A professional development framework for supporting inquiry-based practical in work in resource constrained classrooms

by

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DECLARATION

I declare that the thesis, which I hereby submit for the degree Philosophiae Doctor at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

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Fru Vitalis Akuma

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ETHICS STATEMENT

The author, whose name appears on the title page of the thesis, has obtained, for the research described in this work, the applicable research ethics approval. The author declares that he has observed the ethical standards required in terms of the University of Pretoria's *Code of ethics for researchers and the Policy guidelines for responsible research.*

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ABSTRACT

Inquiry-based teaching and learning has been infused in practical work in science classrooms in schools internationally. However, confirmatory rather than inquiry-based practical work is prevalent in many South African Physical Science classrooms, especially in resource-constrained schools. Against this background, this study addresses the scarcity in a professional development framework (PDF) to support these teachers. The PDF was developed using a research process based on the development studies approach in educational design research. The process involved three research cycles, including a systematic literature review from an international perspective (cycle one and two) and a multi-method, multi-case study in South African schools (cycle three). In each research cycle consisting of an analysis, design/develop prototype, and formative evaluation phase, design principles were generated or revised as a basis for developing the PDF. The case study included interviews, observation and document analysis in favour of a context and needs analysis. The formative evaluation methods consisted of screening and one-to-one evaluation, with the quality criteria evolving from relevance (content validity) to relevance and consistency (construct validity) and finally to expected practically and expected effectiveness. The primary outcomes included ten design principles and the associated context-specific version of the PDF. The PDF contained eight primary components: learning phases, learning theory, professional development strategy (lesson study), instructional functions (for example, reviewing learning periodically), teacher motivation (intrinsic and extrinsic), instructional design perspective, attending to contextual factors, and professional development goals. The first primary goal was to create an environment that better supports teacher learning and practice in the design and implementation of IBPW in South African Physical Science classrooms in resource-constrained schools. The second primary goal was to enhance the competences, professional identity and practice of teachers in the design and implementation of IBPW. The process involved in developing the PDF in addition to the PDF and the ten associated design principles could be considered by users in interventions towards enhancing the design and implementation of IBPW in the present and other contexts. The users include policy makers and professional development providers. Also, though the PDF is potentially effective and practical, researchers are encouraged to evaluate its actual effectiveness and practicality.

LANGUAGE EDITING CERTIFICATE

Exclamation Translations

To whom it may concern

The dissertation entitled, "A professional development framework for supporting inquiry-based practical work in resource constrained classrooms" has been edited and proofread as of 01 April 2017.

As a language practitioner, I have a Basic degree in Languages, an Honours degree in French and a Master's degree in Assessment and Quality Assurance. I have been translating, editing, proofreading and technically formatting documents for the past seven years.

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LIST OF ABBREVIATIONS

5E	-	Engagement, Exploration, Explanation, Elaboration and Evaluation
IB	-	Inquiry-Based
IS	-	Interview Schedule
IBPW	-	Inquiry-Based Practical Work
ID	-	Instructional Design
IM	-	Instructional Model
LS	-	Lesson Study
PD	-	Professional Development
PDF	-	Professional Development Framework
PW	-	Practical Work
SEEMs	-	Science Education Equipment and Materials
SET	-	Science, Engineering and Technology
SLID	-	Science Laboratory Instructional Design
SLR	-	Systematic Literature Review
SRQ1, SRQ2…	-	Secondary Research Question 1, 2 and so on, as stated in section 1.3.2
SRP1, SRP2…	-	Secondary Research Purpose 1, 2 and so on, as stated in section 1.3.3.

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KEY CONCEPTS

Challenge	-	A condition that presents a difficulty for the teacher in terms of moving towards or attaining a goal.
Educational design research	-	A range of approaches (in this case strategies) for developing new theories, practices and artefacts that potentially affect and also account for teaching and learning in naturalistic settings
Design studies	-	Approach in design research involving the design and development of an intervention towards solving a complex educational problem, while advancing knowledge about the characteristics of the intervention, as well as the processes of designing and developing the intervention.
Inquiry-based practical work (IBPW)	-	Experiences in which learners collaboratively manipulate a combination of hands-on and computer-based SEEMs or existing data sets in order to gain an understanding of the natural world as they experience inquiry-based learning practices through structured, directed or open inquiry.
Practical work (PW)	-	Activity that enables learners to develop practical skills as well as an understanding of scientific concepts, phenomena and the nature of science.
Professional Development Framework (PDF)	-	Abstract artefact serving as a blueprint of the associated professional development process and consisting of concepts, assumptions, principles, values and practices linked to the processes, means and ways through which the desired professional development outcomes may be achieved.
Resource-constrained school or classroom	-	School or classroom in a low-income community (community of low socio-economic status).

ACTUAL AND EXPECTED STUDY OUTPUT

The output is and is expected to be primarily in the form of peer reviewed journal articles. In this regard, the table below provides the actual and expected output.

Completion status	Title of article	Type	Chapter
Published	**1**. Framework to reduce teaching challenges relating to the improvisation of science education equipment and materials in schools. Eurasia Journal of Mathematics, Science & Technology Education, 12(10), 2697-2717. doi: 10.12973/eurasia.2016.1305a*	Review paper	Four
Second revision	**2**. Towards enhancing the environment around inquiry-based practical work in South African physical science classrooms.	Original research	five
Submitted	**3**. Professional development needs linked to inquiry based practical work in certain physical science classrooms.	Original research	five
In preparation	**4**. Framework to reduce intrinsic challenges linked to inquiry-based practical work in secondary school science classrooms.	Review paper	four
	5. Towards a systemic reduction of extrinsic teaching challenges linked to inquiry-based practical work in secondary school science classrooms.	Review paper	four
	6. Reality of inquiry-based practical work in certain South African physical science classrooms.	Original research	five
Proposed	**7.** Conceptual professional development framework to support inquiry-based science education.	Review paper	three
	8. Conceptual professional development framework to support inquiry-based practical work.	Review paper	four
	9. Professional development framework to support inquiry-based practical work in certain physical science classrooms.	Original research	five

* Article is contained in Appendix Q.

CHAPTER 1 : INTRODUCTION AND OVERVIEW

This research focused on the development of a professional development framework (PDF). The PDF is to support South African Physical Science teachers in resource-constrained schools in the design and implementation of inquiry-based practical work. For this purpose, an evolutionary prototyping process was used. Here, the process comprised three research cycles spanning four of the six chapters that make up this study. The prototyping process begins in this chapter since the research problem is discussed here.

1.1 CHAPTER OVERVIEW

There are four major sections in this chapter, which include background information; the problem and purpose statement, in addition to the study's contribution and significance. Also included are an overview of the study, and the chapter summary and conclusion. The first section presents the broad international and national context in relation to science education in general, and practical work in particular within which this study was situated (see Section 1.2). It is against this background that the problem and purpose statement are then presented in Section 1.3. The problem is centred on the inadequate design and implementation of practical work in many South African Physical Science classrooms and the scarcity of a professional development framework in this regard. Thus, the research questions are directed towards this practical and research problem. Also discussed in this section is the contribution of this study to science teachers' professional development and beyond. This is followed in Section 1.4 by an overview of the study, including a summary of this introductory chapter followed by an outline of the remaining five chapters of the study.

1.2 BACKGROUND INFORMATION

This study was situated in an international and South African science education context that is undesirable. This section not only presents the context, but also looks at the role that practical work in secondary school science classrooms can play in this regard.

1.2.1 State of science education and related effects

1.2.1.1 International perspective

We live in a world where science affects our lives on a daily basis. Science is necessary to enable citizens to make informed decisions on issues, which include the use of energy and resources, global warming, stem cell research, and genetically modified organisms (Harlen, 2010; Organisation for Economic Co-operation and Development, 2008). However, around the world, the interest of young people in science is declining (Barmby, Kind, & Jones, 2008; Institute of Physics, 2010; Ng & Nguyen, 2006; Sjøberg & Schreiner, 2005). The decline is reflected in the dwindling uptake of Physical Science and other sciences in addition to science-related subjects and careers in many countries (Helliar & Harrison, 2011; Organisation for Economic Co-operation and Development, 2008). The low uptake of school science and science-related careers is likely to have an adverse effect on scientific research and national economic development given that science is an important factor in the socio-economic progress of many countries (Logan & Skamp, 2007; Wynarczyk & Hale, 2008). Thus, in Ireland, for example, a curriculum review has been initiated in an attempt to increase the number of learners choosing to take Physical Science through to the upper secondary level (Donnelly, O'Reilly, & McGarr, 2013).

One question that arises is the cause of the above effects linked to science education. At least part of the answer lies in the field of science education itself. School learners commonly have an unsatisfactory experience of science (Kim & Tan, 2010), for example, learners have misconceptions and face difficulties in learning science (Duit & Treagust, 2003; Skamp, 2008). In particular, school learners experience difficulties in Physical Science in general, and physics in particular (Lee, Guo, & Ho, 2008; Mji & Makgato, 2006; Ng & Nguyen, 2006). The decline in enrolment is often partly attributed to the uninteresting content of science courses with high theoretical content such as physics and chemistry (Organisation for Economic Co-operation and Development, 2008). Thus, the manner in which learners experience science education is not favourable to high levels of interest in the learning of science. How then would the uptake of science and science-related careers not suffer?

1.2.1.2 South African perspective

Science has an essential role to play in the development of the South African economy (South African Agency for Science and Technology Advancement, 2016), like any other economy in the world. However, South Africa is not an exception in terms of the above undesirable state and effects linked to science education. In this country, enrolment in Science, Engineering and Technology (SET) courses at the higher educational level has been lower in relation to a number of none science-based courses for more than a decade (Department of Basic Education, 2012; Department of Education, 2006, 2009). The low enrolment in SET courses coincides with science learners' low performance. This includes Physical Science learners at the end of the Further Education and Training (FET) band, which stretches from Grades 10 to 12. Physical Science combines physics and chemistry, which are enabling sciences (Cooper, Kenny, & Fraser, 2012). However, the number of Grade 12 learners who pass Physical Science at a level to enter science-based university courses is low (Kriek & Grayson, 2009), for example, the average pass rate (40% and above) of Grade 12 Physical Science learners at the National Senior Certificate Examination during the period 2010 to 2014 was only 36% against 61 % in the case of History (Department of Basic Education, 2013, 2014, 2016). In the absence of a healthy supply of science learners, South Africa cannot develop its potential of becoming a rich source of scientific expertise (South African Agency for Science and Technology Advancement, 2016).

In relation to slowing down and possibly reversing the above undesirable effects linked to science education, practical work in science classrooms in schools is one area to focus on.

1.2.2 Role of practical work

Practical work is considered by many people and in many countries as a critical component of science education in general, and Physical Science education in particular (Abrahams & Millar, 2008; Corter, Nickerson, Esche, Chassapis, Im, & Ma, 2007; Lee et al., 2008). Also, practical work is often cited as the central reason behind the enrolment of many high school learners in science (Donnelly et al., 2013). Although some researchers (e.g., Hofstein & Mamlok-Naaman, 2007; Tobin, 1990) have found that the effectiveness of practical work in enhancing the conceptual understanding of learners is unclear, this is not the case considering Secker and Lissitz (1999), who find that practical work can positively affect the achievement of science learners. However, the rationale for practical work in science classrooms provided by many authors (such as Lynch, 1986; Tamir, 1991) goes beyond conceptual learning. The rationale includes assisting learners in the development of procedural knowledge and in the investigation of the natural world. Also, practical work promotes the development of the practical, problem-solving, and analytical skills of learners, in addition to their critical and creative thinking abilities. Furthermore, practical work assists in nurturing the scientific values and attitudes of learners, as well as in enhancing their motivation and interest in science. Practical work is thus useful towards countering the above undesirable effects linked to science education in South Africa and internationally. The usefulness of practical work in this regard has been enhanced by the current emphasis on this area.

At the time of this study, there had recently been a shift in emphasis in the context of practical work in science classrooms in secondary schools around the world. The shift in emphasis is in line with the common conviction that the learning of science ought to focus less on the acquisition of scientific knowledge and more on the understanding and application of scientific concepts and methods. In the light of this conviction, reforms towards making science education in schools inquiry-based began to take place around the world in the 1960s. Examples of these reforms include the Nuffield Secondary Science teaching approach introduced in the United Kingdom in the late 1960s (Gott & Duggan, 1995), and the National Standard In Science Education for Lower Secondary Schools in Germany (Di Fuccia, Witteck, Markic, & Eilks, 2012). Curricular changes towards making science education in general and practical work in particular more inquiry-based have also taken place in South Africa (Department of Basic Education, 2011b; Dudu & Vhurumuku, 2012). This is despite a number of perceived disadvantages linked to inquiry-based science education. For instance, some teachers have safety concerns and fear losing control of the classroom (Deters, 2004). This is in addition to concerns linked to the time demands and the grading of learners engaged in inquiry-based learning (Anderson, 2007; Deters, 2004).

Despite the drawbacks of inquiry-based science education, practical work involving inquiry is potentially useful towards countering the undesirable state and effects linked to science education noted earlier. This is partly because the level of engagement involved in inquiry-based teaching and learning can have a positive effect on the attitudes of learners towards science (Osborne & Dillon, 2008; Rocard, 2007). Also, inquiry-based teaching positively affects learning as it enables learners to better understand scientific concepts and procedures than through rote learning (e.g., Lee & Krapfl, 2002; Minner, Levy, & Century, 2010). In addition, inquiry-based learning assists in the development of higher-order thinking skills (Conklin, 2012), and an understanding of the nature of science (Gaigher, Lederman, & Lederman, 2014a). Furthermore, inquiry-based teaching enhances the interest, motivation and engagement of learners in science (e.g., Mistier-Jackson & Songer, 2000; O'Neill & Polman, 2004; Osborne, 2010).

Against the above background, we see that inquiry-based practical work can contribute towards addressing the above undesirable effects linked to science education in South Africa and internationally.

1.3 PROBLEM AND PURPOSE STATEMENT

1.3.1 Problem statement

Practice- and research-based problem. This study addresses a practice-based (educational) problem and the related research problem. Both problems are linked to inquiry-based practical work in South African Physical Science classrooms, especially in resource-constrained schools. The two problems are outlined in Table 1.1 below.

Table 1.1 Practice- and research-based problems involved in study (Source: Researcher)

Problem type	Problem statement
Practice-based	Confirmatory rather than inquiry-based practical work is prevalent in many South African Physical Science classrooms, especially in resource-constrained schools.
Research-based	The scarcity of data regarding a development process, the design principles and a PDF* to support the design and implementation of inquiry-based practical work in South African Physical Science classrooms in resource-constrained schools.

* PDF = Professional Development Framework

The rest of this section positions the problems contained in Table 1.1 in the context of research and practice in teacher professional development, and inquiry-based teaching and learning in relation to practical work.

State of practical work. In many schools, practical work is inadequately designed and implemented in addition to being unproductive and confusing (Childs, Tenzin, Johnson, & Ramachandran, 2012; Hodson, 1991; Kind, Kind, Hofstein, & Wilson, 2011). It is thus not surprising that research findings have attributed the relatively low performance of South African Physical Science learners, in part, to the inadequate implementation of practical work, especially in resource-constrained schools (Mji & Makgato, 2006; Sedibe, 2011; Singh & Singh, 2012). More specifically, a survey showed that Physical Science teachers in schools in communities with low socio-economic status (resource-constrained schools) exhibit a strong orientation towards expository science instruction followed by confirmatory practical work (Ramnarain & Schuster, 2014). Thus, simply urging teachers to involve their learners in inquiry-based experiences does not lead to the practice of high levels of inquiry in the classroom (Dudu & Vhurumuku, 2012). Thus the practice-based (educational) problem in Table 1.1. The problem stems from the infusion of inquiry into practical work. Although inquiry-based teaching and learning is the widely-accepted direction in science education reform internationally, the implementation of this strategy in science classrooms is a challenge for teachers

(Alhendal, Marshman, & Grootenboer, 2015; Higgins, 2009; Ruhrig & Höttecke, 2015). Extrinsic (contextual) factors that affect inquiry-based teaching include school ethos, professional support, time contraints, resource adequacy, in addition to learner ability and exposure to inquiry (Ramnarain, 2014, 2016; Ramnarain & Schuster, 2014). At the same time, the design and implementation of inquiry-based science lessons are complex processes (Higgins & Spitulnik, 2008; Van Rens, Pilot, & Van der Schee, 2010). This is coupled with the fact that many teachers lack experience in inquiry considering the limited exposure provided in their pre-service education (Tal & Argaman, 2005). Thus, some teachers lack the knowledge and skills to carry out inquiry-based science teaching (Nompula, 2012). Against this background, the need to enhance the knowledge and skills of teachers in relation to inquiry-based teaching has been noted (Dudu & Vhurumuku, 2012; Korthagen, 2010), even by teachers themselves (Kriek & Basson, 2008b). Engaging teachers in curriculum reforms requires professional development (Stolk, De Jong, Bulte, & Pilot, 2011). In fact, teacher professional development is an effective mechanism for realising standards-based reforms in school classrooms (McHenry & Borger, 2013).

Usefulness and scarcity of a Professional Development Framework (PDF). PDFs are increasingly being used to guide the design of professional development efforts (Stolk et al., 2011). A PDF is considered here as essentially the blueprint of the associated professional development programme and thus a predictor of the process that is expected to occur (Stolk, Bulte, De Jong, & Pilot, 2012). However, a PDF to support Physical Science teachers in South African resource-constrained schools in the design and implementation of inquiry-based practical work is not readily available in the literature. This is evidenced by a systematic literature review that was carried out in the context of this study. This literature review (see Section 3.2.2) included a search of ten databases, and included 23 peer reviewed articles from eleven journals in the Web of Science database (2016). However, no such a PDF was found. The literature review also revealed that although some data that is useful in designing a PDF is available (Stolk, Bulte, de Jong, & Pilot, 2009b), there is scarcity in data regarding the associated design principles and development process. The research problem in this study thus encompasses the lack of design principles, a development process and a PDF to support the design and implementation of inquiry-based practical work in South African Physical Science classrooms in resource-constrained schools.

Research into teacher professional development has focused on the process of professional development and not only its outcomes (Hanley, Maringe, & Ratcliffe, 2008; Van der Valk & De Jong, 2009). However, inadequate attention has been given to the process of professional development (Stolk et al., 2009b), leading to the unsatisfactory outcome of some professional development programmes (Stolk et al., 2011). Regarding this process, there is a need for such data useful in designing professional development programmes as the processes, means and ways through which professional development outcomes may be attained (Hewson, 2007). In this case, the missing data consists of design principles, the associated development process, and a PDF to support the design and implementation of inquiry-based practical work in South African Physical Science classrooms in resource-constrained schools. This leads to the research-based problem in Table 1.1.

1.3.2 Research questions

This study was based on the following Primary Research Question (PRQ) resulting from the above problem statement:

PRQ: How can one develop a Professional Development Framework to support teachers in resource-constrained South African Physical Science classrooms in the design and implementation of inquiry-based practical work?

An answer to the above Primary Research Question (PRQ) may be derived from the answers to the following four secondary research questions:

SRQ1a: What are the characteristics of a conceptual content-generic Professional Development Framework to support science teachers?

SRQ1b: What are the characteristics of a conceptual content specific Professional Development Framework to support inquiry-based practical work in secondary school science classrooms?

SRQ2: How inquiry-based is the way in which practical work is being designed and implemented in resource-constrained South African Physical Science classrooms?

SRQ3a: What specific extrinsic challenges are being faced by teachers in these classrooms in relation to the design and implementation of inquiry-based practical work?

SRQ3b: What specific intrinsic challenges are being faced by the teachers in relation to the design and implementation of inquiry-based practical work?

SRQ4: What are the characteristics of a context-specific Professional Development Framework to support these teachers in the design and implementation of inquiry-based practical work?

In this study, the prefixes SRQ1a, SRQ1b, SRQ2, SRQ3a, SRQ3b and SRQ4 above are often used to refer to the respective secondary research questions. Similar prefixes are used in the case of the secondary research purposes, which are contained in the next section.

1.3.3 Purpose of the study

With reference to the Primary Research Question (PRQ) above, the Primary Research Purpose (PRP) in this study was:

PRP: To generate design principles and use them over a number of research cycles to develop a professional development framework. This framework is to support teachers in resource-constrained South African Physical Science classrooms in the design and implementation of inquiry-based practical work.

The above research purpose may be achieved based on the research process shown in Figure 1.1.

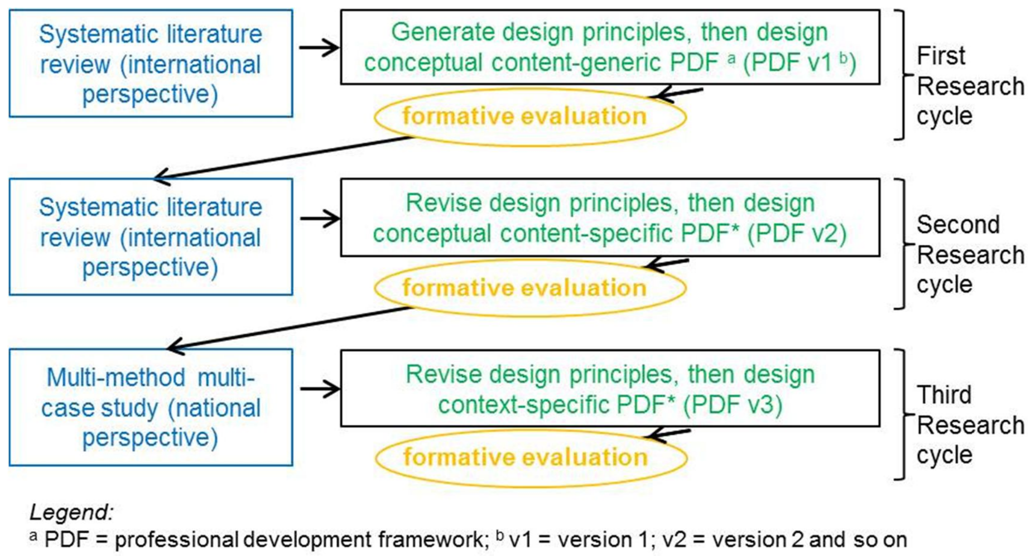


Figure 1.1 Simplified research process used in this study (Source: Researcher)

The process in Figure 1.1 results from the conceptual framework of this study. The conceptual framework is rooted in development studies as a specific approach in design research. The conceptual framework is elaborated on and explained later in Section 2.4.3. In the course of using the process in Figure 1.1 to attain the above Primary Research Purpose, four secondary research purposes were achieved. These purposes are linked to the Secondary Research Questions (SRQ) in Section 1.3.2. The Secondary Research Purposes (SRPs) are as follows:

SRP1a: To generate tentative design principles in relation to effective teacher professional development. This would form the basis for a conceptual content-generic PDF to support science teachers, which was then designed

SRP1b: To generate refined/specified design principles in relation to the design and implementation of inquiry-based practical work and the related challenges, and then design the associated conceptual content-specific PDF to support science teachers

SRP2: To determine how inquiry-based, or not, is the way in which practical work is being designed and implemented in resource-constrained South African Physical Science classrooms

SRP3a: To determine the extrinsic challenges being faced by teachers in these classrooms in relation to the design and implementation of inquiry-based practical work

SRP3b: To determine the intrinsic challenges being faced by teachers in these classrooms in relation to the design and implementation of inquiry-based practical work

SRP4: To generate the final design principles considering SRP2, SRP3a and SRP3b, and then design a context-specific version of the Professional Development Framework.

