioners, and this negatively impact on teachers experimenting with new teaching strategies.

4.11.2 Lack of transfer of indigenous knowledge

There is a tension between the ‘rules’ and the ‘object’ in the classroom as activity system. Even though CAPS highlight that indigenous knowledge should be part of the planned curriculum, in the lived curriculum indigenous knowledge is often ignored, or lip-service is paid to it. This is due to several reasons, amongst others the CAPS as tool. CAPS is very much focused on covering learning content and summative assessment, and indigenous knowledge is marginalised since it does form part of the assessment plan. It does make sense that teachers will opt to not integrate IK in the curriculum because of time constraints and a congested curriculum. Teachers feel overwhelmed by the ‘full curriculum’ and only opt to teach to the test/examination. This results in the teachers not capacitating learners with the border crossing between science and indigenous knowledge. Another tension between tools and the object is that relatively few resource materials exist on indigenous knowledge, for use in the classroom. The tension between the community and the object leads to a contradiction between teacher professional development and transformed teaching. The systemic pressure coming from seniors and the Department of Education leads the teachers to ignore IK and marginalise the affective domain of many learners. Focusing on the shared tenets between IK and school curriculum holds the affordances of providing the decolonised curriculum which is yearned for by many South Africans.

4.11.3 Some of the teachers have challenges in implementing contextualised problem-based learning (PBL) in the Natural Sciences classroom

The CAPS and the accompanying pacesetter (teaching schedule), and preparing learners for summative assessment has resulted as the biggest concern and cause of tension between ‘rules’ and the object. The rules that govern teaching and learning limit the autonomy of teachers. In one of the interviews, when the teacher was asked why there was no transformative teaching post-intervention, her response was *‘Yes, they tell you, you need to be done with this topic on this date then you start with this one at least the principal would be on my case if I do not produce results, they will be on my case, so you just need to teach to the test, and the kids give us the results that they need so there is no time to have fun in the classroom*.’ ‘They’ in this context referred to the pace-setters and the principals. Other teachers did not know how to contextualise problem-based learning. For instance, one of the teachers understood problem-based learning as putting learners in a group and allowing them to define definitions from the textbook.

4.11.4 Evidence of self-directed learning, yet no agency to transform teaching practices

Most teachers made a significant improvement in terms of their SDL. Most of the teachers identified their professional development goals as improving their human capital by enrolling for postgraduate studies in science education, with the exception of one teacher who enrolled for LLB. In terms of the revised Rogan and Grayson heuristic most teachers moved from level one to level two in the domain of self-directed learning. This implies that the intervention capacitated the teachers in terms of the SDL domain. In Knowles parlance, this indicates that teachers can formulate their learning goals, but there is limited evidence that learning resources or learning strategies were identified. Yet, it was disconcerting in the post-intervention classroom to find little evidence of teachers showing agency in the other four domains, namely classroom interaction, practical work, science and society and assessment. What was observed in the post-intervention classroom was that the teachers did not change, did not inspire learners to be self-directed learners, and mostly reverted to 'chalk-and-talk'. In terms of the CHAT there exists a tension between the division of labour and the object. The teachers did not show agency to transform their teaching in the post-intervention, except one teacher who demonstrated nuanced understandings of indigenous knowledge and science and society.

4.11.5 Teachers showed excitement about using frugal science and PhET simulations, yet showed very little transfer of these strategies into the classroom

Large numbers of South African schools lack suitable laboratory equipment (Sebotsa, De Beer & Kriek, 2018; Cronje, 2015; Pretorius, 2015), thus making it challenging for learners engaging in practical skills. During the exit interview one teacher made the following disconserting statement: '*This school makes it impossible. We have fifty kids in the classroom so we cannot do group work we cannot arrange the tables, it asks for space, then we get over and done, and then we move on even when we have to do practical investigations of the classroom it becomes difficult because you cannot keep* *the learners at all the apparatus, there's a shortage of apparatus...'.* It does become imperative that teachers should be assisted in providing experiential learning for the learners and minimising difficulties they experience. Sebotsa, De Beer and Kriek (2018) suggest that in under-resourced schools teachers should show agency and use shoestring approaches to engage learnes in practical work. Jacobs (2015) describes shoestring approaches as using readily available resouces to develop inquiry-based activities.