1.3.4 The study's contribution and significance

1.3.4.1 Contributions

The above primary and secondary purposes of this study indicate that the study has a theoretical and a practical contribution to inquiry-based practical work in national and international schools' science classrooms. However, the contribution of this study also has a methodological aspect. This is partly linked to the essence of development studies as the purpose of such studies is to design and develop an intervention that helps to solve a complex educational problem, while advancing knowledge about the characteristics of the intervention, as well as the processes of designing and developing them (Plomp, 2013).

Methodological contribution. There have been calls for the implementation of design research in a variety of contexts (Plomp, 2007), considering that this research strategy has an emerging status (Plomp, 2013). As a result, this study contributes towards the further development of this research strategy in general, and development studies in particular. The contribution in this regard is located in the specific context of inquiry-based practical work in South African Physical Science classrooms in resource-constrained schools.

Theoretical contribution. In this study, the researcher designed a conceptual content-generic and conceptual content-specific PDF to support inquiry-based science education and inquiry-based practical work, respectively. Both versions of the PDF are based on a systematic review of the relevant international literature, as seen in Figure 1.1. These versions of the PDF are a segment of the theoretical contribution of this study. Other contributions of the study in this category are three sets of design principles generated in the course of developing the completed PDF. Moreover, this study verified the process contained in Figure 1.1 as a process that can be used to develop a PDF for the above purpose. This process adds to the theoretical contribution of this study.

Practical contribution. The practical contribution of this study is found in the completed PDF developed by the researcher. This contribution responds to the educational (practice-based) problem identified in the problem statement (Section 1.3.1, Table 1.1). Specifically, the contribution is the completed PDF, which supports teachers in terms of the intrinsic and extrinsic challenges that they actually face in the design and implementation of inquiry-based practical work in the context under study in this research. This contribution is a reflection of the research strategy implemented in the sense that design research narrows the divide between theory and application, and between practice and research (Mishra & Koehler, 2006).

1.3.4.2 Significance of contributions

A number of parties stand to benefit from the above contributions of this study. These parties include the science education sector in general, learners, and professional development providers.

Teacher professional development provision in various contexts. It has been argued that the lack of opportunities to explore and apply inquiry-based activities in pre-service teacher education, and also in professional development contexts, is one reason for the lack of implementation of inquiry-based teaching (Huziak-Clark, Van Hook, Nurnberger-Haag, & Ballone-Duran, 2007). In order for teachers to implement an inquiry-based approach in science education, they need adequate practice in aligning their lessons with inquiry-based teaching (Al-Abdali & Al-Balushi, 2015; Capps & Crawford, 2013a). In fact, in terms of the successful implementation of inquiry-based activities in science classrooms, even experienced teachers tend to need extended professional support (Lederman & Lederman, 2012). However, designing effective teacher professional development is a complex task (Marra, Arbaugh, Lannin, Abell, Ehlert, Smith et al.,, 2011). In this regard, all the versions of the PDF from this study are useful in making the work of professional development providers less complex.

Teachers practice in contexts that are diverse (Koehler & Mishra, 2009). As is the case in this study, the design principles associated with the conceptual content-generic and content-specific versions of the PDF could assist in the provision of support in different contexts in relation to the design and implementation of inquiry-based science education and inquiry-based practical work, respectively. In this regard, the process for developing a PDF is useful, while the conceptual content-generic and content-specific versions of the PDF could serve as exemplars in the designing of other PDFs in specific circumstances. Alternatively, the completed PDF thus designed may be considered for use by South African professional development providers and policy makers, for example.

Potential benefits of PDF to learners. Professional development is a key determining factor in improved classroom instruction and learner performance (Ostermeier, Prenzel, & Duit, 2010; Zakaria & Daud, 2009). The implementation of the completed PDF designed in this study could contribute to raising the performance of learners in Physical Science. Additionally, by focusing on inquiry-based practical work, the framework could also enhance the interest and continued enrolment of learners in science. These potential benefits lie in the fact that inquiry-based teaching and learning (during practical work), as opposed to rote learning, could positively affect the attitudes of learners towards science (Osborne & Dillon, 2008) while enabling them to better understand scientific concepts and procedures (Minner et al., 2010).

Usefulness of the study in relation to practical science in general. The outcomes of this study contribute to a response to the inadequate attention that has been given to the process of professional development, as noted by Stolk et al. (2009b). In this regard, this study focused on inquiry-based practical work in South African Physical Science classrooms in resource-constrained schools. At the same time, there has been relatively few studies dealing with practical work in science teacher learning (Forsthuber, Motiejunaite, & de Almeida Coutinho, 2011). Therefore, the outcomes of this study may be useful locally and internationally in relation to enhancing reform-based teaching and learning in general, and specifically in Physical Science classrooms.

1.4 STUDY OVERVIEW

In addition to this introductory chapter (chapter one), the other five chapters of this study consist of a research methodology and methods chapter (chapter two), the first design research cycle (chapter three), the second research cycle (chapter four), the third and last research cycle (chapter five) in addition to the final summary and conclusion chapter (chapter six). An outline of each the above chapters is provided below, beginning with a summary of this chapter.

1.4.1 Chapter 1: introduction and overview

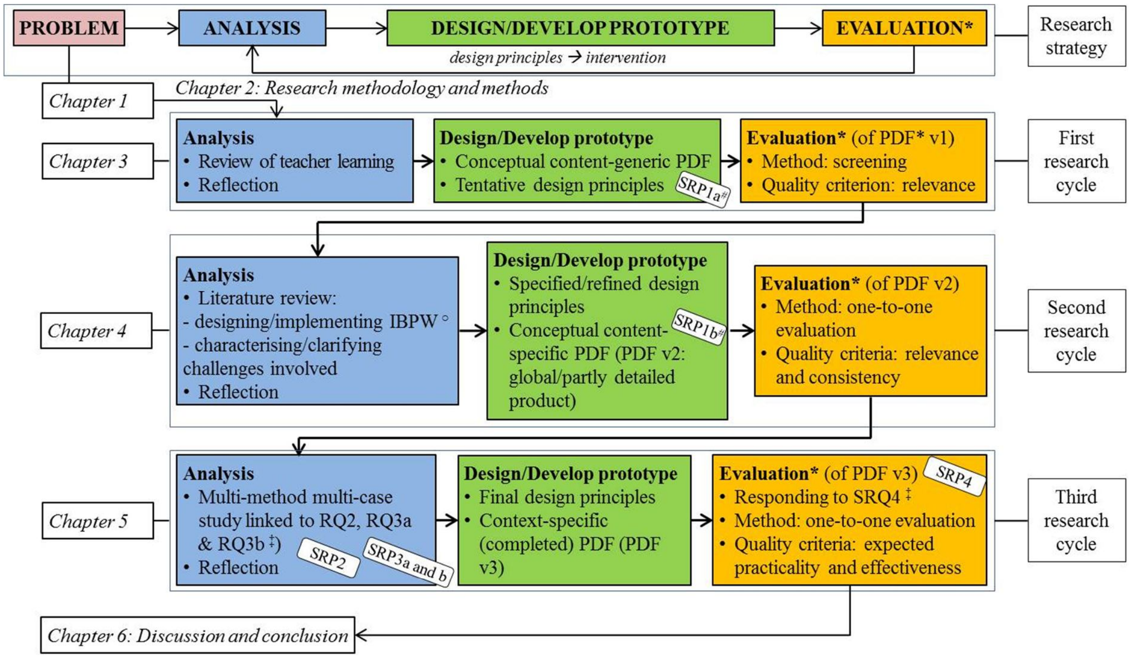
This study is positioned against a background characterised by the relatively low performance of South African Physical Science learners. Regarding this performance, researchers have attributed part of the blame to the implementation of practical work, especially in resource-constrained schools. Inquiry has been infused into the Physical Science curriculum for these and other South African Physical Science classrooms. However, physical science teachers in resource-constrained schools mostly carry out expository science instruction followed by confirmatory practical work. Against this background, the primary purpose of this study was to develop a PDF to support South African Physical Science teachers in resource-constrained schools, in the design and implementation of inquiry-based practical work. In relation to other subjects, the PDF could serve as an exemplar in allowing professional development providers to design a PDF that supports inquiry-based science education and inquiry-based practical work, respectively. This study thus makes a contribution to enhancing reform-based science education in South Africa and internationally. How this contribution is derived is the focus of Chapter 2.

1.4.2 Chapter 2: research methodology and methods

The aim of this chapter is to provide guidance regarding the entire research process undertaken in this study. Thus, Chapter 2 discusses the research paradigm, approach, and strategy, in addition to the techniques used in the data collection and analysis. The discussion is framed using the research process model of Saunders and Tosey (2013).

As explained in this chapter, the paradigm selected to provide direction was pragmatism. Also explained is the choice of a predominately inductive research approach. However, most of the discussion in this chapter is centred around design research, which is the overarching research strategy in this study. The first part of the discussion focuses on linking the outcomes of the study to the outcomes of development studies as an approach in design research. This is followed by a discussion of the implementation of such design research studies. As discussed in the chapter, the implementation of design research in this study was based on a design research process model developed by Plomp (2013). The phases of the model consist of the problem, data analysis, design/development of the prototype, and evaluation.

A conceptual framework linked to the above design research implementation model is developed in this chapter. The conceptual framework details the simplified research process provided in Figure 1.1. The resulting detailed research process for this study is shown in Figure 1.2. The figure identifies the different versions of the professional development (PDF) synthesised. Also identified in Figure 1.2 are the sets of design principles on which each of the versions of the PDF is based.



Legend:
* Consisting of data collection and analysis, in addition to results and reflection
♦ PDF = Professional Development Framework; ° IBPW = Inquiry-Based Practical Work; # SRPi = Secondary Research Purpose i (section 1.3.3)

‡ SRQ1a = What are the characteristics of a conceptual content-generic PDF to support science teachers?
‡ SRQ1b = What are the characteristics of a conceptual content-specific PDF to support IBPW in secondary school science classrooms?
‡ SRQ2 = How inquiry-based is the way in which practical work is being designed and implemented in resource-constrained South African Physical Science classrooms?
‡ SRQ3a = What specific extrinsic challenges are being faced by teachers in these classrooms in relation to the design and implementation of IBPW?
‡ SRQ3b = What specific intrinsic challenges are being faced by the teachers in relation to the design and implementation of IBPW?
‡ SRQ4 = What are the characteristics of a context-specific PDF to support these teachers in the design and implementation of IBPW?

Figure 1.2 Detailed design research process used in this study (Source: Researcher)

At the top of Figure 1.2, the reader can see the primary design research implementation process model employed in this study, which was obtained from Plomp (2013). The rest of the figure mostly shows how this model, in conjunction with two other implementation models (described later in Section 2.4.3.2), is applied through the three research cycles indicated down the right side of the figure. On the left-hand side of the figure, the chapters in which the different cycles of the design research process were achieved are indicated. The middle of Figure 1.2 shows the evolution of the PDF and the associated design principles through three iterations (cycles) of the design research process. Figure 1.2 also indicates the levels in the research process where the different secondary research questions and purposes were addressed. As mentioned earlier, the detailed research process contained in Figure 1.2 is further discussed in Chapter 2.

This chapter also contains a discussion of the techniques and procedures used in the data collection and analysis, in addition to the ethical principles employed in the data collection, analysis and dissemination of the data. The discussion in this regard is applicable to the rest of this study.

1.4.3 Chapter 3: conceptual content-generic professional development framework

This chapter describes the first research cycle outlined in Figure 1.2. It is in this research cycle that the development of the PDF actually commenced. The discussion in the analysis phase of the research cycle first leads to the positioning of the conceptual content-generic version of the PDF in the context of the effective (continuous) professional development of science teachers. In this regard, the characteristics of such professional development are gathered for use in the formative evaluation of the PDF. In the design/develop prototype phase, the components of the conceptual content-generic PDF were identified based on a systematic review of the relevant literature. This allowed seven tentative design principles to be generated. The design principles were used to synthesise the conceptual content-generic version of the PDF. In the evaluation phase of the research cycle, the PDF was then formatively evaluated through screening and using relevance as the quality criterion. The formative evaluation was carried out with reference to the earlier gathered characteristics of effective professional development of teachers. This chapter ends with a reflection on the evaluation results regarding the further development of the PDF and the associated design principles.

1.4.4 Chapter 4: conceptual content-specific professional development framework

Chapter 4 focuses on the second research cycle in Figure 1.2. In this research cycle, the conceptual content-generic version of the PDF from the previous research cycle and chapter was revised in favour of the conceptual content-specific version of the PDF. This version of the PDF reflects how the final (completed) PDF will look. In order to do so, the concept of inquiry-based practical work (IBPW) was clarified in the analysis phase of the research cycle. Also, a conceptual framework for designing and implementing IBPW in secondary school science classrooms was compiled. In addition, the classroom practices and teacher challenges linked to

IBPW are discussed. Regarding the latter, a conceptual framework that considers the teaching challenges linked to IBPW was developed. The discussion clarifies SRQ2 and SRQ3a and b in Section 1.3.2, and informs the reader of the research techniques used to find the answers to these questions. That said, in the design/develop prototype phase, the outcomes of the above discussions were used towards turning the design proposal (content-generic version of the PDF) into the content-specific version of a PDF to support the design and implementation of inquiry-based practical work. In the process, three new design principles were generated, taking the total number of design principles to ten. In the evaluation phase of the research cycle, the content-specific PDF based on the ten design principles was then subjected to formative evaluation using screening as the method and consistency and relevance as the quality criteria. A reflection on the evaluation regarding the further development of the PDF was then carried out to mark the end of the second research cycle in Figure 1.2.

1.4.5 Chapter 5: context-specific professional development framework

This chapter takes off from where Chapter 4 ended regarding the refining of the design principles and the PDF based on these principles. As seen in Figure 1.2, the chapter specifically serves in transforming the specified/refined design principles into the final design principles on which basis a context-specific (completed) PDF was designed. In order to do so, the answers to the secondary research questions SRQ2, SRQ3a and SRQ3b are presented and a reflection on these answers is provided. It is based on this reflection that the professional development needs and contextual factors were incorporated into the design principles stemming from the preceding research cycle. The PDF based on these design principles is one that has now reached a level of development that it could be implemented in the context of South African Physical Science classrooms in resource-constrained schools. However, the PDF needs to be subjected to formative evaluation. This evaluation is linked to SRQ4. As seen in Figure 1.2, the methods of evaluation used were walkthrough (one-to-one evaluation) involving experts, while the quality criteria were the expected practicality and expected effectiveness. A revised completed PDF was designed on this basis.

1.4.6 Chapter 6: summary and conclusion

As the last chapter, this chapter presents a summary of the study and discusses its outcomes in addition to the conclusions. By way of summary, the chapter includes the background to the study, the practice- and research-based problems involved, as well as the research questions and purposes of the research. In this last regard, the chapter includes where in the study each secondary research question or purpose was addressed. The design research-based strategy used towards achieving the purposes of the study is also outlined. The research strategy incorporated the primary outcomes of this study: design principles and the associated PDF as the intervention. How the design principles were generated and applied in the development of the PDF is also summarised in this chapter. As part of the summary, the outcomes of the study are further presented; these include the process of developing a PDF, the ten final design principles, and the completed PDF. This is a PDF to support South African Physical Science teachers in resource-constrained schools, in the design and implementation of inquiry-based practical work.

Following the summary of the study outcomes is a reflection on the primary outcomes and also the contribution of the study to the field in question. The contribution is broken down into three components: methodological, theoretical and practical. The limitations of the study are also discussed in this chapter. This is found before the practice- and research-based implications of the study. The chapter ends with a closing statement.

1.5 SUMMARY AND CONCLUSION OF CHAPTER 1

This chapter positions the study in the context of the declining interest of young people in science and its dwindling uptake internationally and in South Africa. Following this, the related practice- and research-based problems involved have been outlined in Table 1.1 in relation to inquiry-based practical work in South African Physical Science classrooms in resource-constrained schools. On this basis, the study focused on the following Primary Research Question (PRQ) and Primary Research Purpose (PRP):

PRQ: How can one develop a professional development framework to support South African Physical Science teachers in resource-constrained schools in the design and implementation of inquiry-based practical work?

PRP: To generate design principles and use them over a number of research cycles to develop a professional development framework. This framework is to support South African Physical Science teachers in resource-constrained schools in the design and implementation of inquiry-based practical work

Based on the above PRQ and PRP, this study makes a methodological, theoretical and practical contribution to science teacher professional development research and practice, as discussed in Section 1.3.4. In relation to arriving at the contribution, and as seen in the above overview of this study, three research cycles (Chapters 3 to 5) have been used. However, the details and basis of the research process involved in these research cycles is not provided above. This is the subject of the next chapter (Chapter 2).

It is worth noting that Chapter 2 is not the commonly known type of literature review chapter provided in many theses. In this study, the literature review was used as a method for gathering data towards the generation of design principles and the development of the PDF. In this light, the literature reviews span Chapters 3 and 4. The next chapter elaborates on and justifies the process (which includes literature reviews) used in achieving the purpose of this study.

CHAPTER 2 : RESEARCH METHODOLOGY AND METHODS

2.1 CHAPTER OVERVIEW

The aim of this chapter is to provide guidance in terms of the entire research process involved in this study. The process comprised developing a PDF to support South African Physical Science teachers in resource-constrained schools in the design and implementation of inquiry-based practical work. This process was outlined earlier in Figure 1.1. However, details regarding the process are further elaborated on Figure 2.1, which also positions this chapter within the research process.

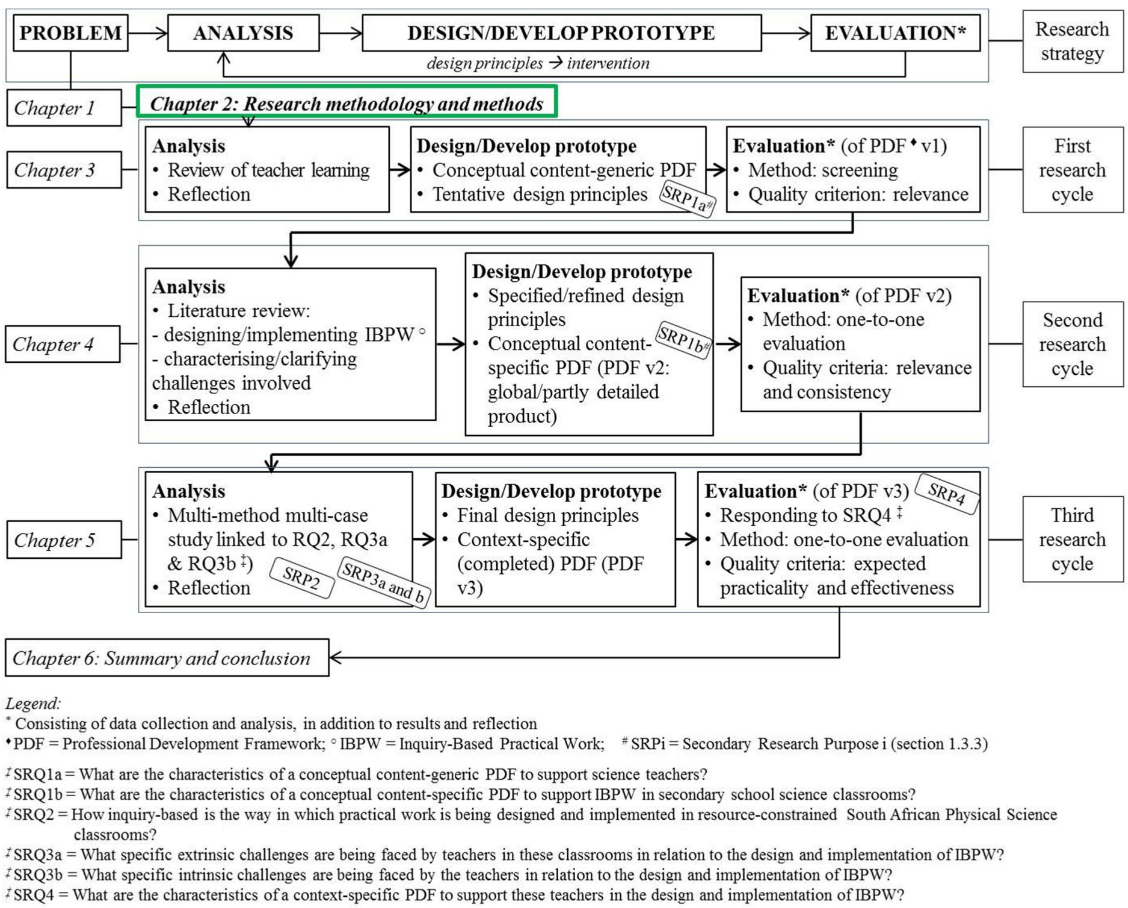


Figure 2.1 Position of Chapter 2 within the design research process

The research process contained in Figure 2.1 is explained in this chapter. In this regard, the chapter includes the research methodology and research methods (techniques) used. Research methods are the procedures used to gather and analyse data, while methodology is the link between the paradigm-related questions being investigated and the research methods (Crotty, 1998). Here, 'methodology' signifies "a general approach to studying research topics' unlike 'method' which refers to 'a specific research technique" (Silverman, 1993, p. 1). More specifically, research methods deal with data collection, analysis and interpretation (Creswell, 2014).

In order to frame the discussion in this chapter, the research process onion model from Saunders and Tosey (2013) has been used. According to this model, research can be carried out by making choices at six different levels. The levels are shown down the right side of Figure 2.2.

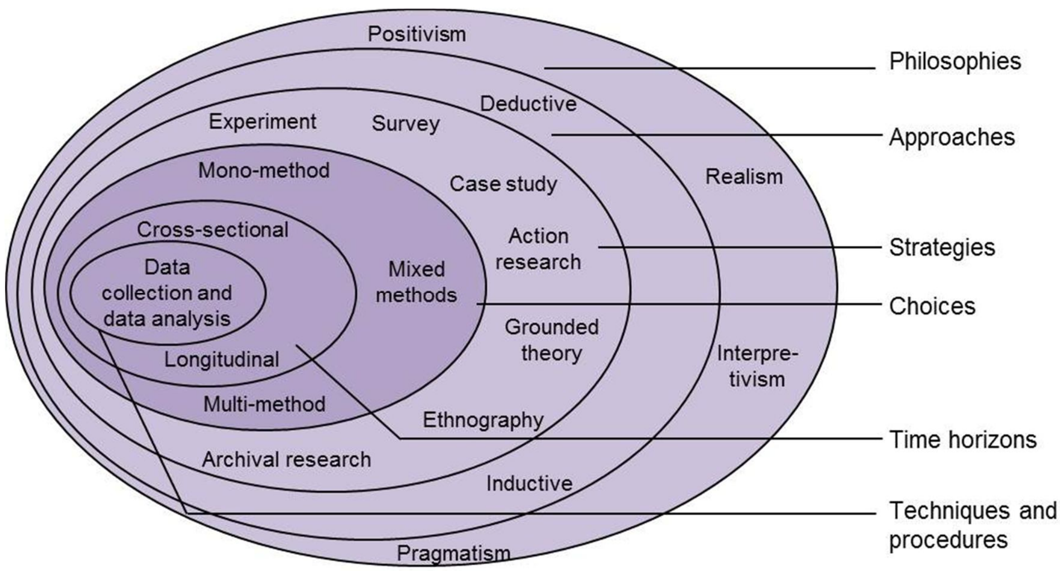


Figure 2.2 Research process onion model (Source: Saunders & Tosey, 2013)

The research methodology and research methods applicable to this study are discussed below. The discussion begins with the more abstract outer layer of the research process model, as shown in Figure 2.2. Specifically, the methodology is discussed in relation to the three outermost layers of the model. This gives way to a discussion of the research methods in relation to the three innermost layers of the model, where more practical decisions were made.