In this study the teachers were engaged in shoestring sciences or frugal scrience experiences. The teachers enjoyed the experience of using cheap resources to build their own 'mini labs'. In the Jigsaw method and science-on-a-shoestring questionnaire one of the teachers shared this sentiment: '*a teacher does not need to use expensive materials to carry out investigations'*, and her particular highlight was to build a spectrosope using cheap resources. Another teacher was asked, after the intervention, if she would consider doing practicals with the learners using shoestring approaches and her response was '*yes, they are easily available resources and does not place strain on learners, to be careful in damaging expensive equipment resulting in being care-free when assembling the device'.* The teacher took time to understand that learners can be engaged in process of science by using cheap resources. During the teaching phases the teachers reverted transmission mode. The tension in the system was between the division of labour and the object. The teachers lacked agency, and systemic pressures (e.g., curriculum schedules) negatively impacted transformed teaching and learning. A particular example is a classroom that was observed post-intervention. The teacher was teaching the same content as the one assisted with in the intervention, namely visible light. During the observation the teacher used transmission mode and did not engage learners in any inquiry learning. This is despite the teacher classroom being equipped with resources such as a tablet loaded with PhET simulations on visible light, optics kits, and skills to build a spectrometer, which all fit well in the content taught. In the questionnaire one teacher mentioned that '*As a teacher, I am responsible to bring about positive change in my classroom regardless of having resources or not'.* At the coal face of teaching this was not evident. Another response from another teacher was *'I think what makes it difficult is on us teachers becouse we do not want to come out of our comfort zones and we* *do not want to learn new things*'. This is another expalantion for not showing agency post-intervention.

In terms of the DNA Barcoding workshop, the teachers were excited to be immersed in authentic laboratory protocols with real scientists. Below I provide diffent phrases from the focus group interview that captures that the teacher were excited. One teacher made the following remark *'Actually I found this very interesting, I did not know how to extract the DNA, I just saw it on the books'.*

4.11.6 Supportive CoPs must include all the stakeholders during the planning phase to enhance teacher learning

In retrospect, the Department of Education and school management (principals) were not involved when planning and executing this intervention. The 'community' was not actively involved, therefore the tension between the community and the object. In Chapter 5, I will address this problem further, and suggest Change Laboratories and fourth-generation CHAT (Mentz & De Beer, 2019) as possible solutions.

4.12 CHAT PROVIDED INSIGHT INTO DICHOTOMOUS, CONFLICTING MIXED-METHODS DATA

It became clear that the quantitative and qualitative data on self-directed learning did not always align. Most often, teachers scored well in quantitative instruments like Cheng et al. (2010), yet little qualitative data supported the development of self-directed learning. CHAT holds affordances to open this 'black box' (Mentz & De Beer, 2019), to highlight the tensions that could inhibit SDL.

CHAPTER 5: MAJOR FINDINGS, LIMITATIONS, RECOMMENDATIONS, DESIGN PRINCIPLES, AND CONCLUSION

5.1 INTRODUCTION

Like Janus, the god of beginnings, duality and doorways in ancient Roman mythology, who had two faces – one looking at the past, and one at the future – I would like to start this chapter by revisiting my research questions, and determining whether they were all answered. I will then look forward, by making recommendations that emerge from the findings, and suggesting topics for further research.

5.2 REVISITING THE RESEARCH QUESTIONS

This study set out to answer the primary research question, 'What are Senior Phase Natural Sciences teachers' lived experiences of participating in a longitudinal and systemic professional development intervention, aimed at addressing their specific professional development needs?'

Given the complexity of this study, I broke this overarching research question up into a number of secondary research questions. I will first answer these secondary questions, and will then, at the end, revisit the primary research question.

5.3 ANSWERING THE SECONDARY RESEARCH QUESTIONS

5.3.1 What is the role of a professional development programme in assisting Natural Sciences teachers to develop more nuanced views of the tenets of science?

Although the teachers had more nuanced understandings of the nature of science after the intervention, little transfer during the post-intervention classroom observations was evident, with the exception of Teachers B and C. Most teachers reverted to their old style of teaching, namely transmission mode teaching, which does not portray the tenets of science.

5.3.2 What is the role of a professional development programme in assisting Natural Sciences teachers to develop more nuanced views of the tenets of indigenous knowledge?

Data from the pre-VNOIK questionnaire indicated that most teachers had partially informed views or uninformed views of the nature of indigenous knowledge (NOIK). In the post-VNOIK questionnaire, most teachers had partially informed or informed views of the nature of indigenous knowledge (NOIK).