2.2 RESEARCH PARADIGM (PHILOSOPHY): PRAGMATISM

The research paradigm selected for this study was pragmatism. In this regard, it is useful to consider how the term paradigm is understood and also why pragmatism was considered in this study. As seen in the literature on educational research (e.g., Creswell, 2014; Mertens, 2010; O'Toole & Beckett, 2013) the terms paradigm, worldview, philosophical framework or philosophies are synonymous. Thus, using these terms interchangeably is technically correct, however, such usage of the terms may be confusing. As a result, the term paradigm is consistently used here. That said, justifying the choice of pragmatism as the paradigm in this study warrants a brief discussion of the concept of a paradigm, in addition to the paradigms commonly used in social science and educational research.

2.2.1 Notion of a paradigm

A paradigm is a complex and broad term (Punch, 1998) referring to collections of disciplinary norms and assumptions that are common to scientists (researchers) working in a given field (Kuhn, 1970). However, a more informative definition of a paradigm can be provided on the basis of its constituents.

There are four realms of a paradigm. These realms consist of the realm of being (ontology), the realm of knowing (epistemology), the realm of values (axiology) and the realm of methods (Humphrey, 2013; Mertens, 2007). On this basis, the structure of a paradigm is illustrated in Figure 2.3.

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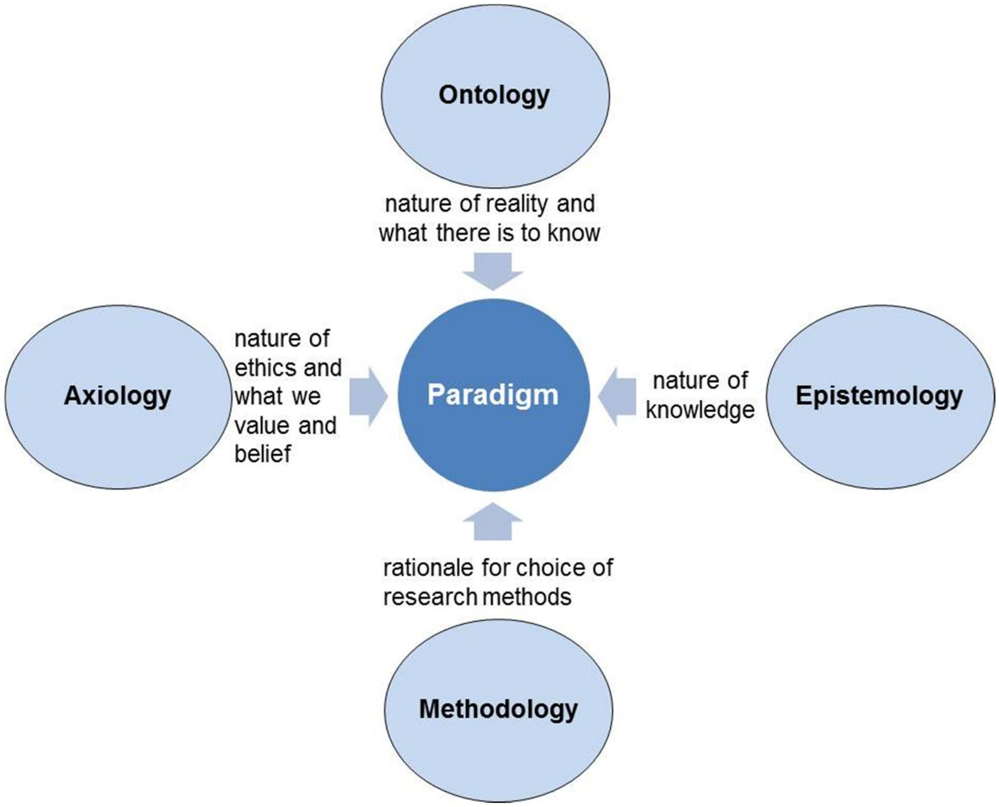


Figure 2.3 The four realms of a research paradigm (Source: e.g., Creswell, 2013; Mertens, 2007)

On the one hand, ontology deals with what there is to know about the world and the nature of reality (Ritchie, Lewis, Nicholls, & Ormston, 2013). On the other hand, epistemology focuses on the matters that form the basis of our knowledge and how we can learn about reality (Cohen, Manion, & Morrison, 2011; Ritchie, Lewis, et al., 2013). More specifically, epistemology deals with how knowledge is derived and accepted as valid (Creswell, 2013; O'Donoghue, 2007). Alternatively, methodology is the general approach to studying a research topic (Silverman, 1993). That being said, axiology is concerned with the reasons for carrying out a particular study and the expected gains from the study, in addition to the values and beliefs that the researcher brings to the study (Cohen et al., 2011; Creswell, 2013; Humphrey, 2013).

Against the above background, a paradigm may be defined more specifically as shared assumptions and beliefs about the nature of the reality under study, how to pursue knowledge, as well as what problems may be investigated and how to investigate these problems (Burian, Rogerson, & Maffei III, 2010; Cohen et al., 2011; Lodico, Spaulding, & Voegtle, 2006; Usher, 1996). This understanding of a paradigm incorporates different realms of the notion of a paradigm and is useful in justifying the choice of pragmatism as the paradigm in this study.

2.2.2 Consideration of paradigms

Paradigms vary according to their epistemological and ontological assumptions (Carspecken, 1996; O'Donoghue, 2007). Four paradigms that are widely discussed in the literature are pragmatism, transformative, constructivism (often merged with interpretivism) and post-positivism (Creswell, 2014). This is reflected to a greater extent in the research process model of Saunders and Tosey (2013) in Figure 2.1. The paradigms incorporated in the model are discussed below in terms of justifying the use of pragmatism in this study.

2.2.2.1 Positivism and realism

In contemporary Social Science research, some researchers adopt a positivist research paradigm (O'Toole & Beckett, 2013). Regarding its ontology, positivism assumes that things are as they seem to be and exist in a manner that is independent of the perceiver (Humphrey, 2013). This paradigm involves the formulation of hypotheses, the collection of clinical observations, as well as the presentation of findings using statistics (O'Donoghue, 2007). Positivism uses methods from the Natural Sciences in social studies on the basis that human behaviour is governed by law-like regularities, coupled with the fact that it is possible to carry out objective, independent, and value-free social research (Ritchie, Lewis, et al., 2013). However, human beings have a complex nature and social phenomena have an intangible and elusive quality, unlike the regularity and order in the physical world (Cohen et al., 2011). This limits the applicability of positivism in social studies such as this one. The same is true of realism, which is often associated with positivism (Flick, 2014).

Realism states that reality exists independently of the mind, and that what the senses of a researcher show her or him is the truth, although the researcher is influenced by world views and his/her own experiences (Saunders & Tosey, 2012). Based on this paradigm, there is a reality that exists in a manner that is separate in relation to the understanding of people about this reality (Ritchie, Lewis, et al., 2013). This paradigm, like positivism, holds that natural and Social Science can and should utilise the same principles to gather and analyse data (Flick, 2014). This is, however, not an attractive proposition considering the research questions addressed in this study.

2.2.2.2 Interpretivism

Interpretivists hold that there is an ontological gap between human beings and their social worlds on the one hand, and on the other hand, other types of beings, things, and processes in the physical world (Cohen et al., 2011; Humphrey, 2013). In interpretivism, research is value-bound as what is being researched is a function of a particular set of individuals and circumstances at a particular time (Saunders & Tosey, 2012). In other words, knowledge is specific to the situation being investigated (O'Donoghue, 2007). Thus, it is useful to consider the professional development needs of teachers within the context in which they operate (National Science Teachers Association, 2007). Interpretivism is useful in this regard.

Interpretivism focuses on interpretation and observation as ways of gaining an understanding of the social world (Ritchie, Lewis, et al., 2013). There is a practical, knowledge-based interest in understanding the social world from a variety of perspectives rather than the proclamation of universal ‘truths’ (Soydan, 2010). In seeking this understanding, interpretivists do not normally begin with a theory (as is the case with post-positivists), rather, they "generate or inductively develop a theory or pattern of meanings" (Creswell, 2003, p. 9).

In interpretivism, “Phenomena must be understood as complex ‘wholes’ that are inextricably bound up with the historical, socioeconomic, and cultural contexts in which they are embedded” (Lodico et al., 2006, p. 8). In fact, the interpretivist paradigm relates to the study of social phenomena in the natural environment in which the phenomena occur (Saunders & Tosey, 2012). The paradigm thus allows for an understanding of human experience (Cohen & Manion, 1994) in natural settings (Saunders & Tosey, 2013). In this study, the experiences focused on were those of teachers, which are linked to the design and implementation of inquiry-based practical work. It is necessary to understand these experiences in order to develop a context-specific PDF in response to SRQ4. Thus, this paradigm (with hermeneutics as the analysis tool) was used in relation to the three middle secondary research questions (SRQ2, SRQ3a and SRQ3b). However, the resulting PDF cannot be adequately evaluated using only the methods inherent in interpretivism. In this regard, the next paradigm was found to be more useful as the primary research paradigm.

2.2.2.3 Pragmatism

Pragmatism serves in bridging the divide between positivism and interpretivism (Krauss, 2005). This is a practice-driven, problem-centred and action-orientated research paradigm, unlike a knowledge-orientated research paradigm (Cohen et al., 2011; Creswell, 2014; Denscombe, 2008; Lodico et al., 2006) such as interpretivism. Pragmatism is thus useful overall in this study, which focused on a practice-orientated problem (Table 1.1). It was also seen as an appropriate paradigm due to the fact that pragmatism does not commit itself to any one type of philosophy or reality (Mackenzie & Knipe, 2006). It therefore does not matter whether there is a single reality or multiple realities provided that the answers sought can be found (Lodico et al., 2006).

Pragmatism focuses on interpretivist and positivist epistemologies on the basis of the criteria of applicability and fitness in relation to purpose (Johnson & Onwuegbuzie, 2004). Thus, tools from both the interpretivist and positivist paradigms such as interviews, observation and experiments may be used (Mackenzie & Knipe, 2006). In fact, pragmatists consider that a single viewpoint cannot give the entire picture (Saunders & Tosey, 2012). However, as these authors further point out, this does not imply that, based on pragmatism, one must use a range of techniques and procedures in the data collection and analysis. Instead, the research design needs to enable reliable, credible and relevant data to be gathered in support of subsequent action. In other words, the research carried out must answer the research questions, providing useful answers (Denscombe, 2008).

It is on the above basis that pragmatism was chosen as the research paradigm in this study. In further considering the methodology of this study, the next decision made in the research process was that regarding the research approach. This is in accordance with Figure 2.2.

2.3 RESEARCH APPROACH

This study combined a number of approaches consisting of applied, exploratory and deductive-inductive research. Before providing details in this regard, it is prudent to firstly consider alternative ways that the term ‘approach’ is used in the literature.

Creswell (2014) considers research approaches to consist of quantitative, qualitative and mixed methods approaches. However, this is not strictly the interpretation of the term ‘approach ’as used here, which is explained further below. In another interpretation of the term ‘approach’, certain authors (e.g., Mortensen, 2011; Plomp, 2007) consider research approaches to include surveys, action research and design research, for example. These concepts are rather considered in the category of research strategy. This is in line with the research process model in Figure 2.1. Thus, as used here, the term ‘approach’ represents the concept of a higher order than the term ‘strategy’. It is in this sense that this study falls under applied, exploratory and deductive-inductive research, as explained below.

2.3.1 Applied research

In one sense, the term ‘approach’ is used regarding the extent to which findings can be applied in educational settings (Lodico et al., 2006). In this regard, research can be basic or applied research (O'Toole & Beckett, 2013). The primary focus of basic research is to develop, test or refine a theory. A theory may be considered “as a set of interrelated constructs (concepts), definitions, and propositions that represent a systematic view of phenomena by specifying relations among variables, with the purpose of explaining and predicting the phenomena” (Kerlinger, 1970, p. 9). Theory-orientated (basic) research is carried out for the sole purpose of uncovering new knowledge (O'Toole & Beckett, 2013). Thus, the findings of theory-orientated studies have a low level of application in practice, although critical in applied research (Lodico et al., 2006). This study falls under the applied research umbrella. Applied research was conducted with respect to a practical purpose (O'Toole & Beckett, 2013). The purpose here was to develop a PDF to support the design and implementation of inquiry-based practical work in the context of South African Physical Science classrooms in resource-constrained schools. In addition to being applied research, this study is also exploratory.

2.3.2 Exploratory research

Exploratory research and the reasons for its use here can be described in relation to the notions of qualitative and quantitative research. Research is regarded as qualitative or quantitative depending on the methods used in designing the study and collecting the data (Lodico et al., 2006). Qualitative research uses open-ended research questions, while the opposite is true of quantitative research, which involves closed-ended research questions (Creswell, 2014). However, polarising research as being either quantitative or qualitative is neither meaningful nor productive in addition to ignoring the compatibility between the two types of research (Ercikan & Roth, 2006). In fact, combining the two types of research is considered useful in providing a more complete understanding of the phenomenon under study (Creswell, 2014). Alternatively, not all qualitative research is interpretivist, and some quantitative research is non-positivist (Onwuegbuzie & Leech, 2005). Thus, instead of the terms 'qualitative' and 'quantitative', they propose the terms "exploratory and confirmatory research" (p. 382). It is in this light that this study is considered as exploratory. Also (and as a result), this study falls under the category of inductive-deductive research.

2.3.3 Inductive-deductive research

People use reasoning, experience and research in an attempt to make sense of the world around them (Mouly, 1978). Here, research and reasoning are combined. Cohen et al. (2011) discuss three types of reasoning: inductive, deductive and inductive-deductive reasoning. In simple terms, deductive reasoning, which is attributed to Aristotle, is based on a self-evident or *a priori* proposition, a minor premise providing a specific instance and a conclusion. Generally, deductive reasoning is a top-down way of gaining knowledge as it begins with a theory and leads to observations about the world that are used to weaken or strengthen the posited theory (Ritchie, Lewis, et al., 2013). Historically, thanks to deductive reasoning, authority superseded empirical evidence until the 1600s when Francis

Bacon began emphasising the place of observation in science (knowing). Noting that the major propositions of deductive reasoning are often predetermined notions that inevitably bias conclusions, Bacon introduced inductive reasoning. Based on this type of reasoning, the consideration of a number of individual cases allows a hypothesis to be formulated and eventually a generalisation can be reached. In general, evidence is first gathered from which knowledge is derived (Ritchie, Lewis, et al., 2013). However, this type of reasoning can be coupled with deductive reasoning in the sense that hypotheses about phenomena can be generated on the basis of deductive reasoning. This produces inductive-deductive reasoning, which involves a back and forth process of inductive (Baconian) and deductive (Aristotelian) reasoning (Mouly, 1978).

Deductive-inductive reasoning was used in this study, for example, in achieving the secondary research purposes SRP2, SRP3a and SRP3b. The *a priori* categories derived from the literature review in Chapter 4 are used in the data collection and analysis described in Chapter 5. This was designed to ensure that a broad range of practices and challenges linked to the design and implementation of IBPW were taken into account. However, the data analysis carried out was inductive. The coupling of deductive and inductive reasoning in this way is in line with several authors (e.g., Blaikie, 2007; Ritchie, Lewis, et al., 2013), who argue that these two approaches are involved at different levels of (qualitative) research.

Regarding the methodology of this pragmatic, applied, exploratory and deductive-inductive research, the research strategy must also be considered.

2.4 RESEARCH STRATEGY: DESIGN RESEARCH INCORPORATING A CASE STUDY APPROACH

As seen in Figure 1.2, the overarching research strategy for this study was design research. However, the case study strategy was used in the third research cycle in Chapter 5. The discussion below on the research strategies utilised in the research process model in Figure 2.2 justifies the use of a case study approach in this study, and also the need for an overall research strategy other than those shown in the model.

2.4.1 Consideration of various research strategies

The distinction between the research strategies in Figure 2.2 in addition to their possible research functions (such as to describe, to explain and to design/develop) could be useful in considering the merits and disadvantages of these research strategies in relation to this study. However, as seen in Plomp (2007), for example, more than one research strategy may serve the same research function. Surveys, case studies and experiments, among others, may all be used to explain the phenomenon being studied. Conversely, although each research strategy has its distinctive characteristics, there are overlaps in this regard (Yin, 2003). Thus, both the distinctiveness and the possible research functions of various research strategies are considered below in the selection of design research and a case study as strategies that were used at the different levels of this study.

Archival research. This research strategy focuses on such questions as ‘who’, ‘what’, ‘where’, ‘how many’ and ‘how much’ (Yin, 2003). In this way, archival research offers a descriptive research function. This research strategy was thus not useful here as the focus was on the development of a PDF (an artefact) to be used in dealing with a contemporary, practice-based problem.

Experiments. This research strategy deliberately divorces phenomena and their context (Yin, 2003). This characteristic limits the usefulness of experiments in the development of a PDF because, for example, teachers are more likely to enhance their competences and thus change their instructional practices when professional development is directly related to their everyday pedagogical experiences (Holland, 2005). However, this research strategy is useful in carrying out a summative evaluation of the context-specific (completed) version of the PDF.

Survey. Although the survey research strategy does not control for contextual factors, it focuses on questions such as ‘who’, ‘what’, ‘where’, ‘how many’ and ‘how much’ (Yin, 2003). However, these are not the type of questions posed in this study, as seen in Section 1.3.2. Instead, the research questions required the use of a research strategy that responded to the development or designing research function in relation to a practical problem. The following strategies are linked to this function to different extents.

Grounded Theory. This research strategy enables the researcher to develop a theory based on qualitative data (Charmaz, 2006). The focus here is rather on the development of an artefact that can be used to resolve a practice-based problem. Research in the field of education is often disconnected from the issues and problems of everyday practice (Anderson & Shattuck, 2012; Design-Based Research Collective, 2003). As a result of this disconnect, there is a credibility gap and thus there is a need for research approaches that directly match the problems of the practice being studied and that lead to the creation of 'usable knowledge' (Design-Based Research Collective, 2003). This criticism may be more applicable to the research strategies considered above than the strategies discussed below.

Ethnography. This research strategy enables us to gain an understanding of the culture or the social world (such as the shared behaviours, beliefs and values) of particular groups, normally through immersion in their community (Ritchie, Lewis, et al., 2013). Such an immersion allows the experiences and practices of teachers in relation to IBPW to be described and understood. In this regard, however, the research questions posed here did not warrant emphasis on a cultural perspective.

Case study. This research strategy focuses on the observation of a spatially restricted phenomenon at a given point in time or over a prolonged duration (Gerring, 2007). While practical work is less adequately designed and implemented in South African Physical Science classrooms especially in resource-constrained schools, these classrooms can be found anywhere in the country and possibly elsewhere. Nevertheless, this strategy was useful in this study considering the secondary research questions SRQ2, SRQ3a and SRQ3a. This is because a case study engages with and reports on the complex settings of educational and social activities (practice) in order to reveal the meanings that the various actors construct in such activities (Chadderton & Torrance, 2011). Here, interest lies in the classroom practices and challenges associated with the design and implementation of inquiry-based practical work in South African Physical Science classrooms in resource-constrained schools. The usefulness of the case study strategy in this regard also lies in its ability to answer the 'how' and 'why' questions relating to a contemporary phenomenon over which the researcher has little or no control (Yin, 2003). As also noted by Plomp (2007), this research strategy has a descriptive and explanatory function. Although these functions are not distinctive, the case study strategy allows for their use in studying practical phenomena without controlling the phenomena. This research strategy was thus useful in gathering in-depth data, especially in relation to SRQ2, SRQ3a and SRQ3b. Specifically, a multi-method, multi-case study research strategy was used. The case study involved six Grade 10 to 12 Physical Science classrooms in two public secondary schools (School O and School P), which are discussed in further detail in Chapter 5.

The interest here is rather on a research strategy that is useful in providing broad guidance regarding the research process as a whole. Such a strategy also needs to have a design or development research function in relation to a practical problem, as Table 1.1 requires. Therefore, action research, the remaining research strategy in Figure 2.2, is discussed below.

Action research. This is a research strategy that can be used in any setting and provides a way to solve a problem (such as that contained in Table 1.1), improve a process or empower participants (Burian et al., 2010). There are different forms of action research, these include the supportive, interactive and emancipatory forms (Mamlok-Naaman & Eilks, 2012). Also included is canonical action research, which stands out in relation to being rigorous, cyclical and collaborative (Davison, Martinsons, & Kock, 2004). However, this form of action research tends to emphasise action research characteristics that are linked to research outcomes rather than to the process (Järvinen, 2007). Instead, a strategy with the opposite emphasis was needed here. In this regard, design research, which is a close cousin of action research (O'Toole & Beckett, 2013), is useful.

As also seen below, the outcomes of the form of design research considered here (development studies) emphasised the research process and not its outcomes. In addition, the outcomes of development studies are aligned to the primary outcomes of this study: an intervention (the PDF) and its design principles. The next section thus focuses on design research in general, and development studies in particular as the overall research strategy in this study. As we see, a case study and an experiment may be incorporated into this strategy where appropriate.

2.4.2 Design research

2.4.2.1 Origins, use and forms of design research

Design research, which is in line with the pragmatic tradition of American educational philosophy, can be traced back to James and Dewey (Anderson, 2005). This research strategy is linked to the experimental processes employed in engineering sciences, although not to traditional experimental research (O'Toole & Beckett, 2013). Probably as a result of its recently emerging status, textbooks on research methodology seldom discuss design research (Plomp, 2013). However, in recent years, design research has become an established research paradigm (strategy) in the field of information systems (Gregor & Hevner, 2013). In education, design research is being increasingly implemented in literacy and language research (Reinking & Bradley, 2008). However, educational design research is not inherently tied to any specific discipline, although much of the work published is linked to mathematics or science education (Kelly, Lesh, & Baek, 2008). In reality, there are many examples of the use of this research strategy in educational research (e.g., Mafumiko, Voogt, & Van den Akker, 2013; Meijer, Bulte, & Pilot, 2013; Prins & Pilot, 2013; Stolk et al., 2012; Vallett, Annetta, Lamb, & Bowling, 2014; West & Wallin, 2013).

Design research comprises a range of approaches (in this case strategies) with the goal of producing new theories, practices and artefacts that potentially affect and also account for teaching and learning in a naturalistic setting (Barab & Squire, 2004). The design research strategy has two possible purposes, which consist of refining theory or practice (O'Toole & Beckett, 2013; Plomp, 2013). The theory-orientated purpose of design research is that of designing and developing educational interventions (e.g. programme, product and system) with the purpose of developing or validating theories (Plomp, 2013). Associated with this purpose is a type of design research known as validation studies (research through interventions) (McKenney & Reeves, 2012). This is defined as “the study of educational interventions (such as learning processes, learning environments and the like) with the purpose of developing or validating theories about such processes and how these can be designed” (Plomp, 2013, p. 16).

The present study rather falls under development studies (research on interventions) (McKenney & Reeves, 2012). The purpose of development studies is to design and develop an intervention that can be used to solve a complex educational problem, while advancing knowledge about the characteristics of the intervention and the processes of designing and developing them (Plomp, 2013). In this study, the intervention is a product (artefact) and is the PDF to support teachers in the design and implementation of IBPW in South African Physical Science classrooms in resource-constrained schools. As in this case, an artefact refers to an artificial object created to help solve a given problem, in contrast to a naturally occurring object (Hevner & Chatterjee, 2010).