5.3.3 What are teachers' experiences of implementing contextualised problem-based learning (PBL) in the Natural Sciences classroom?

Data emerging from the participating teachers showed that they had a better understanding of contextualising the curriculum themes and following problem-based learning approaches after the intervention. Positive experiences were recorded from the Natural Sciences post-questionnaire, post-DNA barcoding questionnaire and the focus group interviews. Teachers showed excitement and readiness to implement problem-based learning (inquiring learning in their respective classrooms). However, post-intervention lesson observations and lesson plans indicated a lack of problem-based learning inquiry in most classes and teachers reverted to chalk-and-talk approaches. In Chapter 4 this tendency has been analysed using CHAT as a lens.

5.3.4 What transfer of newly acquired knowledge and skills took place in the classroom, after the series of professional development interventions?

Even though teachers during the interventions indicated proficiency in using different strategies learned, during the post-intervention classroom observations, a clear 'wash-out' effect was seen, and most teachers relapsed into their old ways of teaching, while others paid lip-service to aspects such as indigenous knowledge and cooperative learning. However, there were a few welcome exceptions, e.g., the teacher who engaged learners in a brewing of 'nkwapa' activity.

5.3.5 How do teachers' views of their own self-directed learning change during the intervention?

The dichotomous data showed huge differences between the quantitative and qualitative components. Most teachers scored lower in the Cheng questionnaire after the intervention, which might create the wrong impression that teachers were less self-directed. The qualitative data provided clear evidence of more self-directed learning after the intervention, e.g., four teachers indicating that the intervention inspired them to pursue postgraduate studies. In the Recommendations section of this chapter, I will explore this in more detail.

5.3.6 What are teachers' experiences of using science-on-a-shoestring (frugal science) approaches in the classroom?

Data that emerged from the interviews and the Jigsaw and shoestring questionnaires indicates that the intervention provided the teachers with 'cognitive apprenticeship'. However, despite the fact that teachers had hands-on experiences of building a spectroscope using inexpensive resources to facilitate inquiry learning, little agency was shown in the post-intervention classroom observations, as teachers did not attempt to devise frugal science approaches for the curriculum themes. Whereas teachers often say that not having resources is their reason for not doing practical work, it was disheartening to see that most of the teachers, despite having received classroom resources during the intervention, did not use them in their classrooms. For example, only two of the 10 teachers displayed the posters that they had received in the classrooms, in an attempt to create an inviting ‘scientific’ environment. Several teachers in the post-intervention interviews blamed the lack of inquiry learning in their classrooms on a lack of resources, but I claim that the lack of teacher agency is a more important reason.

5.3.7 What difficulties do teachers experience in using PhET-simulations (ICT's) in the classroom?

Sadly, only a few teachers actually used the PhET simulations in lessons, and the teachers who did, exclusively did it by way of demonstrating. Not a single teacher used it as a tool in a problem-based learning context, where learners had to do virtual experiments to solve a problem. Like in the above paragraph, this also highlights the lack of teacher agency.

5.3.8 How do teachers contextualise lessons after the intervention?

Although teachers generally held more nuanced understandings of indigenous knowledge and its affordances after the intervention, very few observed lessons provided evidence of infusing indigenous knowledge in creative ways that could stimulate higher-order thinking or skills development. In most cases, ‘lip-service’ was paid to IK, e.g., by referring to an example or two, without learners engaging with it. The best example of the infusion of IK was probably a lesson on anaerobic fermentation and beer brewing, and instead of learners planning their own investigations, the teacher demonstrated the experiment to the learners, who merely had to observe. However, some higher-order thinking skills were developed, where learners were given questions to discuss in small groups.

5.3.9 What are the experiences of the Natural Sciences teachers after engaging in authentic investigations in a real science laboratory at the African Centre for DNA Barcoding?

Data that emerged from the pre- and post-DNA Barcoding questionnaires and the focus group interview indicated that the African Centre for DNA Barcoding (ACDB) experiences provided the teachers with a 'pedagogical laboratory'. Immersing teachers in an authentic lab with ‘real scientists’, was a highlight for many of the participants. During the intervention, the teachers were inspired to replicate such experiences for learners in their classrooms. The data, particularly from the focus group interview, indicated that the teachers were enthused and their views on the nature of sciences and practical work were positively changed. Unfortunately, little of this materialised in the post-intervention classroom, and little evidence was provided of transformed teaching and learning. One could argue that the ACDB experience was too short, and that teachers need to engage in such laboratory experiences over a longer period of time.