2.4.2.2 Characteristics of design research

Design research has a number of characteristics. Included among these is the fact that design research is (Reinking & Bradley, 2008; Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006; Wang & Hannafin, 2005):

- Pragmatic, as it is concerned with developing usable solutions to problems in practice while generating usable knowledge.
- Theory-orientated, given that it is based on theoretical propositions and a conceptual framework and also because systematic evaluation and consecutive versions of the outcome contribute to theory building.
- Grounded, as it uses theory, empirical findings and craft wisdom for guidance.
- Interventionist, as it is carried out to make a change in an actual educational context.
- Iterative, considering that multiple cycles of analysis, design, development, evaluation and revision are used.
- Collaborative, given that the expertise of multidisciplinary partnerships that include researchers and practitioners are used.
- Adaptive because the research design and intervention design are often adjusted in line with emerging insights.
- Process-orientated in the sense that the focus lies in the understanding and improvement of interventions.

- Utility-orientated, given that the merit of a design is determined through its practicality for actual users.
- Context-bound as context-free generalisations are not the focus, although analytical (unlike statistical) generalisations may be made

2.4.2.3 Overcoming challenges linked to design research

Due to its nature, design research poses a number of challenges regarding its implementation. As seen above, this research strategy addresses problems situated in practice with the involvement of practitioners. In research of this nature, there are inherent pitfalls and challenges (e.g., McKenney, Nieveen, & Van den Akker, 2006; Plomp, 2013). The challenges are linked to adaptability and the fact that the researcher is the designer and often also the evaluator and implementer. Furthermore, real-world settings bring real-world complications.

Researcher as designer and often also evaluator and implementer

On the one hand, there is concern about the suitability of developers as evaluators (Jeanpierre, Oberhauser, & Freeman, 2005), for example, design researchers can easily become too attached to the intervention being developed to the point of having a less objective view regarding the problems and comments from respondents. It was thus important in this study to bear this point in mind. On the other hand, respondents may become biased during the evaluation if, for instance, they are aware of the amount of effort the design research team has put into designing the intervention. In this case, they may hesitate to be fully critical of the intervention. Thus, it is important in educational design research to perform formative evaluations early in the design process and to use triangulation. Other compensatory measures are as follows:

- Open the research to professional scrutiny and critique from people outside the project;
- Shift from a dominance of the 'creative designer' perspective in the early phases towards the 'critical researcher' perspective in the later phases; and
- Use a research design of good quality by involving:

- A strong chain of reasoning (Krathwohl, 1998).

- Triangulation of data collection methods and sources, in addition to triangulation in the data analysis, and investigator triangulation (Denscombe, 2007).

- Empirical testing for the usability and effectiveness of the intervention.

- Systematic documentation, analysis and reflection in the design, development, evaluation and implementation process and their outcomes.

- The use of a variety of methods and tactics (e.g. use practitioners and other researchers as 'critical friends'; use multiple observers/raters and determine inter-observer/rater reliability).

- Pay attention to the validity and reliability of the data and instruments.

The last two ways of enhancing the quality of design research studies are especially important in relation to the use of quantitative instruments, which were not needed in this study. However, the preceding ways of enhancing design research studies were involved in this study, as seen in Figure 2.1, and as explained below in Section 2.4.3.

Real-world settings bring real-world complications

The fact that design research is conducted in real-world settings can create difficulties. One difficulty is that the researcher can be a 'cultural stranger' (Thijs, 1999) in the research setting. Conversely, the participants (such as principals and teachers) may hesitate to completely open up to the researcher as an outsider. In the face of this challenge, McKenney et al. (2006) point to the importance of mutually beneficial activities and collaboration in order to gain the trust of participants and a thorough understanding of the context (i.e. insider perspective). This measure is used, as described in Chapter 5. At the same time, McKenney et al. note that being an outsider can be advantageous as this may allow the researcher to have a degree of objectivity, freedom and honesty that is impermissible for those within a given group. This study may have benefited from this effect.

Adaptability of the research design

Each design research cycle takes the findings of the previous cycle into account. The research design has to change (or develop) from one cycle to the other. An ever-changing research design can, however, be weak. In this regard, (Van den Akker et al., 2006) refer to the concept of evolutionary planning, which is a planning framework that responds to field data and experiences. The need for adaptability also applies to the role of the researcher. In this regard, Van den Akker (2005) notes that the synergy between research and practice can be optimised when researchers demonstrate adaptability. This may be done by:

- Being ready to take on the role of designer, facilitator and advisor without losing sight of the primary role of being a researcher;

- Being tolerant regarding the often inevitably blurred role distinctions while remaining open to adjustments in the research design when necessary; and

- Allowing the research projects to be influenced partly by the wishes and needs of all partners.

Although this last way of demonstrating adaptability is not applicable to this study, awareness of the preceding two is considered useful. Alternatively, different ways of enhancing design research studies are comprised in this study. An example of this is systematic documentation in addition to analysis and reflection in the design, development, evaluation and implementation process and its outcomes.

2.4.3 Conceptual framework

The conceptual framework that was used to address the research problem in this study is reflected in Figure 2.1. This was the primary conceptual framework for this study and is reported on in this section with reference to developmental design research outcomes and certain implementation models. However, within this study, there were other conceptual frameworks used for more specific purposes. An example is a conceptual framework for characterising challenges linked to the design and implementation of inquiry-based practical work (Chapter 4). Whether looking at the primary or other frameworks used in this study, it is useful to first consider how the term ‘conceptual framework’ is understood here.

A conceptual framework is synonymous with having a point of view, an angle on reality (Charon, 2001) or a perspective (O'Donoghue, 2007). More explicitly, a conceptual framework helps to make sense of the world (Woods, 1983) or provide an explanation for events (Vithal & Jansen, 2004) to which key principles or concepts are related (Maree, 2007). Maxwell (2012) describes a conceptual framework by using the following question, “What theories, beliefs, and prior research findings will guide or inform your research and what literature, preliminary studies, and personal experiences will you draw on for understanding the people or issues you are studying?” (p. 4). In other words, a conceptual framework could be considered as a coordinated set of ideas and actions that are useful in dealing with a problematic situation (Becker, Geer, Hughes, & Straus, 1961). Against the above background, the conceptual framework to develop the PDF is considered below in relation to the design research process and its outcomes.

2.4.3.1 Linking the study and design research outcomes

Design research involves researchers and practitioners designing and developing workable and effective interventions (such as objects and processes) (Plomp, 2007). This is one outcome of design research. In this study, the intervention was the PDF. This object (artefact) is described in general terms as the blueprint (predictor) of a professional development programme (Stolk et al., 2012), and is defined more specifically for the purposes of this study later in Section 3.2.1.3. The PDF as an intervention was developed through a careful study of successive versions of the intervention in the target context. This aspect of design research is reflected in the list of secondary questions in this study (Section 1.3.2). While developing an intervention, design principles are generated through reflection. Design principles are heuristic statements that suggest how problems (such as the ones in design research) may be addressed (Plomp, 2013). These principles constitute the second, and a theoretical, outcome of design research. In this study, these principles responded to the Primary Research Question (PRQ): How can one develop a Professional Development Framework to support teachers in resource-constrained South African Physical Science classrooms in the design and implementation of inquiry-based practical work?

The two primary types of design principles utilised were procedural design principles and substantive design principles (Van den Akker, 1999). On the one hand, the latter refers to how the intervention should look (its characteristics). On the other hand, procedural design principles refer to how the intervention should be developed (characteristics of the design approach). The following format may be used in formulating design principles (Van den Akker, p.9):

> “If you want to design <intervention X> for the <purpose/function Y> in <context Z>, then you are best advised to give <that intervention> the <characteristics A, B, and C> [substantive emphasis], and to do that via <procedures K, L, and M> [procedural emphasis], because of <arguments P, Q, and R>.”

Against the above background, the type of design principles applicable to this study, and thus their format, can be determined with reference to the nature of the intervention involved. As earlier noted, the invention here is a PDF. This is essentially the blueprint of the associated professional development programme and thus a predictor of the process that is expected to occur (Stolk et al., 2012). Thus, the PDF describes how the professional development programme should look. As result, this study focuses on substantive design principles. For this purpose, the above format of a design principle may be reduced to the following:

> If you want to design <intervention X> for the <purpose/function Y> in <context Z>, then you are best advised to give <that intervention> the <characteristics A, B, and C>, because of <arguments P, Q, and R>

Design principles provide insight into the following (Linn, Davis, & Bell, 2004; Van den Akker, 1999):

- Function/purpose of the intervention;
- Key characteristics of the intervention (substantive emphasis);
- Guidelines for designing the intervention (procedural emphasis);
- Theoretical and empirical proof (arguments) of the characteristics and procedural guidelines;
- Implementation conditions for the intervention

Design principles are useful to a variety of target groups:

- Through these principles, researchers show the contribution of design research to the existing knowledge base (as mentioned above in Section 1.3.4.1).
- For educational designers, the principles contain rich data for designing similar interventions in similar settings (as noted here in Section 1.3.4.2)
- The principles provide future users the information needed in selecting and applying interventions, and provide insight into the required implementation conditions.
- Design principles also assist policy makers in making research-based decisions in relation to addressing complex educational problems.

The concept of design principles sets action research aside in relation to design research, and further justifies the use of design research in this study. In this sense, although action research is also concerned with real-world problems in the aim of improving practice, and is collaborative and cyclical in nature, this research strategy does not focus on the generation of design principles (Denscombe, 2007).

The above discussion identifies the outcomes of this study in design research terms: an intervention (the PDF) and the associated design principles. These two outcomes respond to the PRQ reflected in the Primary Research Purpose (PRP) of this study:

PRP: To generate design principles and use them over a number of research cycles to develop a professional development framework. This framework is to support teachers in resource-constrained South African Physical Science classrooms in the design and implementation of inquiry-based practical work

After thus linking the outcomes of this study and the research strategy, attention can now be focused on detailing the process used in reaching these outcomes. This calls for a discussion on useful design research implementation models.

2.4.3.2 Implementation of design research in study

Design research begins with educational problems for which there are no or only a few validated guidelines for structuring and supporting design and development activities (Plomp, 2007). However, different design research implementation models exist. Three of the models have been considered here for the purpose of designing the research process for this study. This process was earlier represented in Figure 2.1. In this regard, the three models considered are shown in Figure 2.4 and discussed thereafter.

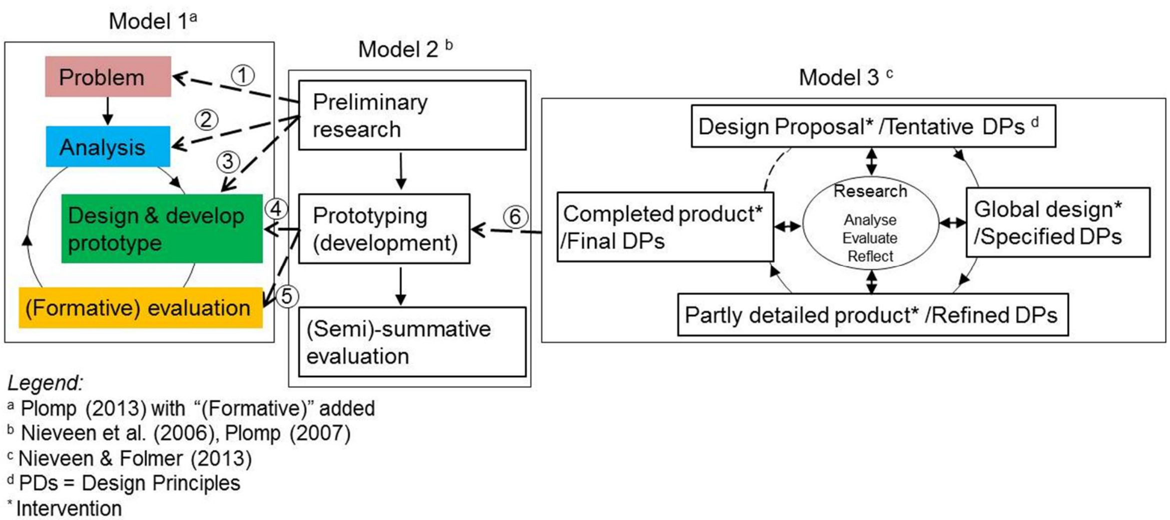


Figure 2.4 Design research implementation models used as the basis of the conceptual framework of this study

The models in Figure 2.4 are positioned vertically and horizontally in relation to their application in this study. Model 3 focuses on design research outcomes and emphasises the dependence of the evolution of these outcomes on a research process. It is this research process that Models 1 and 2 depict. However, these models consider the design research process based on a different sequence of activities. Thus, in this study, as reflected in Figure 2.4, Model 2 is taken apart and used to inform the implementation of Model 1. Similarly, Model 3 is used in enabling the prototyping phase of Model 2 to better inform the 'design & develop' prototype phase of Model 1. Model 1 was the primary design research implementation model in this study.

Design research involves a cyclical process in which analysis, design, evaluation and revision are carried out until a satisfactory balance between reality and ideals is achieved (Plomp, 2013; Van den Akker, 1999). Although this is reflected in Model 1, as contained in Figure 2.4, this is better seen in the complete version of the model in Figure 2.5.

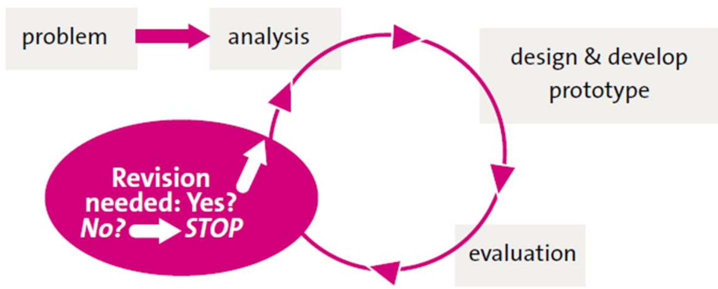


Figure 2.5 Design research process model (Source: Plomp, 2013; Van den Akker, 1999)

As seen in Figure 2.5, Model 1 includes an exit condition in the research process. The model was coupled with Model 2 and 3, as illustrated in Figure 2.4, to provide a basis for reaching the outcomes of this study. Regarding Model 2, Nieveen and Folmer (2013) note that design studies usually begin with a preliminary research phase, followed by a prototyping (development) phase and lastly, a summative evaluation phase. The phases of design research are briefly described in Table 2.1.

Table 2.1 Phases of design research process (Source: Nieveen, McKenney, & Van den Akker, 2006; Plomp, 2007)

Phase	Description
Preliminary research*	Context and needs analysis, review of the literature and projects addressing similar research questions, development of a conceptual or theoretical framework for the study, guidelines (in this case design principles) and the first blueprint of the intervention.
Prototyping*	Development of a sequence of prototypes tried out and revised based on formative evaluations. Focus is on improving and refining the intervention. Early prototypes may be paper-based and involve formative

	evaluation via expert judgment.
Assessment phase*	(Semi-) summative evaluation is needed to determine whether the solution or intervention meets pre-determined specifications, if the target audience can use the intervention and are willing to do so, and whether the intervention is effective. Recommendations for improving the intervention are often included. Thus, a phase can be described as semi-summative.

* Systematic reflection and documentation takes place throughout the phases of design research

Although outlined in Table 2.1, a further discussion on the phases of Model 2 is required for a better explanation of the research process in relation to Model 3.

Preliminary research phase

In describing this phase of design research, Nieveen and Folmer (2013) note that this phase is important in gaining insight into the educational problem at hand; this is shown in Figure 2.4 using arrow 1. In this regard, the PRQ is: what problem in terms of practice does the intervention need to address? In this case, the problem is contained in Section 1.3.1 (Table 1.1). However, the preliminary research phase also involves gaining insight into and applying potential approaches to addressing the educational problem, the conditions for innovation (Chapter 4), as well as the context and the needs of the participants (Chapter 5). In these chapters, the relevant aspects of the preliminary research phase of Model 2 are considered in the implementation of the analysis phase of Model 1, as represented in Figure 2.4 by arrow 2. However, the preliminary research phase aims not only to gain insight into the educational problem at hand and the possibilities for innovation and improvement, but it also specifies the desired tentative features of the intervention and how these features could be developed, which is depicted by arrow 3 in Figure 2.4.

Content analysis. As seen in Table 2.1, part of the research activities involved in the preliminary research phase is the exploration of the existing scientific knowledge base. A knowledge base analysis examines the perceptions of stakeholders of the existing situation and the features of a more desirable situation. This aspect is partly covered in Chapter 5. However, (as in Chapters 3 and 4), a knowledge-based analysis can also be done by means of a literature review, in addition to the analysis and evaluation of products and projects that address similar problems. In this way, the knowledge base analysis allows relevant and valid design decisions to be made, and depends on a state-of-the-art knowledge base. The following questions may therefore be posed:

- What recent insights from educational research and subject matter discipline could be used in the design?
- What available (related or promising) interventions could serve as a source of inspiration and what lessons could be learned from the implementation and the effect of these products?

The above questions are used in Chapter 3 towards designing the conceptual content-generic version of the PDF to support inquiry-based science education.

Context analysis. This analysis explores the problem environment and maps out the scope of the intervention. The questions to be asked during a context analysis include:

- What does the users' context look like?
- What is the innovation scope, considering the needs and abilities of those involved (e.g. their willingness to change), and conditions in each school (e.g. room for collaboration)?
- What means, including time, finances, and staff, are available for development?

The context analysis for this study is found in Chapter 4 (from an international perspective) and Chapter 5 (from a South African perspective). A case study strategy, interviews, lesson observation and document analysis can be used in carrying out an analysis on the context and needs of the participants (Nieveen & Folmer, 2013) as is the case in Chapter 5. Also, focus groups can be used.

The above discussion indicates that the preliminary research phase of Model 2 was involved in different research cycles, especially in the analysis phase of Model 1 in this study. Similarly, the following phase of Model 2 is applied across different research cycles in the 'Design & develop' prototype and 'Evaluation' phases of Model 1.

Prototyping phase and formative evaluation

As seen in Table 2.1 and implemented in Figure 2.1, several prototypes were developed, evaluated and revised, making this phase highly iterative. Each cycle of this phase improves the educational intervention under development (in this case PDF), as well as the associated design principles. In terms of the research process in this study, this phase of Model 2 was incorporated and used in Model 1 in the 'Design & develop' phase and the (Formative) evaluation phase. This is shown in Figure 2.4 by arrows 4 and 5. A key research activity in the Prototyping phase is evaluation. The importance of this aspect is reflected in Model 1 where it is a phase in its own right.

Formative evaluation. Nieveen and Folmer (2013) compared and synthesised the definitions of formative evaluation from several scholars (e.g., Brinkerhoff, Brethouwer, Hluchyj, & Nowakowski, 1983; Flagg, 1990; Tessmer, 1993). On this basis, they formulated a definition of formative evaluation in an educational design research context, that formative evaluation is "a systematically performed activity (that includes research design, data collection, data analysis and reporting) aiming at quality improvement of a prototypical intervention and its accompanying design principles" (p. 158). In a developmental research context (as in this case), formative evaluation focuses on finding the shortcomings of an object during the process of its development while generating suggestions on how these shortcomings can be resolved or how the intervention may otherwise be improved (Nieveen & Folmer, 2013; Van den Akker, 1999). One question that arises, however, concerns how this important research activity can be carried out. This is where Model 3 comes into Figure 2.4, as shown using arrow 6.

The prototypes (and design principles) of an intervention may be continually refined based on the formative evaluation results and the reflections of developers on the prototype in a process that can be referred to as evolutionary prototyping (Nieveen & Folmer, 2013). This process may be broken down into four phases consisting of design proposal, global design, partly detailed intervention/product, and completed intervention/product, as seen in Model 3 in Figure 2.4. A detailed version of Model 3 is shown in Figure 2.6.

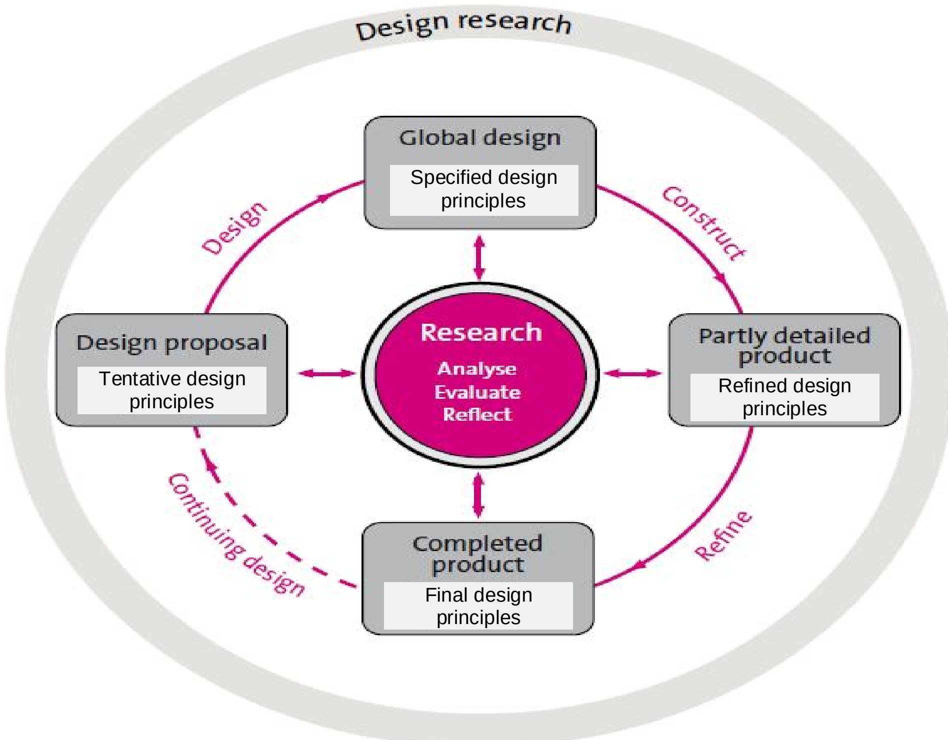


Figure 2.6 Prototyping phase in a design study (Source: Nieveen & Folmer, 2013)

The phases of the prototyping process depicted in Figure 2.6 may be described as follows (Nieveen & Folmer, 2013):

Design proposal. In this phase, the prototype contains only a general description of the completed intervention and is based on tentative design principles resulting from preliminary research results. These results include a review of the relevant literature in addition to a needs and context analysis. However, these analyses are not carried out here until later as the design proposal depends on the literature only. In this study, the design proposal was the conceptual content-generic version of the PDF (PDF v1), which was synthesised in the first research cycle, as shown earlier in Figure 2.1. The second research cycle combines the following two prototyping phases.

Global design. A prototype in this phase of development contains tentative details of all or some components of the completed intervention. The prototype provides an idea of how the completed intervention will appear. However, the prototype cannot be implemented as it is not yet ready for use in the target context.

Partly detailed intervention/product. In this phase, part of the completed intervention has been developed to an extent that it can be implemented in the target context. This corresponds with the second version of the PDF (PDF v2) completed in the second research cycle, as seen in Figure 2.1. Together with the associated specific/refined design principles, this version of the PDF comprises the outcomes of the second research cycle.

Completed intervention/product. At this level, the intervention is complete and ready for implementation in the intended setting. This version of the intervention is the completed context-specific version of the PDF. It results from the third research cycle. This version of the PDF is based on the final design principles, which form the other outcome of the research cycle. Alongside the intervention, its design principles have now evolved from a tentative set through to a more specific/refined set of principles, to the final set of design principles.

The above discussion is limited to the evolution of the intervention and the associated design principles used throughout the design process. The quality criteria, which are useful in the evaluation, as reflected in Figure 2.1, are also important in this regard.

Quality criteria for evaluating interventions. Generic criteria exist to evaluate the quality of the prototype in the different cycles of the design process. The set of criteria used in this study consist of content validity (relevance), construct validity (consistency), practicality, and effectiveness. These criteria are described in Table 2.2 below.

Table 2.2 Criteria for high quality interventions (Source: Nieveen, 1999, 2013; Van den Akker, 1999)

Criterion	Description
Content validity (Relevance)	The extent to which the design of the intervention is based on state-of-the-art (scientific) knowledge.
Construct validity (Consistency)	The extent to which the intervention is 'logically' designed (the extent to which the components of the intervention are consistently linked to each other).
Practicality	The extent to which experts and users consider the intervention as usable under 'normal' circumstances: - Expected practicality: The intervention is expected to be usable in the context for which it has been designed. - Actual practicality: The intervention is usable in the context for which it has been designed.
Effectiveness	The extent to which outcomes and experiences resulting from the intervention are consistent with the intended purposes: - Expected effectiveness: The use of the intervention is expected to yield the expected results. - Actual effectiveness: Use of the intervention yields the expected results.

The quality criteria in Table 2.2 may have different emphasis in the different phases of design research (Plomp, 2007). Specifically, during the preliminary research phase, the content validity (relevance) criterion is most important, although attention is also given to construct validity (consistency) and practicality. However, at this stage no attention is accorded to effectiveness, which in addition to practicality is an important criterion in the summative evaluation phase. In the preceding prototyping phase, the practicality criterion is emphasised. The use of the above quality criteria in this study is included in Figure 2.1.

Summative evaluation phase

This final phase of many design studies aims to gather evidence of the effectiveness of an intervention and evidence to support the decision to continue or discontinue the project (Nieveen & Folmer, 2013). Thus, summative evaluation may not be carried out until the intervention has been developed to an extent that it has adequate potential effectiveness. This is because these types of evaluations are time consuming, costly, and need to meet criteria that are difficult to meet in an educational context. That being said, the best research design to reveal cause-effect relationships is a (quasi-) experiment. In this regard, interpretivism is not useful, unlike pragmatism, which also accommodates formative evaluation. However, summative evaluation may also involve a large-scale survey combined with a number of in-depth case studies. This further strengthens the usefulness of pragmatism in this study. While this last form of summative evaluation cannot detect cause-effect relationships, it nevertheless can provide data on the effectiveness of the intervention in a cost-effective manner.

2.4.4 Literature reviews

2.4.4.1 Definition and usefulness

Literature reviews are commonly conducted in order to learn about the breadth of existing research on a topic; to provide theoretical grounding for imminent research; or to answer practical questions through an understanding of existing research results (Okoli & Schabram, 2010). The last two purposes above were required in this study. The second purpose was used in Sections 1.2 and 1.3. The third purpose was needed and used in the first and second research cycles (in Chapters 3 and 4 respectively). This enables the PDF to be theoretically grounded. Thus, it was useful to further consider literature reviews in relation to this research.

A literature review is "a systematic, explicit, and reproducible method for identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researchers, scholars, and practitioners" (Fink, 2005, p. 3). Similarly, Rousseau, Manning, and Denyer (2008) argue that literature reviews need to be a “comprehensive accumulation, transparent analysis, and reflective interpretation of all empirical studies pertinent to a specific question” (p. 7). The question here concerns how one can develop a professional development framework to support South African Physical Science teachers in resource-constrained schools in the design and implementation of inquiry-based practical work.

2.4.4.2 Types of literature reviews

Okoli and Schabram (2010) identify and discuss three general types of literature reviews: a "literature review" or "theoretical background" to a journal paper, a thesis literature review, and a stand-alone literature review. The stand-alone literature review may also be called a systematic literature review. The literature review carried out in the context of this thesis was drawn from all three types of literature reviews. The first type of literature review anchors the rest of a scholarly paper by describing the content and quality of knowledge already available, presenting the significance of previous research, in addition to explaining its findings as grounding for the subsequent work (Fink, 2005). Okoli and Schabram (2010) highlight the need for this type of literature review to provide a scholarly critique of theory. This type of literature review is further discussed in this and the next chapter.

The literature review in a thesis allows the student to synthesise all understandings of the subject matter in relation to justifying future research (including the thesis itself) (Bruce, 2001). The literature review also serves as a basis for future discussions (Okoli & Schabram, 2010), as in this case. Unlike the other two types of literature reviews, the stand-alone literature review is in itself a complete research pursuit. Among other purposes, stand-alone literature reviews are useful in gathering knowledge on professional practice, in identifying effective research projects and techniques, as well as in identifying unpublished sources and experts within a particular field (Fink, 2005). Such knowledge, projects and experts were useful in the development of the PDF in this and the subsequent chapters, for example, the experts provided formative evaluation data. That said, while stating that the above purpose of a stand-alone literature review is shared by the other two types of literature review, Okoli and Schabram (2010) note that a distinguishing feature of stand-alone literature reviews are in their scope and rigor. A stand-alone literature review also provides a framework for positioning research endeavours in addition to supporting practice and informing policy (Okoli & Schabram, 2010; Petticrew & Roberts, 2006). Its usefulness can be seen, for example, in the fact that design principles also assist policy makers in making research-based decisions in relation to addressing complex educational problems (Linn et al., 2004; Van den Akker, 1999). This type of literature review was thus useful in this study in terms of the PDF and related design principles.

2.4.4.3 Stand-alone literature reviews

A stand-alone literature review is also known as a Systematic Literature Review (SLR), which is a more rigorous approach to conducting literature reviews, although varying levels of rigor exist (Okoli & Schabram, 2010). In terms of qualifying the rigor needed, two criteria may be used. One is that an SLR needs to be carried out in an open-minded and transparent manner regarding how and why the topic has been chosen (Hart, 1999). This criterion was implemented in this study in Chapter 3 and 4, with reference to the research questions (Section 1.3.2). However, in addition to synthesising the available literature, a SLR must also involve the scholarly critiquing of theory (Kekäle, Weerd-Nederhof, Cervai, & Borelli, 2009). Authors of doctoral theses and theoretical backgrounds need to use SLRs in their studies as much as possible (Okoli & Schabram, 2010). Here, a SLR was used in the first and second research cycles (Chapters 3 and 4, respectively), with reference to principles useful in this regard.

There are a number of principles for conducting an SLR (Okoli & Schabram, 2010). The principles based on a review of the literature across a broad range of domains that include the social sciences consist of (Okoli & Schabram, 2010):

Purpose of the literature review. This is the first step in any review. In this step, the reviewer clearly identifies the purpose and the intended goals of the literature review. This clarification is necessary in terms of making the literature review explicit to its audience.

Protocol and training. This step is needed in any review that employs more than one reviewer. In this regard, it is essential that the reviewers be in agreement and that they are completely clear about the detailed procedure to be used. This requires a written and detailed protocol document. Also, training for all the reviewers is needed to ensure consistency in the conduct of the review. This principle is not applicable here, unlike the ones below.

Searching for the literature. The reviewer has to be explicit in describing the details of the literature search, and needs to justify and explain all steps towards ensuring the comprehensiveness of the literature search.

Practical screening. This step is also known as screening for inclusion. It requires that the reviewer be explicit regarding the studies considered in the literature review, in addition to the studies that were eliminated from the review. In terms of the excluded studies, the reviewer needs to state what the practical reasons were for their exclusion. How the resulting review remains comprehensive despite the exclusion criteria must also be explained.

Quality appraisal. In this step, which is also known as screening for exclusion, the reviewer must explicitly state the criteria used to determine which articles are nevertheless of a quality that is inadequate for inclusion in the literature review. In addition, all included papers must be scored for their quality, based on the research methodologies used in the papers.

Data extraction. After identifying the studies to include in the literature review, the reviewers must systematically extract the applicable data from each study.

Synthesis of studies. This step is also called the analysis step, and involves combining the extracted data from the studies based on appropriate techniques. These techniques may be qualitative, quantitative, or both.

Writing the review. The SLR process needs to contain adequate detail. This allows the results of the review to be independently reproduced. Also, the standard principles in writing research articles are to be followed.

Thus, in this section the methodology of this study was discussed, which included pragmatism as the research paradigm, and which involved applied, exploratory and deductive-inductive research in relation to the research approach. On this basis, the study used a design research strategy, incorporating a multi-method, multi-case study. In relation to the scope of this chapter, it remains for this chapter to present the research methods useful in completing the different research cycles in this study.

2.5 CHOICES (CHOICE OF METHODS)

The choices of the methods used in this study were made with reference to the research strategy and research questions. Based on the strategy (the development studies approach in design research), a survey or an experiment may be useful only in conducting a summative evaluation of the completed context-specific version of the PDF being developed. Otherwise, qualitative methods are adequate, as seen from the research questions.

This study used multiple qualitative research methods in the data collection. The use of multiple methods enhances the credibility and trustworthiness of research projects (Burian et al., 2010; Samaras, 2011). Specifically, this study used the multi-method choice, as shown in Figure 2.2. It is worth noting that the term multi-method is used here in a different sense than that of Swanson and Holton (1997), whose use of the term multi-method implies combining qualitative and quantitative research methods. This combination is rather considered here as mixed methods research. Combining quantitative and qualitative methods in mixed methods research enhances the meaning and implications of the research results (Malterud, 2001). However, quantitative research relies mostly on the use of positivist claims in order to develop knowledge based on statistical data (Creswell, 2003). While such knowledge has more generalisability, as Mortensen (2011) notes, this limits its application in practice. Also considering the research questions, quantitative and thus mixed methods research is not useful here.

Qualitative research methods are useful in studies (such as the present study) interested in understanding, exploration and discovery (Burian et al., 2010). In particular, qualitative research is useful in exploring such dimensions of practice as processes, goals and failures (Skinner, Tagg, & Holloway, 2000). Here, the importance lies in exploring the process of designing and implementing IBPW in relation to the practices and challenges experienced by teachers. It is to this end that multi-method qualitative research was used in this study. The specific methods of data collection are described later within Section 2.7.

2.6 TIME HORIZONS

This research was cross-sectional in order to focus on answering the research questions and addressing the educational problem at this given point in time (Saunders & Tosey, 2013). Thus, the longest data collection episode lasted six weeks and was associated with the secondary research questions SRQ2, SRQ3a and SRQ3b (Section 1.3.2). This study was designed as a cross-sectional study considering that the shorter the time for data collection, analysis and dissemination, the greater the chances that the results of the study would actually be used in the design research process (Van den Akker, 1999). This is the efficiency dimension of design research. However, design research, like other research strategies, also strives for rigor. Thus, there is often the triangulation of data collection and analysis methods, instruments, sources, and sites (Van den Akker, 1999). Peeling back the ‘time horizons’ layer allows the ‘techniques and procedures’ layer of the research process onion in Figure 2.2 to be explored.

2.7 TECHNIQUES AND PROCEDURES

In this study, existing and empirical data was used, thus, it is useful to consider the corresponding techniques and procedures used for data collection and analysis. In relation to existing data, a systematic literature review was the technique used for data collection. This technique has already been discussed in Section 2.4.4. Thus, it remains to consider techniques and procedures used for empirical data collection and analysis.

2.7.1 Empirical data collection

2.7.1.1 Sampling

In design research, (empirical) data collection is normally limited to relatively small and purposive samples compared to sampling procedures in research strategies used for other purposes (Van den Akker, 1999). The need to use relatively small samples lies in the fact that opportunities for using 'rich' data collection techniques, such as observations and interviews, are limited when big samples are involved.

The actual nature and size of the samples used in this design research were dependent on the research cycle (two or three) and the purpose of the data collection in the given research cycle. Details in this regard are contained in Table 2.3.

Table 2.3 Samples of participants per research cycle and purpose (Source: Researcher)

Research cycle	Purpose	Sample
Two	Formative evaluation of a content-specific version of a PDF.	Two experts (E1 and E2) in teacher professional development practice and/or research with collective experience in several countries.
Three	Context and needs analysis towards designing a context-specific version of the PDF.	Six Physical Science teachers and one demonstrator in two South African resource-constrained schools were approached.
	Formative evaluation of the context-specific version of the PDF.	Two experts (E3 and E4) in teacher professional development, as well as inquiry-based teaching and learning practice and research in South Africa

Research cycle one is missing in Table 2.3 since this research cycle combines a systematic literature review and self-evaluation as the methods of data collection. While research cycle two also used a systematic literature review, the formative evaluation of its primary outcome is based on a one-to-one evaluation involving experts (E1 and E2). In research cycle three, the outcome is based on data collection involving a set of teachers and one demonstrator, followed by the formative evaluation of this outcome using two experts (E3 and E4).

2.7.1.2 Techniques of empirical data collection

These consisted of the techniques used in the formative evaluation, as well as the techniques needed for context analysis.

Context analysis techniques

Methods often used in design research to conduct a context analysis include (a combination of) interviews, focus groups, lesson observations and document analysis (Nieveen & Folmer, 2013). Although focus groups were not used in this study because of the challenges in bringing busy teachers and other practitioners together, the remaining three were augmented with field notes and used in relation to the secondary research questions SRQ2, SRQ3a and SRQ3b in the third research cycle (Figure 2.1).

It is useful to combine a number of techniques of data collection. Relying on what teachers say is inadequate in understanding what they do due to self-protection and/or a lack of sufficient understanding of the expectations and definitions of the research (O'Sullivan, 2006). In addition to the social desirability effects, researcher bias can play a role in data collection using interviews (Creswell, 2006). Being aware of this bias is important for the researcher in terms of watching out for and preventing it. However, in relation to the participants, it can only be assumed that their responses to interview questions are sincere. Due to the fact that the above shortcomings of interviews cannot be completely eliminated, the use of multiple techniques and sources of data collection is useful in this research. Also, certain aspects of practice cannot be examined without observing the interactions between teachers and learners in the classroom (Burstein, McDonnell, Van Winkle, Ormseth, Mirocha, & Guitton, 1995). Furthermore, the responses that the interviewees provide are less likely to be 'rhetorical' in nature and more effectively linked to reality when interviewees consider that the interviewer has observed the practice under discussion (Abrahams & Millar, 2008).

Formative evaluation techniques, questions and techniques of data collection

Each design research cycle should begin with one or more research/evaluation questions reflecting the quality criteria to be emphasised in that cycle (Plomp, 2013). This allows for the design and development of an appropriate research/evaluation design. The syntax of the evaluation questions is: “What is the [quality criterion a, b, c and/or d] of the prototype that is in [development stage w, x, y, z]?” (Nieveen & Folmer, 2013, p. 161), for example: What is the internal consistency [quality criterion] of the attainment targets for science in upper secondary education in which three out of seven domains are elaborated in detail [development stage]? Similar evaluation questions are contained in each research cycle (Chapter 3, 4 and 5) in this study.

Several formative evaluation methods exist in the literature (Brinkerhoff et al., 1983; Tessmer, 1993). These methods consist of self-evaluation (screening), walk through or one-to-one evaluation, small group (micro-evaluation), expert appraisal (focus group) and try-out (field test) evaluation.

Self-evaluation (screening). Based on this method, members of the design research team check the intervention design. This check is based on a checklist of the required design specifications or important characteristics. This method was chosen for use in the first research cycle, as seen in Figure 2.1.

Walkthrough or one-to-one evaluation. Using this method, one or more representatives of the target audience and the design researcher or research team together go over the prototype. Useful data collection methods for this evaluation consist of a checklist, interviews and observing the respondent(s) running through the prototype. This method was used in the second and third research cycles, as seen in Figure 2.1.

Focus group (expert appraisal). This involves a group of respondents who react to the prototype of the intervention (product). In this regard, interviews may be used in the data collection. However, this method was not used in this study, instead, the previous method was used in order to allow each practitioner to evaluate the intervention at a time that best suited their schedule.

Small group (micro-evaluation). Based on this method, a small group of the target users (e.g. teachers, professional development providers) use parts of the product (intervention) outside the normal user setting. Data may be collected through interviews, observation, and questionnaires, for example. This method was not used here due to the nature of the intervention involved. This is in the sense that before a PDF can be implemented, the PDF must first be translated into a professional development programme by the user. As a result, this and the next method are less efficient in relation to time. Design research strives to balance rigor and efficiency (in this case in relation to time) in the formative evaluation process in order to increase the actual use and effect of the evaluation on the prototyping process (Van den Akker, 1999; Venable, Pries-Heje, & Baskerville, 2012).

Try-out (field test). Based on this method, the target group uses the product (intervention) in practice. If the focus of the evaluation lies in its practicality, observation, interviewing, and requesting logbooks and questionnaires are commonly used for data collection. However, if the emphasis in the evaluation is on the effectiveness of the intervention, a report or a test may be used in the case of a classroom intervention, for example. A test would require drawing from positivism. However, this is not necessarily the case when using a questionnaire and unquestionably not the case regarding the other formative evaluation methods outlined above. For those evaluation methods, interpretivism would be the paradigm of choice.

Suitable formative evaluation methods may be used in progression from less to more rigorous methods of evaluation (Plomp, 2007), as is the case in

Figure 2.1. The paradigm choice of pragmatism thus allows for the use of any of the above formative evaluation methods when suitable. That said, the notion of rigor in the formative evaluation method is embodied in Figure 2.7.

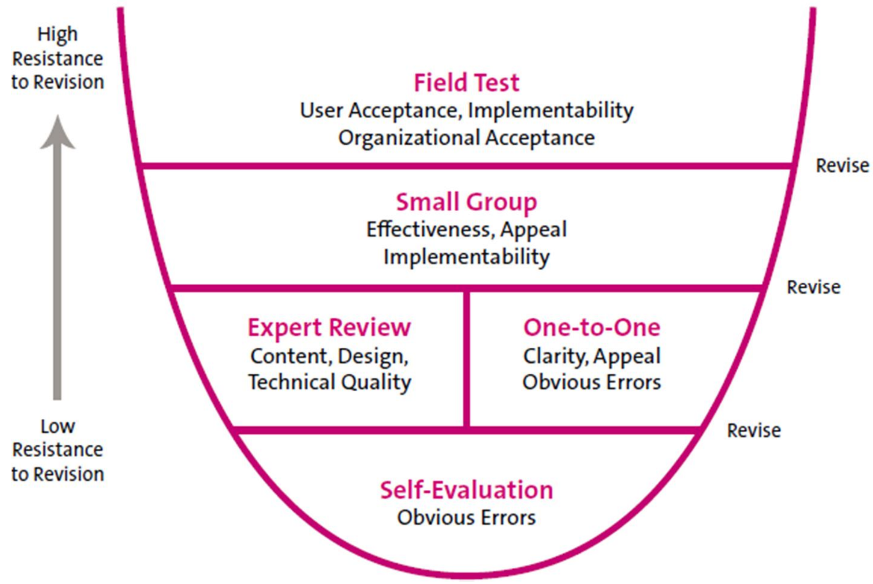


Figure 2.7 Layers of formative evaluation (Source: Tessmer, 1993)

It is worth noting that in some cases, the actual practicality and effectiveness of an intervention cannot be established through a field trial, although this evaluation method offers a high resistance to revision, as seen in Figure 2.7. In this case, the study may limit itself to demonstrating the expected practicability and expected effectiveness through expert appraisal and/or micro-evaluation. However, the actual effectiveness and practicality will remain to be established (Plomp, 2007). This was the case for Mafumiko (2006), who investigated whether micro-scale practical work could contribute to enhancing the chemistry curriculum in Tanzania. As reflected in Figure 2.1, actual effectiveness was also not established in this study.

2.7.2 Analysis of existing and empirical data

Existing data was used in the systematic literature reviews (Chapter 3 and 4), while empirical data results from the context and needs analysis (Chapter 5). The formative evaluation of the intervention (Chapter 4 and 5) also yielded empirical data. Independently of the research cycle and the purpose of the data collection, the data analysis was based on a combination of two approaches to thematic analysis.

It has been argued that inductive and deductive reasoning cannot be meaningfully separated (Blaikie, 2007). Thus, in using the thematic technique of data analysis in this study, it assisted in combining the two approaches. These approaches consist of the data-driven inductive approach (Boyatzis, 1998), and the deductive *a priori* template of codes approach (Crabtree & Miller, 1999). In line with the latter approach, code books are developed and used, as seen later in the different research cycles (Chapter 3, 4 and 6 respectively). It is based on these code books that an in-depth analysis of the data based on the data-driven inductive approach is then carried out. In this regard, the method of constant comparison (Glaser & Strauss, 1967; Strauss & Corbin, 1990) has been used. In doing so, each concept in the data (such as extrinsic/intrinsic challenge or inquiry-based teaching practice) is coded as a category. Each code is then compared with the previous codes belonging to the same *a priori* category in order to identify similarities and differences (for example in practices and challenges) in the data. This procedure was repeated across the different data sources or techniques used. Regarding the third research cycle (Chapter 5), a similar procedure was followed in the cross-case data analysis.

2.8 PERMISSION AND ETHICAL CONSIDERATIONS

Ethical clearance and permission to carry out the (empirical) data collection was obtained first from the Institutional Review Board (Ethics Committee of the Faculty of Education) of the University of Pretoria and then from the Gauteng Provincial Department of Education. The Ethics Committee approval is contained in Appendix H. The initial and the renewed governmental approval letter are found in Appendix I and Appendix J respectively. Alternatively, the recruitment of schools and teachers for the context analysis was carried out on the basis of a permission letter for school principals (Appendix K), a consent letter for teachers (Appendix L) and for the demonstrator (Appendix M). Also, consent letters for parents/guardians (Appendix N) and assent letters for learners (Appendix O) were used. In addition to the above, emails were used to request the informed consent of the experts who participated in the formative evaluation of the content-generic and content-specific versions of the PDF in Chapters 4 and 5 respectively. These letters and emails were designed to include the following (Sarantakos, 2005):

- The identification of the researcher;
- The identification of the sponsoring institution;

- The specification of the purpose of the study;
- The identification of the benefits for participants;
- A guarantee of confidentiality given to the participants;
- The assurance that the participant can withdraw at any time; and
- Provision of details of persons to contact if questions arise.

The thus designed consent letters promised the observation of specific ethical principles in the conduct of the research. The areas of concern consisted of safety in participation, voluntary participation, informed consent in addition to privacy and trust (Bryman, 2001 citing Diener & Crandall, 1978; Human-Vogel, 2007). The principles observed in these areas of concern are discussed below in accordance with a number of authors (e.g., Lodico et al., 2006; Saunders, Lewis, & Thornhill, 2003).

Informed consent requires that participants give consent for their participation and are fully informed about the research process and goals at all times. Voluntary participation partly entails that the participants are free to decline participation in the data collection. However, if they agree to participate in the study, participants may withdraw from the study at any time that they wish to do so. Safety in participation requires that the participants are protected from harm and are not put under strain. In this regard, the researcher refrained from prolonging the duration of the interviews and from subjecting participants to questions that put them under stress or discomfort. The interview excerpt below illustrates protection from discomfort.

> Participating teacher: "… what can I make an example of . . . [Silence] I am running out of ideas now…"
>
> Researcher: "Maybe we can come back to that one later in our discussion."

Moreover, the participants were informed that they were free to decide which questions or set of questions to answer or not, and when to participate in data collection.

Privacy, this is considered to consist of confidentiality and anonymity. In this regard, the participants were protected throughout the research process from the beginning of the sampling through to the dissemination of the outcomes, for example, the participating schools, teachers and experts were allocated pseudonyms, which are known only to the researcher. Confidentiality was explained to the experts, demonstrator, participating teachers and their learners. In relation to anonymity, the teachers were told that their specific position and identity would not be revealed in the research report. Also, the interviews were audio and not video recorded to further safeguard the identity of the participants. Based on the principle of trust, the participants were not deceived or betrayed in the process of carrying out this research nor will they be deceived in the dissemination of its outcomes. Even though, for example, it is necessary that consent letters should not change participants, a general description of the purposes and procedures of this study was nevertheless provided.