5.3.10 What insight does an auto-ethnography offer when evaluating the intervention?

An important insight that emerged from the researcher’s auto-ethnography is that the intervention created a supportive Community of Practice (CoP) that facilitated teacher learning. It became clear that such a CoP should have certain characteristics, e.g., it should be built on mutual respect, and should also provide informal learning opportunities. One aspect of supporting learning in a CoP that did not come to fruition in this study was the utilisation of ICTs. Whereas I originally envisaged the creation of a virtual CoP, this aspect never really took off. When planning the teachers' professional development programme, the focus should be based on the teachers' real – not perceived – needs. Such interventions should be longitudinal and systemic in nature. All the teachers were happy to be part of the study and enjoyed the perks that came with the interventions, such as receiving resources for their classrooms.

5.4 ANSWERING THE PRIMARY RESEARCH QUESTION:

'What are Senior Phase Natural Sciences teachers' lived experiences of participating in a longitudinal and systemic professional development intervention, aimed at addressing their specific professional development needs?' Without a doubt, the data shows that the teachers benefited from the intervention, in terms of their own self-directed learning, their motivation, and in terms of their understanding of the tenets of natural sciences and indigenous knowledge. They were sensitised regarding the affordances of problem-based and cooperative learning approaches. Unfortunately, the post-intervention data also showed limited transfer to the classroom, and many of the teachers reverted to transmission-mode approaches. In the interviews teachers blamed this on systemic pressures, such as the focus on formative assessment, and a lack of resources. The data however also exposed a lack of teacher agency, in addressing these challenges that plague science education. Major findings of this research are presented as themes below:

5.4.1 Theme 1

The intervention helped teachers to develop more nuanced understandings of the nature of science, yet little evidence of transfer and acknowledgement of the tenets of science (transformed teaching) was observed in the post-intervention classroom.

Most of the teachers showed some improvement in their understanding of science. Also, in some of the lesson plans, I saw science language in terms of methods of science. However, when lessons were observed, post-intervention, chalk-and-talk approaches were utilised that marginalised the tenets of science. When Cultural Historical Activity Theory was used as a secondary analysis, tensions existed between the tools and the object. Tools such as chalk-and-talk approaches, lower-level Bloom questioning, and over-dependence on textbooks continued to dominate the post-intervention classroom, not providing learners with nuanced understandings of the nature of science. This lack of transformed teaching thus resulted in a contradiction of control between the professional development in one activity system and transformed teaching in the other activity system. This observation was not surprising, as the literature indicates similar trends in the studies of Antoniou (2017), Jackson et al. (2016) and Pretorius (2015).

5.4.2 Theme 2

The intervention assisted teachers to develop more nuanced understandings of the nature of indigenous knowledge, yet little evidence of transfer of such indigenous knowledge (transformed teaching) was observed in the post-intervention classroom.

Even after sensitising teachers during the SLP to integrate indigenous knowledge into the CAPS curriculum through pragmatic solutions such as applying the Kirby-Bauer technique for testing the anti-microbial activity of muthi plants, making soaps and utilising the Matrix Method to determine the ethnobiological knowledge index (EKI) and Species Popularity Index (SPI) no transfer of the border crossing between science and IK became evident post-intervention observation, with the exception of one teacher. Similar findings emerged from the study of Jackson et al. (2016).

5.4.3 Theme 3

Despite the fact that teachers showed greater sensitivity towards contextualising curriculum themes through indigenous knowledge, the majority of them have challenges to implement contextualised problem-based learning (PBL) in the Natural Sciences classroom.

During the intervention, the teachers were excited with integrating IK in the science curriculum and also showed agency to use problem-based learning when they return to their classes for teaching. Unfortunately, the CAPS and the accompanying teaching schedule and preparing learners for summative assessment have resulted in the exchange of such approaches for transmission mode teaching.

5.4.4 Theme 4

Evidence exists of nascent self-directed learning, but this does not yet direct transformed teaching practices or the development of teacher agency.

There were encouraging trends, such as teachers registering for postgraduate studies as a result of the motivational value of the intervention, yet it did not assist teachers as change agents to overcome some of the systemic pressures that they faced in the classroom.

5.4.5 Theme 5

Despite teachers' enthusiasm about frugal science and PhET simulations, very little transfer took place in the classroom, and little evidence of the use of science-on-a-shoestring approaches or ICT approaches was observed.

The argument that one often hears, namely that inquiry learning cannot be done due to a lack of resources, was debunked in this study. Although teachers received resources, due to a generous grant by the Fuchs Foundation, little evidence were provided that the teachers actually used these resources in their striving for more inquiry approaches.

5.4.6 Theme 6

Despite experiencing 'the world of a scientist' at the ACDB at UJ, none of the teachers demonstrated these tenets of science in the post-intervention classroom, probably because of their lack of knowledge and skills of laboratory protocols.

The laboratory experience at ACDB promoted scientific thought and scientific methods. In the post-questionnaire, the teachers made significant improvements in terms of laboratory protocols. Whilst that is the case, unfortunately during the post-classroom observation, none of the teachers showed transformed teaching that engaged learners in lessons that promoted the nature of science as tentative, inferential, socially and culturally entrenched, to mention few. This was not surprising as a similar insight was made by Motambatamba (2018).

5.4.7 Theme 7

A longitudinal professional development programme, fostering a supportive community of practice, could enhance teacher learning but should involve all stakeholders during the planning phase.

Whilst the CoP was contextualised to be a safe and supportive space for teachers, in hindsight, the researcher realised it was important to also have the teachers themselves as the keystone members (facilitators) during the intervention, taking initiative for their own learning. This could have provided a safe space where teachers could have learned from one another, particularly as the study promoted SDL. Another improvement for consideration is that the teachers should run the intervention themselves, while the facilitators provided guidelines, instead of a ‘consumer’ type of approach. Louws et al. (2017) emphasise that teachers should take ownership over their own learning, and have a sense of personal autonomy in their learning.

In an era where we cannot ignore the importance of technologies, the CoP should also have used blended learning; this would have saved the teachers from always having to come to the university, unless the activities required experiential learning. In the planning the researchers only involved the teachers, and in retrospect, teacher professional development should include all stakeholders including the SGBs, school principals, members of society and the department of education. I am of the view that this will enhance teaching and learning.

5.5 LIMITATIONS OF THIS RESEARCH

When critically reflecting on this research, there are a number of limitations that should be highlighted:

(a) The sample group (n=10) was small, and no generalisations could be made.
(b) Some of the teachers did not cooperate well in data collection due to the work pressure emanating from their busy schedules. Also, due to the positive relationships and mutual respect that were established in the project, some teachers did not want to disappoint the researcher, and for example had excuses when he wanted to observe lessons. This led the researcher to omit some of the profiles that were supposed to be in chapter 4, due to incomplete post-intervention

data. I am of the opinion that teachers either felt overwhelmed at the prospect of submitting all the instruments back to the researcher due to their busy schedules, or in fact they felt exposed, insecure or vulnerable.

(c) Another important limitation is the limited time that I as a researcher had to do this research, especially given the fact that so many interventions were done, and instruments used. As a Junior Lecturer, I have teaching and learning obligations as well as community engagements which are key performance areas in terms of my work, which placed pressure on my time.

(d) Some of the systemic tensions mentioned in the CHAT section in Chapter 4 (such as undue pressure from school management) could have been prevented, if all the different stakeholders (such as principals and the Department of Basic Education) had been involved in the planning of the intervention. This will be further discussed in the recommendation section in this chapter.

(e) The researcher originally planned to do more advanced descriptive statistical analysis of the SDL data, but the small sample, and the fact that some teachers did not complete both the pre- and post Cheng questionnaires, made this impossible.

5.6 RECOMMENDATIONS

Based on the insights gained during this research, the following recommendations can be made.

5.6.1 Recommendations in terms of teacher professional development

Based on this research, there are a number of design principles that should be kept in mind when planning and implementing teacher professional development programmes. In Chapter 3 I have indicated that I will use CHAT on both personal (as in Chapter 4) and institutional levels, as I will do here. Here, using CHAT on an institutional plane, the ‘subject’ becomes teacher professional development programmes, as seen in Figure 5.1.