2.9 CHAPTER SUMMARY

This chapter explained the processes carried out in developing the PDF to support South African Physical Science teachers in resource-constrained schools. This is in the design and implementation of inquiry-based practical work. The research methodology and methods have been discussed based on the research design model of Saunders and Tosey (2013). Specifically, a discussion of the research methods has been related to the three innermost layers in Figure 2.8.

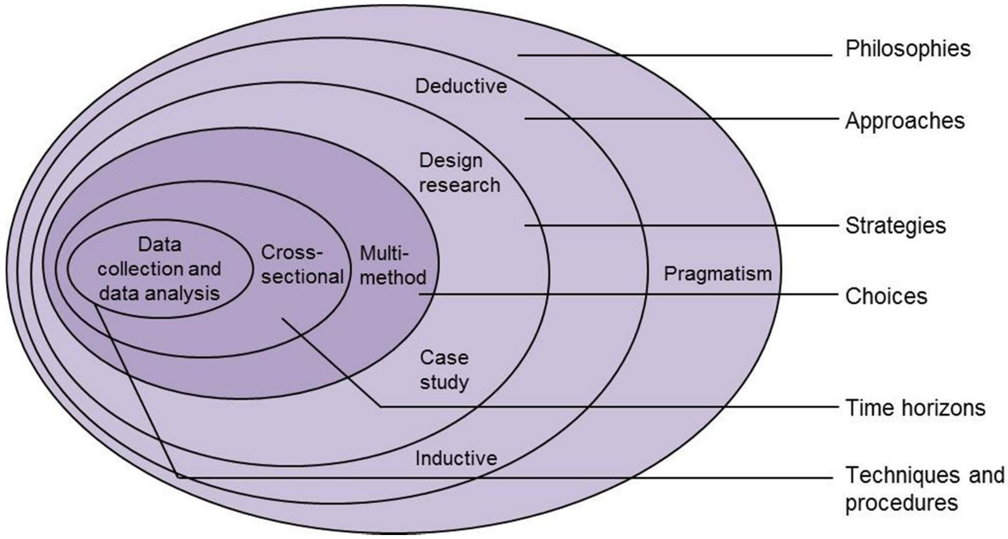


Figure 2.8 Research process onion model used in this study (Source: Adapted from Saunders & Tosey, 2013)

Conversely, the research methodology covers the three outermost layers. It incorporates pragmatism as a philosophy, a deductive-inductive approach, and design research as the overarching research strategy (Figure 2.8). Specifically, the research strategy is based on development studies due to its alignment with the primary purpose of this study (Section 1.3.3). The purpose requires the generation of design principles and the development of an intervention, which, in addition to the development process, are the outcomes of development studies. The intervention in this case is a PDF to support South African Physical Science teachers in resource-constrained schools. The support is in the design and implementation of inquiry-based practical work. Certain characteristics of design research are useful in the development of this intervention and in the generation of the related design principles. The characteristics include the fact that design research is theory-orientated, iterative, process-orientated, collaborative, utility oriented and context-bound (Section 2.4.2.2). Due partly to these last three characteristics, design research poses important challenges to be addressed as discussed above (Section 2.4.2.3) in order to ensure that this study would be adequately rigorous.

This chapter links the outcomes of this study (the PDF and the associated design principles) to the outcomes of development studies (an intervention and the associated design principles). In relation to reaching these outcomes, three implementation models informed the conceptual framework of the study (Figure 2.4).

The conceptual framework is contained in Figure 2.1 as the research process for this study. The conceptual framework addresses some of the challenges inherent in design research, which include concerns about the suitability of a researcher as an evaluator, the real-world complications involved in design research and the changing nature of the research design. As an example, the conceptual framework involved a shift from a dominance of the 'creative designer' perspective in the early phases towards the 'critical researcher' perspective in the later phases. The framework also involved systematic documentation, analysis, and reflection in the design, development, evaluation and the implementation process and their outcomes. However, other ways of enhancing design research have been considered in this chapter, although these were outside the conceptual framework.

Having thus discussed the research methodology and research methods involved in this study, it remains to present the development of the PDF. The development process begins in the first research cycle, which is detailed in the next chapter.

CHAPTER 3 : CONCEPTUAL CONTENT-GENERIC PROFESSIONAL DEVELOPMENT FRAMEWORK

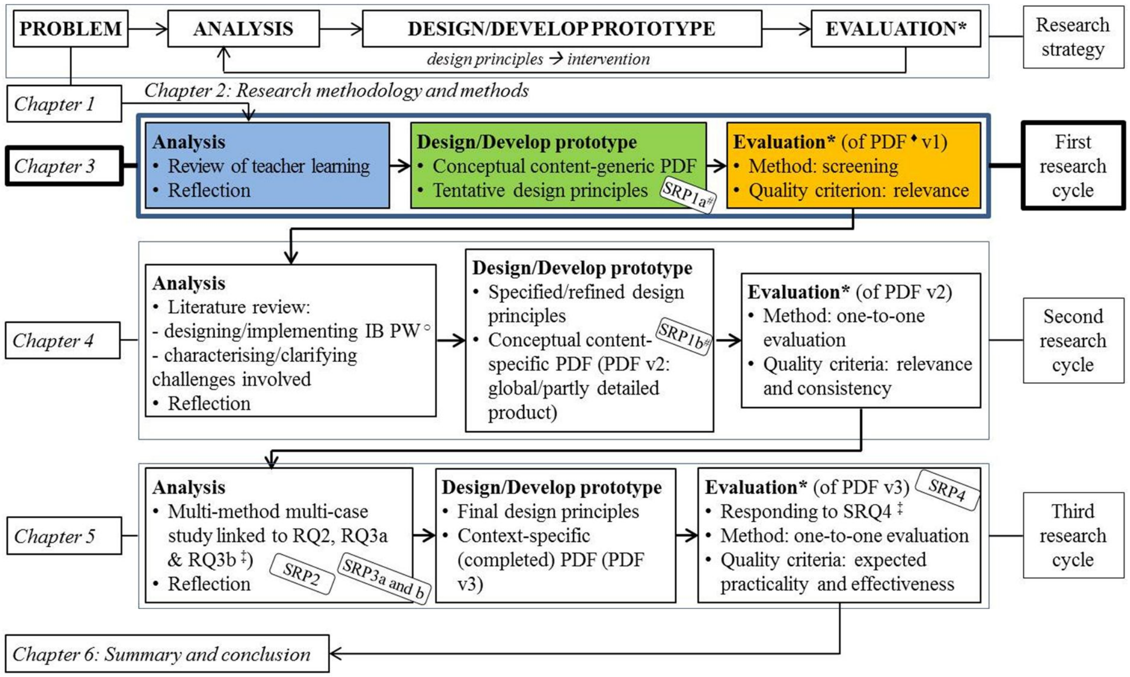
3.1 CHAPTER OVERVIEW

This chapter contains the first research cycle in the process outlined earlier in Figure 1.1 for developing a Professional Development Framework (PDF). The outcome of this research cycle is a conceptual content-generic version of the PDF (design proposal), to support South African Physical Science teachers in resource-constrained schools. This was specifically relevant to the design and implementation of inquiry-based practical work. This outcome is largely based on a review of the international literature on effective (science) teacher professional development. Much of the literature review is a systematic literature review, as explained in Section 2.4.4.3.

The primary research activities involved in this research cycle comprised:

- Gathering core features and principles to design teacher learning;
- Identifying and tentatively specifying components of a PDF;
- Generating design principles and the PDF with reference to the components identified; and
- Carrying out a formative evaluation of this PDF based on the core features and principles of teacher learning.

The position of this research cycle and this chapter within the overall research process is shown in Figure 3.1.



Legend:
* Consisting of data collection and analysis, in addition to results and reflection
♦ PDF = Professional Development Framework; ° IBPW = Inquiry-Based Practical Work; # SRPi = Secondary Research Purpose i (section 1.3.3)

‡ SRQ1a = What are the characteristics of a conceptual content-generic PDF to support science teachers?
‡ SRQ1b = What are the characteristics of a conceptual content-specific PDF to support IBPW in secondary school science classrooms?
‡ SRQ2 = How inquiry-based is the way in which practical work is being designed and implemented in resource-constrained South African Physical Science classrooms?
‡ SRQ3a = What specific extrinsic challenges are being faced by teachers in these classrooms in relation to the design and implementation of IBPW?
‡ SRQ3b = What specific intrinsic challenges are being faced by the teachers in relation to the design and implementation of IBPW?
‡ SRQ4 = What are the characteristics of a context-specific PDF to support these teachers in the design and implementation of IBPW?

Figure 3.1 Position of Chapter 3 within the design research process (Source: Researcher)

Figure 3.1 is, simply put, the conceptual framework of this study (Figure 1.2) in which the first research cycle is highlighted. As seen in the figure, the research cycle contained in this chapter responded to the first Secondary Research Question, SRQ1 (Section 1.3.2) in achieving the first Secondary Research Purpose (SRP1a in Section 1.3.3). In this regard, the research cycle is divided in three major parts: the analysis phase, the design/develop prototype phase, and the evaluation phase.

The analysis phase (Section 3.2), considered the type of teacher learning that the conceptual content-generic PDF needed to serve. In this regard, it discusses the definition, approaches and implementation models in teacher professional development. This provided data that positioned the conceptual content-generic PDF in this study, and assisted in the formative evaluation of the PDF. The definition of a PDF was considered, in addition to the description of a systematic literature review for the purpose of gathering data to synthesise the conceptual content-generic version of the PDF.

In the design/develop prototype phase (Section 3.3), the results of the systematic literature review are presented. This applied to the components of a PDF, which consisted of the PD goal, learning phases, learning theory, strategies, instructional functions and teacher motivation. Simultaneously, tentative design principles were generated, which were then used to create the conceptual content-generic PDF (design proposal).

The evaluation phase (Section 3.4), provided an opportunity to evaluate the PDF. In line with Figure 3.1, the evaluation question was: What is the relevance (content validity) of the conceptual content-generic version of the PDF (PDF v1)? Thus, the evaluation showed the extent to which this version of the PDF was based on state-of-the-art knowledge regarding the designing of effective (science) teacher professional development programmes. For this purpose, the screening (self-evaluation) method was used.

3.2 ANALYSIS PHASE 1

This phase of the current research cycle contained a systematic literature review (Section 2.4.4.3) aimed at the identification and specification of the components of a PDF. In this regard, it was useful to first consider teacher professional development approaches. This led to the choice of effective (continuous) professional development as the teacher professional development approach to adopt. Regarding this approach, there are core features of effective teacher professional development coupled with a range of principles for designing effective teacher professional development programmes. These features and principles are assembled below, and were used later in the formative evaluation of the content-generic version of the PDF.

3.2.1 Teacher professional development and a professional development framework

3.2.1.1 Definition and importance of teacher professional development

First of all, professional development is the means by which organisations deal with the introduction of innovations into their practice (Wells, 2007). The innovation in this case was the infusion of inquiry-based methods in practical work in secondary school Physical Science classrooms. That said, the professional development of teachers comprises activities that should enable them to improve their knowledge, skills, instructional practices, attitudes, as well as the learning outcomes of their learners (Clarke & Hollingsworth, 2002; Guskey, 2000; Organisation for International Co-operation and Development, 2009; Stolk et al., 2011; Wei, Darling-Hammond, Andree, Richardson, & Orphanos, 2009). Teacher professional development is an important means of enhancing the quality of instruction and learning in schools (Ingvarson, Meiers, & Beavis, 2005). In particular, teacher learning is necessary in the successful introduction of educational innovations (Visser, Coenders, Pieters, & Terlouw, 2013). Thus, the desired reform in science education cannot be accomplished without the significant professional development of practicing teachers (Dass & Yager, 2009; Hoban, 2002). However, it must be asked, how can teacher professional development be best carried out?

3.2.1.2 Professional development approaches

Two distinct approaches to teacher professional development that were found in the literature are the traditional approach, and effective (continuous) professional development.

Traditional approach

Workshops are the most common approach to professional development despite being widely criticised (Garet, Porter, Desimone, Birman, & Yoon, 2001; Weiss, Banilower, McMahon, & Smith, 2001). Workshops fall under the traditional approach to teacher professional development. This usually takes the form of a one-shot training event that lasts a short period of time, such as one or two days

(Crawford, 2003; Starrett & Rodgers, 2003). This approach to professional development focuses on the transmission of knowledge and skills through training on a specific topic without considering the perceived needs or the daily instructional problems encountered by the participants (Bransford, Brown, & Cocking, 2000; Ostermeier et al., 2010). The training often occurs outside the school setting and context, using hardware and/or software tools that are unfamiliar to teachers or are different to those available in the classroom (Fullan & Steigelbauer, 1991). Also, teacher professional development has often been "intellectually superficial, disconnected from deep issues of curriculum and learning, fragmented and non-cumulative" (Ball & Cohen, 1999, p. 5).

For the purpose of dealing with instructional innovations (as in this case), the traditional approach to professional development does not allow teachers to integrate and adopt new knowledge and skills (Wells, 2007). In fact, the traditional approach to professional development is inadequate and inappropriate in the light of current efforts to reform science education (Dass, 1999; Dass & Yager, 2009). This rules out the traditional approach for use in the PDF. Instead, the PDF needed to be situated in the context of effective professional development.

Effective teacher professional development

Effective (continuous) teacher professional development is context-specific (Wells, 2007). Research is in support of professional development that enables teachers to try out innovations in the context of their classrooms in collaboration with other teachers (Garet et al., 2001). With specific reference to science teachers, there is consensus regarding the core features of such professional development (effective professional development). These features are contained in Table 3.1.

Table 3.1 Core features of teacher professional development programmes

Core feature of effective teacher professional development programmes	Source
1. Collective participation in professional learning communities. 2. Content focus. 3. Using similar methods to those needed in the classroom. 4. Adequate duration. 5. Active learning. 6. Coherence.	(Desimone, Porter, Garet, Yoon, & Birman, 2002; Ingvarson et al., 2005; Marx & Harris, 2006; National Science Teachers Association, 2006).

Details regarding the features of effective professional development in Table 3.1 are available in the literature (e.g., Birman, Desimone, Porter, & Garet, 2000; Cohen & Hill, 2000; Ingvarson et al., 2005). Duration and collective participation are structural aspects of a professional development programme. On the one hand, duration refers to the number of contact hours and the span of time over which professional development occurs. On the other hand, content focus and active learning fall under the process aspect of a programme. Referring to active learning, professional development programmes need to involve teachers in analysing their practice in relation to good teaching and learning standards. With respect to content, the focus is on the extent to which professional development focuses on deepening and improving the content knowledge of science teachers. Teacher professional development is more likely to affect learners if it increases teachers' understanding of the content that they teach in addition to how learners learn the content, and how to represent and convey this content in an explicit manner. Collective participation deals with whether teachers from different schools participate individually or teachers from the same school, grade level or department collectively take part in professional development. The level of professional community generated is considered as a mediating variable in enhancing the impact of a professional development programme on the classroom practice of teachers. Teachers can strengthen, construct, expand, and challenge their understanding about the teaching of science in a professional learning community (Luft & Hewson, 2014). The aspect of coherence is concerned with whether professional development is designed to encourage communication among teachers in addition to whether it incorporates experiences that are aligned with State standards and assessments in addition to the goals of the teachers themselves.

Linked to the above features of CPD are certain principles that have been identified as critical to the designing of effective teacher professional development experiences. These principles were found in the literature (Loucks-Horsley, Love, Hewson, Stiles, & Mundry, 2003; National Research Council, 2005a; Ostermeier et al., 2010; Rogers, Abell, Lannin, Wang, Musikul, Barker et al.,, 2007; Rozenszajn & Yarden, 2014; Wells, 2007). Some of these principles are included in Table 3.2.

Table 3.2 Principles for designing effective teacher learning programmes

Principle		Source
A.	Addressing central problem areas in teaching.	(Loucks-Horsley, Love, Hewson, et al., 2003; National Research Council, 2005a; Ostermeier et al., 2010; Rogers et al., 2007; Rozenszajn & Yarden, 2014; Wells, 2007).
B.	Introducing processes of quality development in school.	
C.	Collaboration and cooperation at all levels, especially amongst teachers.	
D.	Supplementing the work of teachers with support from other teachers and through research on learning and instruction.	
E.	Attending to both the pedagogical content knowledge and educational beliefs of participants.	
F.	Demonstrating activities and teaching strategies linked to curricular needs and providing teachers with the required resources.	
G.	Establishing multiple opportunities for teachers to experience activities from the perspective of learners.	
H.	Developing a network of support for participating teachers	
I.	Reflecting research on effective classroom learning and teaching.	
J.	Using instructional strategies that are research-based and reflect those needed in the classroom.	
K.	Facilitating the building of a learning community of teachers.	
L.	Supporting teachers to serve in leadership roles.	
M.	Aligning professional development to local and state priorities and systems.	

Principle		Source
N.	Using the learning needs of learners as a basis and helping teachers to address learner difficulties in subject-matter knowledge and skills.	
O.	Basing professional development on the needs of participating science teachers and assessing and refining professional development to meet teachers' evolving needs.	
P.	Engaging science teachers in transformative learning experiences that confront deeply held beliefs, knowledge, and habits of practice.	
Q.	Maintaining a sustained focus over time and providing opportunities for continuous improvement.	
R.	Actively involving teachers in observing, analysing, and applying feedback to teaching practices.	
S.	Concentrating on specific issues regarding science content and pedagogy that are derived from research and exemplary practice.	
T.	Promoting collaboration among teachers in the same school, grade, or subject.	
U.	Providing on-going support in the form of long-term, continuous pedagogical, technical and social assistance.	
V.	Sustaining change through a cyclical professional development process that ensures durability.	

The above discussion (reflected in Table 3.1 and Table 3.2) indicates that the desired conceptual content-generic PDF needs to involve a continuous professional development process. This process should be in line with specific features and principles linked to effective teacher professional development. However, the discussion does not provide data regarding the contents that allow the PDF to reflect such a professional development process. Firstly, an understanding of the concept of a PDF was useful in exploring the prerequisite content.

3.2.1.3 Professional development framework (PDF)

This is not uniquely defined. In one case, a PDF is a national programme for professional development that includes the professional development activities that teachers undertake, in addition to the professional recognition and accreditation linked to these activities (General Teaching Council for Wales, 2006). Here, a different definition of a PDF has been formulated for use. The definition combines an existing definition of a PDF, the definition of a framework in general, and other relevant data (Table 3.3).

Table 3.3 Notion of a professional development framework

Artefact	Definition/Description	Source
Professional Development Framework	- Blueprint of associated Professional Development process and thus a predictor of the process that is expected to occur.	- Stolk et al. (2012).
	- A synthesis containing such tools for designing and evaluating professional development programmes such as learning theory, goals, principles and strategies.	- Stolk et al. (2011), Stolk, Bulte, de Jong, and Pilot (2009a), Stolk et al. (2009b).
Framework	Abstract construct consisting of concepts, assumptions, values and practices, and containing guidance in terms of its implementation	Tomhave (2005)
"Unspecified"	Data is needed regarding the processes, means and ways by which professional development outcomes may be attained	Hewson (2007)

Based on Table 3.3, a PDF is defined here as follows:

> *A PDF is an abstract artefact serving as a blueprint of the associated professional development process and consisting of concepts, assumptions, principles, values and practices linked to the processes, means and ways through which the desired professional development outcomes can be achieved.*

3.2.2 Systematic review in the process of creating a content-generic PDF

In the above regard, this section describes how the data was gathered and analysed. The purpose of the literature review, as reflected in Figure 3.1, was to:

1. Generate the related tentative design principles towards creating a conceptual content-generic version of the PDF. This is to support the design and implementation of inquiry-based science education.

2. Synthesise the PDF based on the design principles (SRP1a in section 1.3.3).

In reaching the above goal, the systematic literature review needed to fulfil the requirements of a systematic literature review as set out in Section 2.4.4.3. The requirements may be applied here with reference to studies in education (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012; Rutten, van Joolingen, & van der Veen, 2012; Schneider & Plasman, 2013). The purpose of the literature review has been specified above. The data collection, coding and analysis are described next.

3.2.2.1 Data collection

Included in this section are the databases searched, the search terms, in addition to the search criteria and the search results.

Databases searched. To allow for a comprehensive literature review, ten electronic databases were used here. These databases include three considered by Creswell (2014) as being among the major electronic databases for journal articles. These databases were ERIC, EBSCOhost and the Social Sciences Citation Index. In addition to the above databases, the following seven databases were also searched: Emerald Insist, Scopus, SSRN (Social Science Research Network), Springer Link, Taylor & Francis (Journals), ASSIA (Applied Social Sciences Index and Abstracts) and Web of Science Core Collection.

Search terms, criteria and results. The search terms used included terms related to the topic and the field of study, in addition to the educational level of the participants. The terms were based on prior research (e.g., Birman et al., 2000; Stolk et al., 2012; Stolk et al., 2009b) and were as follows:

"professional development framework" OR "framework for professional development" OR "designing professional development" OR "professional development process"

Several criteria were used to focus and limit the output of the searches conducted in the different databases. The criteria included the source type, document type, publication date, subject area and educational level. The implementation of these criteria for the different databases is shown in column two of Table 3.4.

Table 3.4 Databases searched, search criteria and number of articles found (Source: Researcher)

Database	Search limited to/by	Number of articles found
ASSIA (Applied Social Sciences Index and Abstracts)	- Peer reviewed. - Duplication date: 2007-2016. - Source type: Scholarly journals.	5
EBSCOhost	- All text. - Limit your results: Full text; Scholarly (Peer reviewed) Journals. - Published date: January 2007-July 2016.	7
Emerald Insight	- Only content I have access to. - Accepted articles. - Content type: Articles and chapters. - Publication date: January 2007- Jul 2016. - Keyword: Education.	6
ERIC	- Full text. - Peer reviewed. - Publication date: Jan 2007- July 2016. - Journal or document: Journal articles. - Publication type: Journal articles. - Educational level: Secondary Education. -Subject: Secondary school teachers. - Professional development.	15

Database	Search limited to/by	Number of articles found
Scopus	- Article title, abstract and keywords. - Date range (inclusive): 2007-2016. - Subject areas: Physical Science. - Document type: Article or review.	10
Social Sciences Citation Index	- Title. - Document type: Article. - Category: Education/educational research. - Publication date: 2007-2016.	2
Springer Link	- Education and language. - Sub-discipline: Science education - Content type: article.	30
SSRN (Social Science Research Network)	- Title, abstract, keywords and full text. - Date: Last three years.	14
Web of Science Core Collection	- Education Scientific disciplines. - 2007-2016. - Articles.	6
Wiley Online Library	- Article titles. - Date range: 2007-2016.	29
Total		124

As seen in Table 3.4, a total of 124 articles resulted from the literature search of the ten different databases. These articles were all peer-reviewed journal articles published during the last decade (2007 to 2016) at secondary educational level. The criterion of educational level was used to limit the search given that the conceptual content-generic PDF was a precursor to the ensuing PDF (completed product) for use by secondary school Physical Science teachers. Limiting the search results to the last decade was meant to base the conceptual content-generic PDF on more recent research in education. Conversely, limiting the search results to peer-reviewed journal articles contributed to providing data of superior quality for designing the conceptual content-generic PDF.