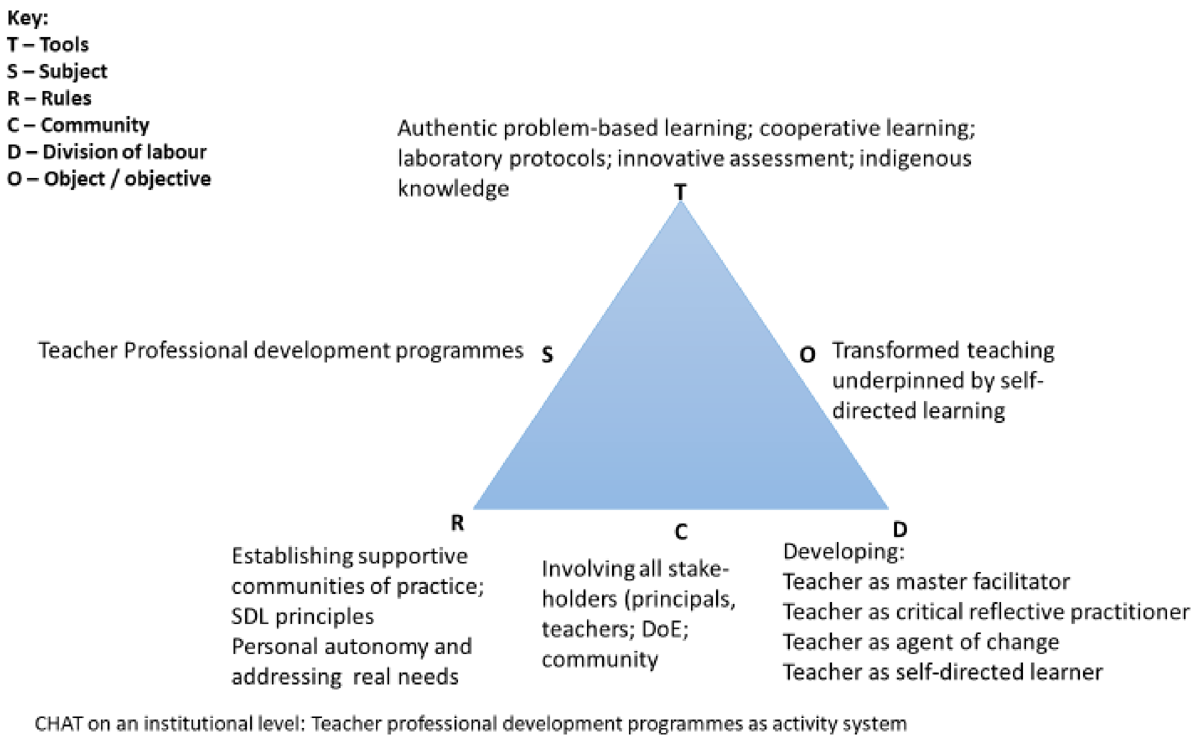

Figure 5.1: CHAT on an institutional level providing insights into design principles for teacher professional development

The object in Figure 5.1 is 'transformed teaching underpinned by self-directed learning'. Self-directed learning should underpin all teacher professional development interventions. Teachers should be involved in deciding upon the content of teacher professional development programmes, and they should take ownership of their own learning. Personal autonomy should be one of the design principles underpinning professional teacher development (also refer to Louws et al., 2017).

There is a big need to engage in-service teachers in authentic laboratory work, to enhance their understanding of the tenets of science (refer to 'tools' in Figure 5.1). An international example of this is the Target Inquiry project of Miami University in Ohio (www.targetinquirymu.org), spearheaded by Yezierski and Herrington, 2011. Elements of this were introduced in my research, with teachers engaging in laboratory work at the African Centre for DNA Barcoding at the University of Johannesburg. However, this short-lived experience was not enough, and longer interventions are needed. Furthermore, teachers also need support in developing knowledge and skills in engaging pedagogies, and in indigenous knowledge systems, in order to contextualise science curriculum themes for culturally diverse South African students.

Under 'rules' I list communities of practice. There are several guidelines that should underpin such CoPs, namely they should provide a safe space for personal development, and teachers should be actively involved, and develop agency. In a 21st century context, ICTs and social media could be effectively used to support on-line CoPs.

All stakeholders (refer to 'community' in Figure 5.1) should be involved from the beginning when such professional development is planned. Mentz and De Beer (2019) and De Beer (2019) refer to the value of 'Change Laboratories', where all the stakeholders engage in negotiating a shared 'object'. Engeström (2011:612) portrays a change laboratory as 'a microcosm in which potential new ways of working can be experienced and experimented with'. Stakeholders come together during such Change Laboratories, to discuss the intended object (in this context, the intended outcomes of professional development), and to reach consensus on a shared object. My data has shown that teachers often fall back on transmission mode approaches, despite the intervention that emphasised inquiry learning, due to expectations of, and pressure from, principals and parents.

By involving teachers, principals, subject advisors, the Department of Education, teacher unions, parents and the broader community in the conceptualisation of the PD intervention, one could avoid the 'contradiction of control' between the intended and realised objects, as was highlighted in Chapter 4. Engeström (2011) speaks of 'runaway objects', meaning that all the different stakeholders hold diverse views of what the object of the activity should be. This is illustrated in Figure 5.2.

5.6.2 Recommendations in terms of future research

Based on the above suggestion of engaging in 'Change Laboratories', fourth-generation Cultural Historical Activity Theory, as proposed by Engeström (2011) and Mentz and De Beer (2019), would be an ideal lens. This is nascent research that has not been done in South Africa as yet. In Figure 5.2 I show how fourth-generation CHAT would involve multiple activity systems. Each of the stakeholder groups (e.g., principals, subject advisors, teacher unions, parents, etc) would constitute an (interdependent) activity system.

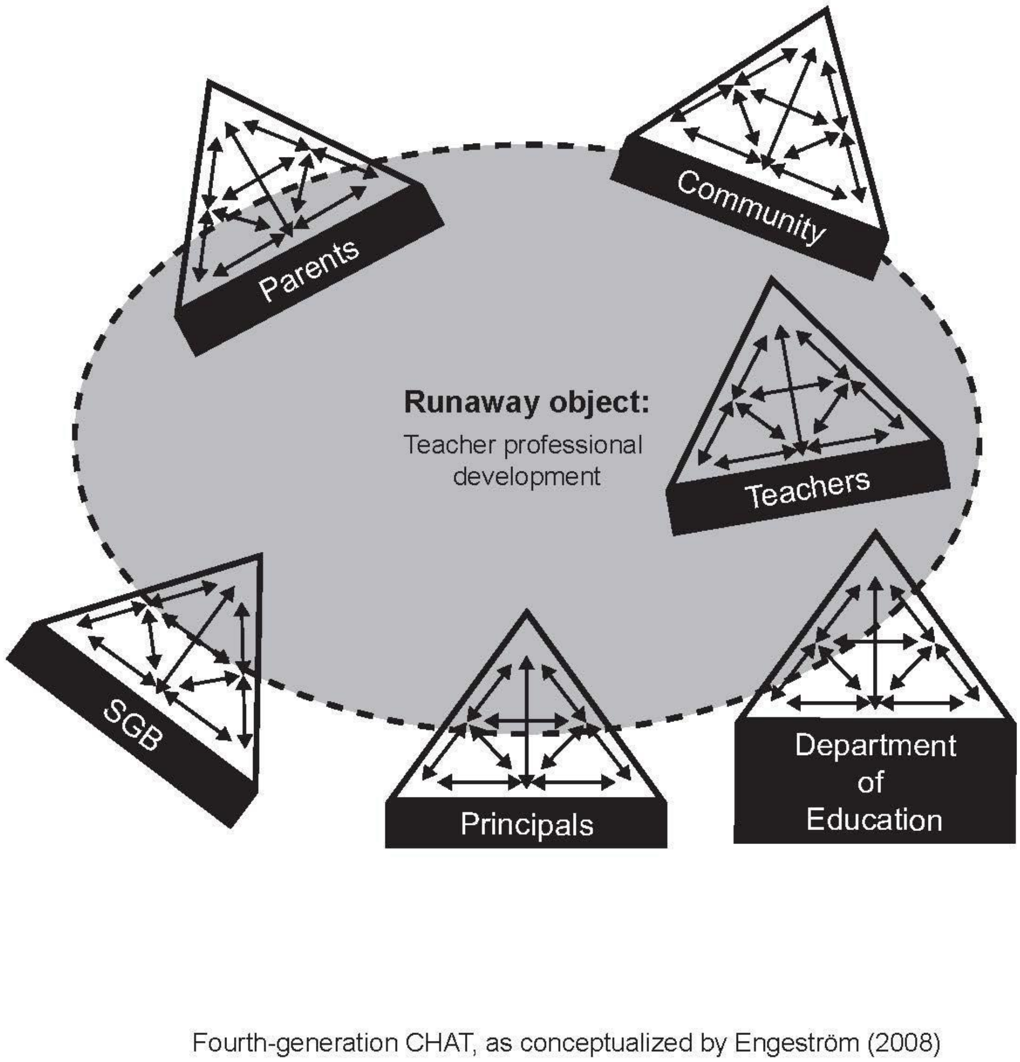

Figure 5.2: Using fourth-generation CHAT to study the 'runaway object' (taken from Mentz & De Beer (2019:263).