Based on the above search terms and criteria, different numbers of peer reviewed journal articles were found in the various databases searched. The distribution of the articles across the different databases is shown in the third column of Table 3.4.

Screening for inclusion or exclusion. The screening of the peer-reviewed journal articles was meant to ensure that each article further considered in this literature review met certain minimum criteria. This process is outlined in Figure 3.2, beginning with the total number of peer reviewed articles that were found from searching the different databases.

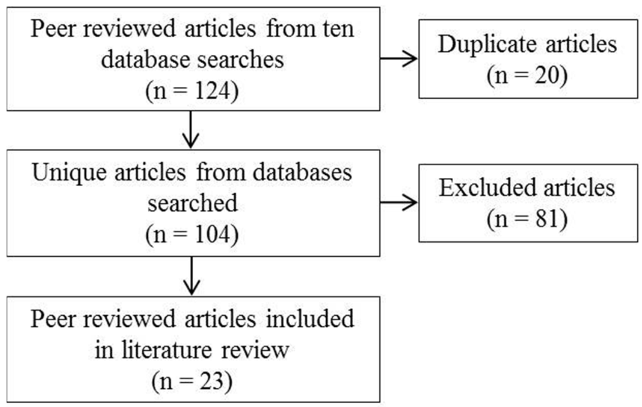


Figure 3.2 Process of finding articles on designing teacher professional development (Source: Researcher)

The screening criteria used on the 104 unique articles here consisted of the discipline, the educational level, the definition given for PDF in these journal articles, the type and number of research methods/instruments used and the quality of the article.

Regarding discipline, only articles in which science teachers were included among the participants were included. The educational level considered was limited to secondary schools. The papers were also checked in relation to whether they focused on PDF as understood in this study (Section 3.2.1.3). Furthermore, the search results were screened in relation to whether subjective judgment, such as feedback questionnaires, was the only instrument used in the data collection. In relation to the overall quality of the journal articles, the registration of the journal in the Thomson Reuters Web of Science Core Collection (2016) database was used in line with Rutten et al. (2012). The articles from journals not included in this database were excluded.

It is in the above manner that the 23 peer review articles used in the literature in this section were selected. The articles comprised 19 empirical studies and four literature review articles. All of the articles were peer reviewed articles from the Thomson Reuters Web of Science Core Collection (2016) database of journals. Thus, these articles were assumed to provide data of good quality.

3.2.2.2 Coding

The included articles were coded in relation to the participants in the research presented, the publication date, the method (s) of data collection employed and the location of the study. This last aspect was based on the institutional affiliation of the first author of the article. The coding of the articles allowed their distribution along the different dimensions that were determined. These distributions provided information on the nature of the dataset on which the tentative design principles and the associated conceptual content-generic PDF were based.

Distribution of articles in terms of disciplinary area studied. In this regard, some of the articles involved teachers of a single disciplinary area (e.g., Stolk et al., 2012) or multiple disciplinary areas (e.g., Hennessy & Deaney, 2009; Ostermeier et al., 2010). Figure 3.3 shows the percentage of the articles per disciplinary area for the participating teachers.

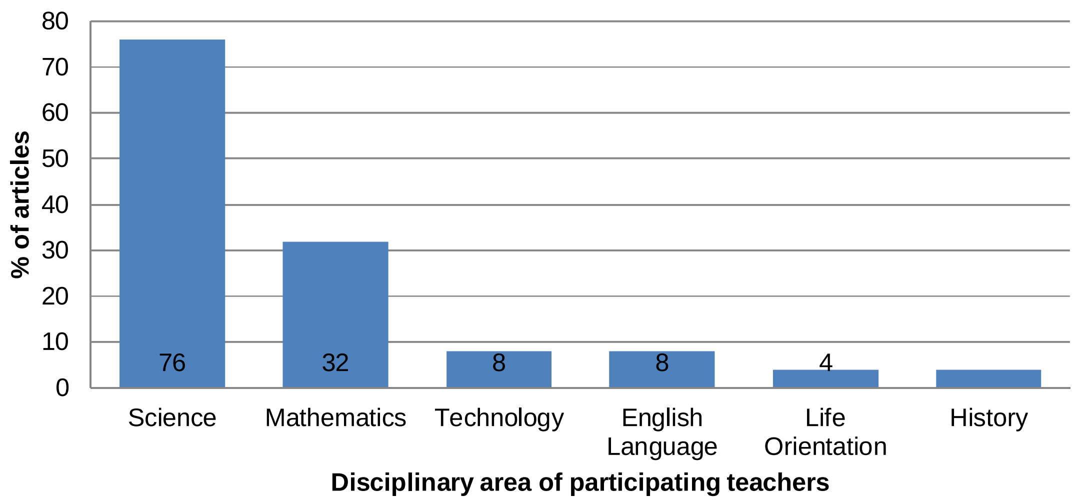


Figure 3.3 Disciplinary area of the participants in the included articles (Source: Researcher)

The science teachers referred to in Figure 3.3 were biology, chemistry and physics teachers. The figure shows that the majority of the included articles (84%) had science teachers as the only participants or in combination with participants from other disciplinary areas. This is a reflection of the limiting criteria applied in searching some of the databases used (such as subject areas: Physical Science; sub-discipline: science education). That said, the fact that the majority of the included articles had science teachers as participants was useful in the design of a conceptual content-generic PDF which evolved into a PDF to help Physical Science teachers.

Distribution of articles in relation to location of study. The distribution of the included articles regarding the location of the study presented is shown in Table 3.4.

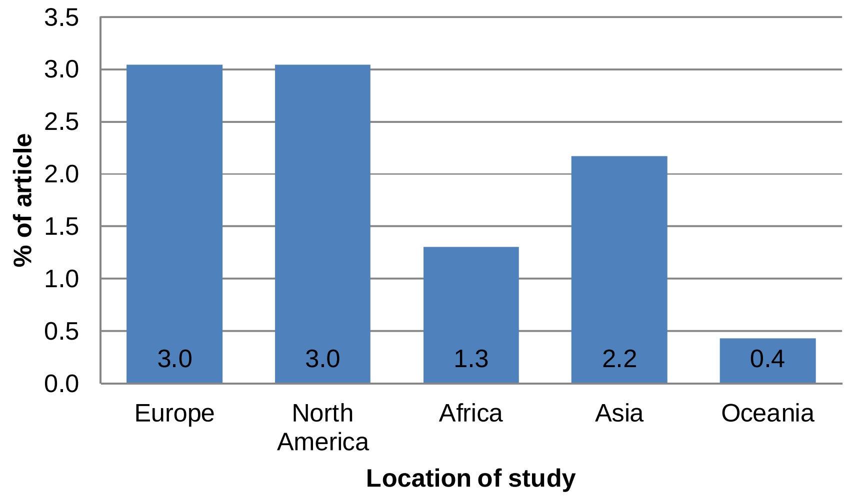


Figure 3.4 Study location for included articles (Source: Researcher)

Figure 3.4 shows that the included articles came from studies carried out on five different continents. The included peer reviewed articles thus constituted an international database. This was useful in generating the tentative design principles and then synthesising the associated conceptual content-generic PDF.

Distribution of articles per year of publication. The included articles varied widely between the publication dates 2007 to 2015, as seen in Figure 3.5.

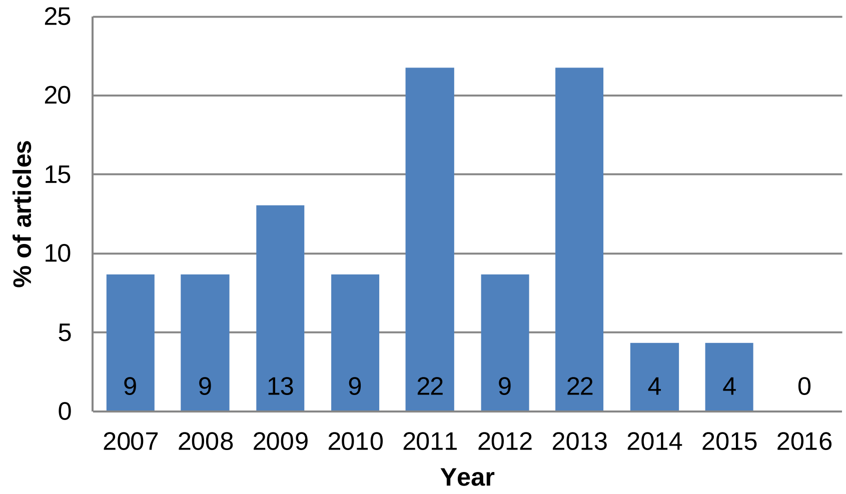


Figure 3.5 Publication dates for included articles (Source: Researcher)

While no article from 2016 was included, the database of included articles spanned across nine years, as seen in Figure 3.5. It can be determined from the figure that the majority (61%) of the included articles lie from the middle to the upper end of this period. Thus, there is still considerable interest in the educational research community regarding the designing of teacher professional development.

Distribution of articles in relation to data collection methods. This is shown in Figure 3.6, which shows the percentage of peer reviewed articles in which the given data collection methods were used in combination with one or more data collection methods, for example, 33% of the articles employed a survey as one of at least used data collection methods. This is line with the criteria used in screening articles for inclusion in the literature review.

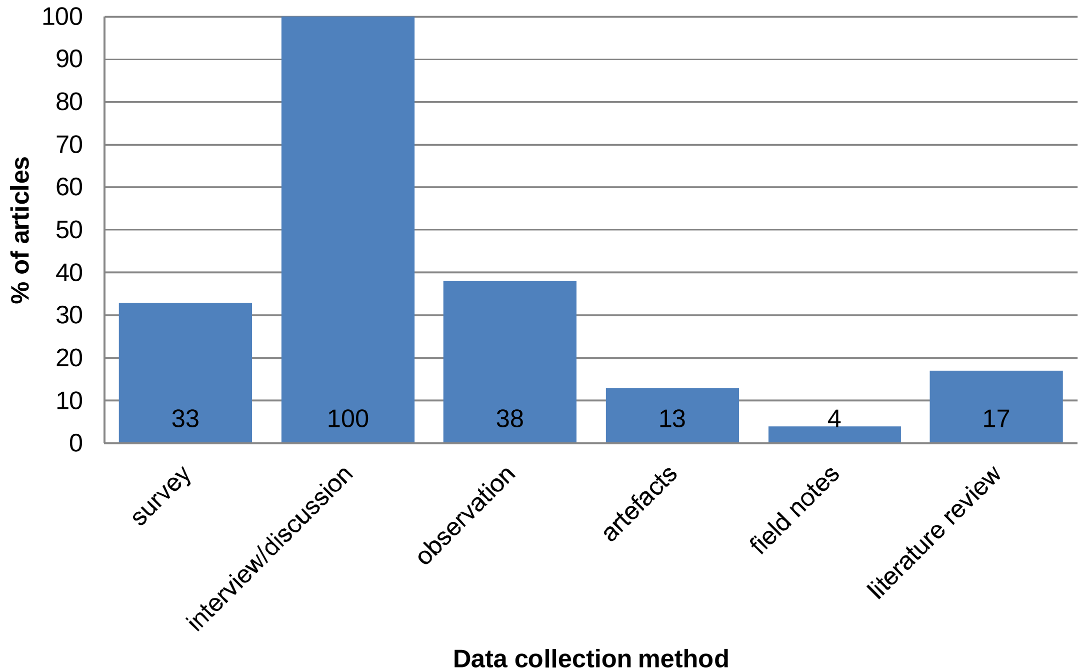


Figure 3.6 Data collection methods used in included articles (Source: Researcher)

Figure 3.6 shows that a range of data collection methods was used in the included articles.

Distribution of articles across different journals. As noted earlier, only peer reviewed articles from journals in the Web of Science database (2016) were included. The journals and the respective number of articles included are shown in Table 3.5.

Table 3.5 Articles included per Web of Science Core Collection (2016) database of journals (Source: Researcher)

Journal	Number of articles
International Journal of Science and Mathematics Education	7
Journal of Science Education and Technology	4
International Journal of Science Education	3
Research in Science Education	2
Chemistry Education Research and Practice	1
International Journal of Technology and Design Education	1
Journal of Biological Education	1
Journal of Research in Science Teaching	1
Physical Review Special Topics - Physics Education Research	1
Review of Educational Research	1
Teachers and Teaching	1
Total	23

Based on Table 3.5, we see that the included peer reviewed articles came from eleven different Web of Science Core Collection (2016) database journals. Prominent among the journals was the International Journal of Science and Mathematics Education with seven articles. This is in line with Figure 3.3, which shows that the majority of the included articles had science and mathematics teachers as participants.

The coding of the included articles in relation to the data collection methods, publication dates, location of study and participants revealed the nature of the data on which the conceptual content-generic PDF and the tentative design principles were based. This consists of data on the professional development of mostly science teachers, which accumulated internationally for almost a decade (2007-2015). The data was gathered using more than one data collection method and collectively included a wide range of data collection methods.

Data extraction, synthesis and writing. The definition of a PDF, as formulated above (Section 3.2.1.3), provided direction regarding the data to be extracted from the thus coded 23 peer reviewed journal articles included in this literature review. It is however worth noting that unlike Tomhave (2005), authors do not always define or distinguish between the terms ‘model’ and ‘framework’. Alternatively, some studies combined the two constructs (artefacts). An example is Stolk et al. (2011), who used a PDF consisting of a model of teacher professional development. Thus, it was necessary during the data collection to also consider whether what was identified in the literature as a professional development model matched the definition of a PDF used here. Where this was the case (e.g., Chikasanda, Otrel-Cass, Williams, & Jones, 2013), the professional development model was considered here as a PDF.

On the above basis, each of the included articles was read in detail allowing data in line with the definition for PDF to be summarised on an article-by-article basis. With the data thus extracted, the method of constant comparison (Glaser & Strauss, 1967; Strauss & Corbin, 1990) was useful in synthesising the data. In this light, each PDF concept in the article-based summaries was coded as a category. The codes were then compared across the different article-based summaries to find commonalities and differences in the PDF concepts. This sense-making process involved reading and re-reading both the full articles and their summaries (Ward, 2016).

Having discussed the data extraction and synthesis, it remains to note that the ‘writing’ of the results of this systematic literature review is contained in the next and third phase of this first design research cycle. Alongside the ‘writing’ of the results, tentative design principles were formulated and then used to design the conceptual content-generic version of the PDF. Regarding the formulation of the principles, the following general format discussed in Section 2.4.3.1 is useful:

If you want to design <intervention X> for the <purpose/function Y> in <context Z>, then you are best advised to give <that intervention> the <characteristics A, B, and C> because of <arguments P, Q, and R>.

However, in this research cycle, X, Y and Z remained unchanged for each design principle. The design principles all read as follows:

In order to design a conceptual content-generic PDF useful in any educational setting to support the design and implementation of inquiry-based science education, it is "best advised to give <that intervention> the<characteristics A, B, and C>, because of <arguments P, Q, and R>".

If the part of the design principle containing X, Y and Z and the italicised script above are assumed, then the design principles may be stated simply in relation to A, B, C, P, Q and R as follows:

> Give the PDF the <characteristics A, B, and C>, because of <arguments P, Q, and R>.

3.3 DESIGN/DEVELOPMENT PROTOTYPE PHASE 1

Results of the systematic literature review described above are presented in this phase. The results consist of the components of a PDF that were identified and specified. However, also included here are the associated tentative design principles. The principles have been generated on a just-in-time basis as the results are presented. The generation of these principles allowed the conceptual content-generic version (design proposal) of the PDF to be designed. The PDF for use in any educational setting in supporting the design and implementation of inquiry-based science education is also embedded in the results. Thus, with the exception of the design principles and the PDF, this phase of the current research consist of results of the systematic literature review described above.

3.3.1 Components of a professional development framework

The literature review identified components of a PDF in the work of a Dutch educational design research group (Stolk et al., 2012; Stolk et al., 2009a, 2009b; Stolk et al., 2011). Through a number of design research cycles, the group developed a PDF to support the design of an innovative context-based chemistry curriculum. Based on the work of this group, the components of a PDF consist of:

- Professional development goals;
- Learning phases;
- Learning theory;

- Strategies;
- Instructional functions; and
- Teacher motivation.

The above components were found in different combinations in certain articles included in this literature review (e.g., Chikasanda et al., 2013; Elster, 2009; Visser et al., 2013). These were the tentative components of the conceptual content-generic version of the PDF being developed.

3.3.1.1 Professional development goal

The professional development goals available in the literature were useful in informing the formulation of a professional development goal for the content-generic PDF. Some of the goals are contained in Table 3.6 below.

Table 3.6 Some professional development goals

	Goal	Source
1.	To improve teachers' knowledge of mathematics, to enhance understanding of how students learn mathematics and to enhance understanding of how to represent mathematical concepts.	Higgins and Parsons (2011).
2.	To improve classroom instruction in mathematics and science in order to enhance student learning and understanding, in addition to motivation and interest in those domains.	Ostermeier et al. (2010).
3.	To change the knowledge, beliefs, attitudes and practices of science teachers so as to improve the results of their students.	Bell and Gilbert (1996), Fishman, Marx, Best, and Tal (2003), Loucks-Horsley, Love, Hewson, et al. (2003).
4.	To use an inquiry-based strategy in the classroom as a means of enabling learners to advance their understanding of scientific concepts and the nature of science.	Ramnarain and Modiba (2013).
5.	To support teachers in enhancing their abilities and their implementation of the tasks and units that they develop in	Elster (2009).

accordance with the principles of context-based science education.

Except for Goal 1, the rest of the goals in Table 3.6 were applicable to the professional development process for which the conceptual content-generic PDF was being designed. In line with these goals, and also the purpose of the current design research cycle (Section 3.2.1), the following tentative design principle was generated:

> *Design Principle #1.1:* Aim the PDF to enhance the related knowledge, attitudes, beliefs and practices of teachers as this is a goal in effective teacher learning.
>
> (Elster, 2009; Fishman, Marx, Best& Tal, 2003; Loucks-Horsley, Love, Hewson, Stiles & Mundry, 2003; Rozenszajn & Yarden, 2014).

3.3.1.2 Theory of teacher learning

Learning theories provide a description of the learning process (Stolk et al., 2011). Thus, contemporary learning theories (perspectives) are discussed here in relation to the PDF. Contemporary perspectives on learning consist of the participatory perspective, the sociocultural perspective, and the cognitive perspective (Scott, Asoko, & Leach, 2007).

In terms of the cognitive perspective, learning was first considered as the development of conceptual understanding through assimilation, accommodation and equilibration (Stolk et al., 2009b). A new concept may be integrated into the structure of existing concepts without changing the structure (assimilation), whereas accommodation involves a change in the structure in order to allow for the incorporation of the new concept (Kitchener, 1992; Piaget, 1952). Constant balancing between accommodation and assimilation, called equilibration, is needed for conceptual change. Subsequently, the cognitive learning perspective has been extended and further developed with the inclusion of conditions for conceptual development and the influence of existing concepts (Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1992). Based on the cognitive perspective, learning also involves the active construction of knowledge (Stolk et al., 2009b). Thus, teachers can no longer adhere to their traditional role of transmitting knowledge. Conversely, if teachers are assumed to learn essentially in the same way as their learners, then teachers also need to construct their own knowledge. Thus, teacher learning needs to be facilitated through the creation of favourable learning environments in which teachers direct their own learning (Loucks-Horsley, Love, Hewson, et al., 2003; Peers, Diezmann, & Waters, 2003).

Originating in the work of Vygotsky, the sociocultural perspective on learning has been elaborated further by Galperin, for example (Arievitch & Haenen, 2005; Vygotsky, 1978). This perspective assumes that learning cannot be separated from interpersonal interactions within cultural frameworks (Cole, 1996; Lave & Wenger, 1991b). This learning perspective can be applied to teachers by regarding them as learners. A child (learner) learns the habits of mind of her/his culture, including written language and speech patterns through social interactions. This process, known as internalisation, also involves appropriation in which a child takes a tool and makes it his own. In this process, he or she follows the example of an adult in gradually developing the ability to carry out certain actions in the absence of assistance or help. The gap between what the child can do without guidance and that which the child can do with help is called the zone of proximal development (Vygotsky, 1978). In essence, learning is a social process in which the interactions between individuals serve as a means for learning (Wertsch, del Rio, & Alvarez, 1995). The sociocultural perspective is often implemented in teacher professional development (Chikasanda et al., 2013; El-Deghaidy, Mansour, & Alshamrani, 2015; Stolk et al., 2011).

Based on the participatory perspective (also known as situated cognition), learning is considered as the process of participating in socially-organised practices (Brown, Collins, & Durguid, 1989). In this case, learners gain knowledge and develop skills through legitimate peripheral participation (Lave & Wenger, 1991a) or cognitive apprenticeship (Rogoff, 1990). During learning, the responsibility of the learner as part of a community of practice grows from a peripheral to a more central position. In the case of teachers, the acquired knowledge is context-bound and, together with the associated practices, is difficult to change. Thus, it is useful to situate teacher learning in multiple learning settings in which teachers play an important role

(Putnam & Borko, 2000). The situated cognition perspective is often implemented in projects and studies (Chinn, 2007; Elster, 2009; Ostermeier et al., 2010; Yerushalmi & Eylon, 2013).

The participatory (situated cognition), sociocultural and cognitive learning perspectives may be viewed as complementary rather than exclusive (Scott et al., 2007). In terms of considering the above perspective in this regard, it is useful to bear in mind the purpose of this research cycle. The purpose was to design a conceptual content-generic PDF to support the design and implementation of inquiry-based science education. In many other countries, inquiry-based teaching is new to most science teachers (Capps & Crawford, 2013a; Kapanadze & Eilks, 2014; Kim & Chin, 2011; Onwu & Stoffels, 2005). Thus, from the cognitive perspective, designing and implementing inquiry-based science education is an activity that can bring about equilibration. This can also lead a teacher to become dissatisfied with traditional science education and gain awareness regarding the fruitfulness of inquiry-based science education (Stolk et al., 2009b). In terms of the socio-cultural perspective, the design and implementation of inquiry-based science education is in teachers' zone of proximal development. Based on the participatory (situated cognitive) perspective, a teacher needs the guidance of experts in order to gradually develop the capability to design and implement instructional innovations.

Professional development programmes and PDFs are commonly based on a single learning perspective. However, there is no perspective for learning that can objectively be considered as the best perspective (Stolk et al., 2009b). Data from the present literature review, and also the principles for designing effective teacher learning (Table 3.2), were useful in selecting a learning perspective for use in the PDF. The principles for designing effective professional development include the use of active learning and methods similar to those needed in the classroom. In this case, this method was inquiry-based science teaching and learning. Inquiry-based teaching and learning is consistent with the popularly held view that learning involves both individual and social construction of knowledge (e.g., Minstrell & Van Zee, 2000; Vygotsky, 1978). As also noted in Section 3.2.1.2, the effective professional development of teachers requires collective participation in professional learning communities. Such communities can act as a strong mechanism for their growth and development (e.g., Little, 2002; Stein, Smith, & Silver, 1999). Professional learning communities are aligned with the sociocultural learning perspective (Grossman, Wineburg, & Woolworth, 2001). However, as seen above, there are also professional learning communities based on situated cognition (Chinn, 2007; Elster, 2009; Ostermeier et al., 2010; Yerushalmi & Eylon, 2013). In seven of 23 peer reviewed articles included in this literature review, the learning perspective used was identified. This is summarised in Table 3.7.