In this study I have introduced self-directed learning as a fifth domain in a Profile of Implementation. I have highlighted that researchers such as Mentz and De Beer (2019) argue for more mixed-methods research in the field of SDL, which is currently dominated by quantitative methodologies. My data have showed that there are often disparities between quantitative and qualitative data on SDL, and a mixed-methods approach provides a better description of self-directed learning gains. In the Profile of Implementation, I have utilised the Cheng et al. (2010) SDLI instrument in the quantitative section. However, some of the other SDL quantitative instruments, such as the self-directed learning readiness scale (SDLRS) by Guglielmino (1977), the self-directed learning readiness scale for nursing education (SDLRSNE) developed by Fisher, King and Tague (2001), the Williamson (2007) self-rating scale of SDL (SRSSDL), or the continuing learning inventory (OCLI) of Oddi (1986), might be more aligned with the qualitative SDL section in the heuristic. I therefore recommend that this is further researched.

Several other researchers have also utilised the VNOIK instrument (as I did in this study), e.g., Cronje (2015), De Villiers (2018), Jacobs (2018), and Reddy (2019). There should be a suitable data basis by now, to engage in Rasch modelling, to further refine construct validity of the instrument.

5.7 CONTRIBUTIONS OF THIS RESEARCH

5.7.1 Epistemological contribution

My study has contributed to two fields of literature, namely (a) teacher professional development, and (b) contextualising natural science through the infusion of indigenous knowledge. I hope that this study has added to the area Balfour (2019:xxxvii) mentioned in the foreword to a book[2] that I have contributed a chapter to, namely 'the nascent scholarship concerning the decolonization of the curriculum (in fields beyond postcolonial literary studies), and positioning indigenous knowledge systems as a means through which curriculum and curriculum making, pedagogy and teaching methodologies come to be re-envisioned'.

5.7.2 Methodological contribution

I introduce a revised Profile of Implementation in this study, with five domains, of which self-directed learning is the fifth. This heuristic could be useful when developing teacher professional development programmes, as I am vehemently advocating for self-directed learning as the foundation of all teacher professional development

[2] De Beer, J. (Editor). (2019). The decolonization of the curriculum project: The affordances of indigenous knowledge for self-directed learning. AOSIS. [name of chapter or name of book? Include both?]

programmes. The fifth (SDL) domain in the heuristic provides for three types of data interpretation, namely, quantitative, qualitative or mixed-methods interpretations.

5.7.3 Practical contribution

I collected my data over an extended two-year PhD programme, and due to generous funding by the NRF and Fuchs Foundation, we could provide science teachers with experiences such as working in the African Centre for DNA Barcoding, and doing a SLP on indigenous knowledge. It is hoped that this intervention would, in the long run, inspire a new generation of young scientists. My study also informed choices related to the development of teaching and learning resources, as part of the Fuchs Foundation's 'Teachers without Borders' project.

5.8 CONCLUSION

Self-directed learning should be considered as the nuts and bolts of teacher professional development in the conceptualisation stage. Such a take holds affordances for teachers to set their individual goals related to their central needs, in terms of classroom interaction, practical work, science and society and lastly assessment in terms of the revised Rogan and Grayson heuristic. The learning goals should be realistic (not too high or too low), but enough to be challenging, and the teachers should evaluate whether or not their learning goals were achieved, which requires teachers to be critical reflective practitioners.

Battisti (2018) talks about the winds of new change, and most often facilitators of teacher professional development programmes (TPDP) conceptualise TPD based on their own perceived ideas of teachers' professional development needs. My belief is that TPD should take a new departure, which is to structure TPDP based on teachers' real professional development needs within a well-established community of practice (CoP), that centralises teachers' autonomy and considers SDL as *sine qua non* in TPTP.

This has been a long journey for me as a neophyte researcher, and I experienced the joy, as well as the exasperation, that research brings. The joy of getting published, as well as the frustration of research participants cancelling appointments at the last moment, gave me a taste of the bitter-sweet fruit of research.

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APPENDICES

Please take note that the appendices are submitted as a separated pdf document., named **M.Ed Appendices**.