Table 3.7 Learning perspectives in included articles (Source: Researcher)

Perspective	Number of articles	Articles
Cognitive perspective	0	"None"
Sociocultural perspective	3	Chikasanda, Otrel-Cass, Williams and Jones (2013), El-Deghaidy, Mansour and Alshamrani (2015), Stolk et al. (2011).
Participatory (Situated cognition)	4	Chinn, (2007), Elster, (2009), Ostermeier et al., (2010), Yerushalmi and Eylon (2013).

Table 3.7 is in support of the following tentative design principle:

Design Principle #2.1: Using a sociocultural or a situated learning perspective is recommended as the learning perspective for the PDF in order to allow for collective participation in professional learning communities.

(El-Deghaidy, Mansour & Alshamrani, 2015; Marx & Harris, 2006; National Science Teachers Association, 2006; Ostermeier et al., 2010).

3.3.1.3 Phases of professional development

Many professional development processes occur in distinct phases. Some of these phases and their use are contained in Table 3.8. Based on the table, a set of common phases in professional development frameworks may be identified.

Table 3.8 Some phases of professional development in the literature (Source: Researcher)

Phases	Source/Used in
• Reflection on practice (e.g. experiences, needs and goals); • Design and classroom implementation of new teaching and learning materials; • Assessment and reflection; • Reporting and dissemination.	Rozenszajn and Yarden (2014).
Cyclical action research process involving: • Planning; • Implementation; • Observation; and • Reflection.	Gilbert and Newberry (2004); Mamlok-Naaman, Navon, Carmeli, and Hofstein (2003); Mamlok-Naaman and Eilks (2012).
• Base line data collection; • Exploration and planning; • Implementation and on-going reflection; • Final reflection.	Chikasanda et al. (2013).
Teaching strand: • Creating conditions for empowerment (motivating teachers and providing learning goals); • Orientation (exchange of views on context-based education and given context-based unit, discuss implementation); • Application (teachers' implementation unit in own classrooms). • Reflection (on teaching and learning experiences, creating a product and evaluating learning) *Designing strand:* • Creating conditions for empowerment (motivating teachers and providing learning goals);	Stolk et al. (2012), Arievitch and Haenen (2005).

Phases	Source/Used in
• Orientation (exchange of views on designing context-based lesson unit and views on designing one such a unit; showing how to design unit, discuss implementation); • Application (implementation of unit in the classroom); • Reflection (upon design and learning experiences, create product and evaluate learning results).	
Teaching strand: • Motivation and orientation (towards teaching pre-developed lesson unit); • Application (teaching unit in own classroom); • Reflection (sharing and discussion of experiences). *Designing strand:* • Motivation and orientation (towards designing new unit); • Application (designing new unit); • Reflection (sharing and discussion design).	Stolk et al. (2011)
• Presentation of the research literature; • Constructivist activities (designed to expose existing beliefs and conflicts with the literature); • Development of instruction and materials; • Implementation; • Reflection.	Yerushalmi and Eylon (2013).
• Before teaching the module (Individual preparation and Preparation seminar); • During teaching (Online support); • After teaching module (Reflection meeting).	Visser et al. (2013), Visser, Coenders, Terlouw, and Pieters (2010).
• Conceptual work (linked to standards); • Concrete development of tasks/materials; • Testing in the classroom; • Exchange of experiences/Reflection on preceding phases.	Elster (2009).

Four major phases in PDFs can be identified from Table 3.8. These are: the pre-participation phase, exploration/planning phase, implementation phase and post-implementation phase. The components of each of these phases are listed and briefly discussed below.

Pre-participation phase

Some components of this phase in Table 3.8 include (e.g. Chikasanda et al., 2013; Visser et al., 2013):

- Individual preparation; and
- Baseline data collection.

Baseline data may be used in determining the effectiveness of a professional development programme. Also, such data can be used in designing professional development that meets the needs of science teachers in the context in which they work (Mansour, EL-Deghaidy, Alshamrani, & Aldahmash, 2014). For this purpose, the data is part of a needs assessment.

Exploration/planning phase

The elements of this phase from Table 3.8 include (e.g. Chikasanda et al., 2013; Elster, 2009; Rozenszajn & Yarden, 2014):

- Conceptual work (linked to standards);
- Reflection on practice (e.g. experiences, needs and goals);
- Presentation of the research literature;
- Constructivist activities (designed to expose existing beliefs and conflicts with the literature);
- Orientation (exchanging views on pre-developed unit, discussing implementation); and
- Development of instruction (including tasks and materials).

Implementation phase

In Table 3.8, the following components of this phase of professional development were identified (e.g. Stolk et al., 2012; Mamlok-Naaman &Eilks; 2012; Yerushalmi &Eylon, 2013):

- Implementation of new teaching and learning materials in own classroom;
- Observation;
- On-going reflection; and
- Online support (during teaching).

Post-implementation phase

Based on Table 3.8, the following components of this phase were identified (e.g. Visser et al., 2013; Yerushalmi &Eylon, 2013; Rozenszajn & Yarden, 2014):

- Assessment and reflection (sharing and discussion of experiences);
- Reflection (on teaching and learning experiences, creating a product and evaluating learning) (teaching strand);
- Reflection (upon design and learning experiences, create product and evaluate learning results) (designing strand); and
- Reporting and dissemination.

The above major phases of professional development were inductively generated in this literature review. However, the phases were used in professional development programmes, not in the research initially included here. The programmes included one on technology integration, as discussed by Wells (2007). This programme (Trek 21 Project) has been successful in bringing lasting change to teachers' classroom practices (Mitchem, Wells, & Wells, 2003). The second programme is the Iowa Chautauqua Programme (ICP), which is a cyclical professional development process that emerged as an exemplary model of professional development (Dass & Yager, 2009). These programmes contained a pre-participation phase, Summer Institute (planning phase), as well as an implementation and post-implementation (evaluation) phase.

Based on the above discussion, the following tentative design principle was generated:

> *Design Principle #3.1:* Incorporate a pre-participation phase, an exploration/planning phase, an implementation phase and a post-implementation phase into the PDF with reference to studies on effective teacher learning.
>
> (Chikasanda et al., 2013; Mansour, EL-Deghaidy, Alshamrani & Aldahmash, 2014; Rozenszajn & Yarden, 2014; Yerushalmi & Eylon, 2013)

3.3.1.4 Professional development strategies

The term strategy refers to the sequence in which the activities in a programme are planned or implemented (McKenney et al., 2006; Reigeluth, 1999). A strategy can be a combination of strategies and can be as important in teacher learning as in classroom learning. In order to be effective in planning and teaching, it is essential for teachers to be clear regarding the means (strategy) by which intended leaning goals may be attained (Hodson, 2014; Jordan, Ruibal-Villasenor, Hmelo-Silver, & Etkina, 2011). Here, strategy is considered to have a similar role to play in relation to the designing of teacher learning. Examples of professional development strategies used in a continuous professional development context are provided in Table 3.9.

Table 3.9 Continuous professional development strategies (Source: Researcher)

Strategy	Source/Used in
Action research (occurs in different forms).	Bencze and Hodson (1999), Eilks and Ralle (2002).
Content focused coaching.	Staub, West, and Bickel (2003).
Teachers' learning communities.[a]	Putnam and Borko (2000), Elster (2009), Stolk et al. (2012), Klieger and Bar-Yossef (2011).
Knowledge-creating schools.	McIntyre (2005).
• Teaching an exemplary, pre-developed	Davis and Krajcik (2005), Deketelaere

Strategy	Source/Used in
context-based unit; • Designing an outline of a new context-based unit; • Interacting with colleagues and curriculum leader .[b]	and Kelchtermans (1996), Parchmann, Gräsel, Baer, Nentwig, Demuth, and Ralle (2006), Stolk et al. (2012).
• Teacher collaboration; • Reflection on action; • Educative innovative units and curriculum development.	Carl (2009), Deketelaere and Kelchtermans (1996), Loucks-Horsley, Love, Hewson, et al. (2003), Davis and Krajcik (2005), Hawley and Valli (1999).
Reflection on practice	Gerard, Spitulnik, and Linn (2010), Yerushalmi and Eylon (2013).
• Providing access to innovative units; • Organising reflection on practical experiences; • Stimulating collaboration with peers; • Organising teachers in designing new units	Ball and Cohen (1996), Davis and Krajcik (2005), Stolk et al. (2009a), Stolk et al. (2009b)

[a] Involving teachers and science education researchers/teacher educators, subject experts.
[b] Experienced chemistry teacher.

Most of the professional development strategies in Table 3.9 are useful only in specific phases of a professional development process that is aligned with *Design Principle #3.1* above. These strategies include reflection on practice and designing an outline of a new context-based unit (exploration/planning phase) in addition to reflection on action or organising reflection on practical experiences (post-implementation phase).

Table 3.9, however, does not contain strategies specific to the pre-participation and implementation phases of continuous (effective) teacher professional development. Considering *Design Principle #2.1* and *#3.1* above, an adequately elaborate, and not a content-focused strategy like content focused coaching, is needed for a PDF. The strategy needs to consist of or allow for the use of a combination of strategies in order to fulfil the different phases of an effective professional development process. Examples of such strategies contained in Table

3.9 comprise action research and teachers' learning communities. However, this literature review did not yield a description of teachers' learning communities and action research, in addition to models for implementing either strategy in the design and implementation of inquiry-based science lessons. For this purpose, additional literature has been used in the rest of this section.

Action research (also discussed in Section 2.4.1), is a strategy that can be used in any setting and provides a method for solving a problem, empowering participants or improving a process (Burian et al., 2010). Teachers' learning communities are examples of professional learning communities. The term professional learning community has shades of interpretation in different contexts. However, there appears to be broad consensus that the community consists of a group of people (in this case teachers) sharing and critically interrogating their practice in an ongoing, reflective, collaborative, inclusive, learning-orientated and growth-promoting manner (Toole & Louis, 2002). In terms of developing teachers' learning communities, lesson study can be used as a vehicule (Lieberman, 2009) as is normally the case in Japan (Doig & Groves, 2011). This powerful professional development strategy (Department for Children Schools and Families, 2008), has been introduced in South Africa (Ono & Ferreira, 2010). In China the enhancement of teaching and learning has traditionally been achieved through school-based learning communities called Teaching Research Groups (Yang, 2009). However, this professional development strategy involves activities that are identical to or closely reflect those involved in lesson study (Doig & Groves, 2011). On the other hand, lesson study has parallels with action research based on which teachers work collaboratively to develop their practice (Revans, 1982). In fact, lesson study can be considered as a type of action research (Lewis, 2002a). Thus, lesson study can be used here as the implementation model of a teachers' learning community engaged in action research. This is in the design and implementation of inquiry-based science lessons.

A lesson study brings teachers together to deliberate on lessons that they have designed collaboratively and observed in the classroom (Lewis, Perry, Hurd, & O Connell, 2006; Perry & Lewis, 2009). Generally, lesson study is a low-cost professional development strategy (Gaible & Burns, 2005). Thus, lesson study may be used in resource-rich and less-resource-rich contexts. Against the above background, the following tentative design principle may be generated:

> *Design Principle #4.1:* Adopt lesson study as the professional development strategy in the PDF given, for example, that lesson study is usable across different socio-economic contexts, involves active learning in a professional learning community, and is aligned to core features of effective teacher learning.
>
> (Desimone, Porter, Garet, Yoon & Birman, 2002; Gaible & Burns, 2005; Lewis et al., 2006; Perry & Lewis, 2009).

As the professional development strategy for the conceptual content-generic PDF, it is useful to discuss lesson study in more detail. This includes what lesson study involves, its possible effect on participants, the number of participants it may involve, and the role of external expertise. Also included are lesson study variants, and the phases of lesson study. This last aspect can be seen to inform *Design Principle #3.1* above.

What lesson study involves. Lesson study has been described as a professional development strategy that combines on-going and collaborative teacher learning, as well as curriculum renewal with particular reference to classroom teaching (Fernandez & Yoshida, 2004; Ono & Ferreira, 2010). A relatively more informative description of the lesson study process is provided by Lewis (2002b) as an instructional improvement process in which teachers collaboratively:

- Formulate goals for student learning and long-term development;
- Collaboratively plan a ‘‘research lesson’’ in order to bring to life the goals;
- Carry out the lesson in the classroom, with one member of the group teaching and other members gathering evidence on student learning and development;
- Discuss and reflect on the evidence gathered in classroom, using it to enhance the lesson, the unit, and instruction in general; and if desired,
- Teach, observe, and improve the ‘‘research lesson’’ again in one or more other classrooms.

Lesson study is a cyclical professional development strategy, as evidenced by the above description and the illustration of the lesson study process in Figure 3.7.

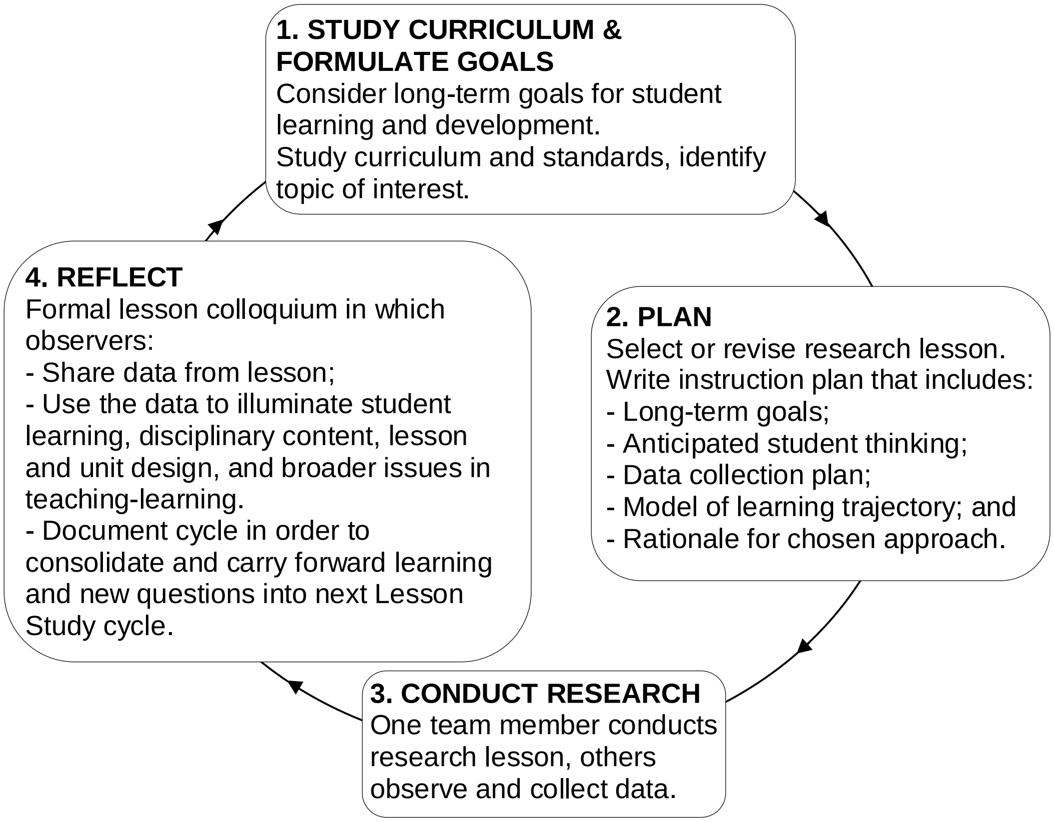


Figure 3.7 Lesson study cycle (Source: Lewis, Perry, & Murata, 2006)

Significance of lesson study. This strategy embodies many of the features of high quality professional development such as active learning about content. Moreover, it is driven by data and goals and is sustained, intensive, collaborative, and practice-based (e.g., Hiebert, Gallimore, & Stigler, 2002; Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003; National Research Council, 2001). Furthermore, the lesson study strategy enables teachers to collaborate with their peers during their activities, making teacher learning most likely to carry over into classroom practice (Fernandez, 2002; Glazer, Hannafin, Polly, & Rich, 2009; Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2009). The optimal lesson study group size is probably about four to six teachers (Lewis & Hurd, 2011). That said, and referring to Lewis and Tsuchida (1997), Fernandez (2002, p. 395) notes that, “Key educational innovations and improvements have been linked to lesson study.” An example of this is the transformation of the traditional science lessons of the 1950s to the inquiry-based science lessons of today.

Enriching lesson study. For this purpose, an outside advisor is commonly included (Fernandez, 2002). The advisor, with strong subject matter and pedagogical knowledge (in this case technological knowledge as well), is invited to key meetings to observe and comment on lessons planned by the lesson study group. Advisors often facilitate the access of the group to theoretical information or research findings. While the role of an advisor is typically played by "instructional superintendents" assigned to schools (Fernandez, 2002) and university professors, they could be district curriculum specialists or specialists from a regional education agency (Richardson, 2004).

Phases of lesson study. Figure 3.7 denotes the lesson study phases. In a similar light, Richardson (2004) discusses seven phases consisting of forming a lesson study group, focusing the lesson study, planning the study lesson, planning lesson observation, teaching and observing the study lesson, debriefing the lesson in addition to reflecting and planning the next steps. With the exception of the first, these phases of lesson study are in line with those considered by Lewis, Perry, and Murata (2006). The phases are: goal setting, planning, implementing and reflecting. A separate phase of the lesson study process considered by Fernandez (2002) is writing a lesson study report. Based on the above three sources, the lesson study process consists of six phases, which are as follows: 1) Forming a lesson study group, 2) Focusing the lesson study, 3) Planning a study lesson and its observation, 4) Teaching and observing a study lesson, 5) Debriefing, reflecting and deciding on the next steps, and 6) Writing a lesson study report. These lesson study phases are described in Table 3.10.

Table 3.10 Description of lesson study phases (Source: Lewis, 2002b; Lewis, Perry, et al., 2006b; Richardson, 2004)

Phase of lesson study	Description
1. Forming a lesson study group	Recruitment of teachers: • Interested in lesson study concept; and • Working with a similar group of learners; or • Working on a similar topic.

Phase of lesson study	Description
	A group includes: • A teacher or outside person as facilitator; and • A 'knowledgeable other' or outside advisor.
2. Focusing a lesson study	• Group selects a unit or lesson based on curriculum and topics learners find difficult; • Discuss links to other topics in present and future grades; and • Agree on long-term learner (and teacher) learning goals.
3. Planning a study lesson and its observation	• Participants share and discuss existing lessons on a topic of interest; • Build on best available existing lessons, map out unit; • Plan in detail one 'research lesson'; • Try out the lesson at group level; • Anticipate learner thinking and response; • Identify data on learner learning/motivation and behaviour to collect in the classroom; • Set ground rules for observation; and • Select classroom and teachers to present study lesson.
4. Teaching and observing a lesson	• One member teaches the lesson; and • Other teachers collect data, as planned.
5. Debriefing, reflecting and deciding on the next steps	• Preferably done face-to-face (rather than online) and on the same day as the observed lesson; • The teacher who presented the lesson speaks first, followed by planning group members, observers and advisor; • Discussion focuses on data collected, not the teacher; and • The group decides on: - What went well, - Whether to revise/refine and re-teach the lesson in another classroom, and - Issues/problems to address in the next research lesson cycle.
6. Writing a lesson study	• This is done periodically; and

Phase of lesson study	Description
report	• Consists of a record of the work carried out and insights gained.

The lesson study phases described in Table 3.10 can be considered as secondary phases of professional development. This can be seen by comparing the description of the different phases of lesson study in Table 3.10 and the discussion of the different phases of professional development (Section 3.3.1.3). Based on the above reflection, *Design Principle #3.1* may be revised as follows:

> *Design Principle #5.1:* Incorporate lesson study phases into the PDF under related major phases of professional development (pre-participation, exploration and planning, implementation and post-implementation) in order to provide a sequence for planning professional development activities within these major professional development phases.
>
> (McKenney et al., 2006; Reigeluth, 1999).

This design principle may be implemented as shown in Table 3.11.

Table 3.11 Fusing profession development (PD) [a] phases and lesson study [b] phases (Source: Researcher)

Primary PD phase	Lesson study phase incorporated.
Pre-participation	Forming lesson study group.
Exploration/Planning	Focusing the lesson study.
	Planning a study lesson and its observation.
Implementation	Teaching and observing lesson.
Post-implementation	Debriefing, reflecting and deciding next steps [c]
	Writing a lesson study report.

[a] (Fernandez, 2002; Chikasanda et al., 2013, Lewis et al., 2006b; Richardson, 2004; Mansour, EL-Deghaidy, Alshamrani, & Aldahmash, 2014; Rozenszajn & Yarden, 2014).

[b] (Lewis, 2002b; Lewis et al., 2006b; Richardson, 2004).

[c] Whether to revise/refine and re-teach the lesson in another classroom.

3.3.1.5 Instructional functions

Instructional functions are general operations or measures that are implemented in order to complete the phases of a learning programme (Mettes, Pilot, & Roossink, 1981). In addition, instructional functions serve as a transition between the phases and the activities of the learning programme. However, instructional functions not only provide guidelines for designing and planning the activities of a professional development programme, but also render these activities more effective and transparent (Terlouw, 2001). It may be worth noting that although instructional functions inform the activities of a professional development programme, these activities are rather part of the professional development programme and not the PDF from which the programme is derived (Stolk et al., 2012). Rosenshine and Stevens (1986) provides a list of instructional functions in a classroom context. These are summarised as follows:

- Reviewing prior learning;
- Presenting new skills and content, providing objectives, overviews, and checking for understanding;
- Guiding student practice, checking for understanding and giving additional explanations;
- Providing feedback and correctives;
- Giving independent student practice, alerting students that homework will be checked, and actively supervising their work; and
- Systematically and periodically reviewing previously learned material, and giving frequent tests.

Amongst the instructional functions considered here as also applicable to teacher learning are the following instructions: reviewing relevant prior learning; providing overviews and learning goals; allowing for active participation; and providing opportunities for practice. Also included is the provision of guidance and feedback in addition to reviewing learning periodically. If we assume that classroom and teacher learning are similar, then the above instructional functions are applicable to later learning. Against this background, the following characteristic of the conceptual PDF was generated:

Design Principle #6.1: Include instructional functions (such as reviewing relevant prior learning, providing overviews and learning goals, providing guidance and feedback, and reviewing learning periodically) in the PDF so that professional development can be more effective, and that this may also serve as a transition between its phases.

(Mettes, Pilot & Roossink, 1981; Rosenshine &Stevens, 1986; Stolk et al., 2012; Terlouw, 2001).

3.3.1.6 Teacher motivation

In addition to the strategies, instructional functions, phases, and a learning theory, Stolk et al. (2009b) include the notion of motivation in their PDF. Attracting teachers and sustaining their involvement so that they can receive the full dose of professional development is a primary challenge in teacher professional development (Boyd, Banilower, Pasley, & Weiss, 2003). However, teachers need to be motivated if they are to change their practice (Gaible & Burns, 2005), for example, motivated teachers put effort into enhancing learning experiences and use creative methods to achieve learning goals (Pintrick & Schunk, 1996). Although improved performance is effective as an intrinsic incentive, motivation is difficult to sustain without extrinsic incentives such as access to new or additional educational resources, as well as job retention, promotion or advancement linked to professional development (Gaible & Burns, 2005). Thus, the following characteristic of the conceptual PDF was developed:

Design Principle #7.1: Incorporate intrinsic and extrinsic teacher motivation into the PDF given that teachers need to be motivated to change their practice and that although improved performance is effective as an intrinsic incentive, motivation is difficult to sustain without extrinsic incentives.

(Boyd, Banilower, Pasley & Weiss, 2003; Gaible & Burns, 2005; Pintrick & Schunk, 1996; Stolk et al., 2009b).

3.3.2 Outcomes of design/develop phase 1

This section presents the two-fold outcomes of the design/develop phase of the first design research cycle. The outcomes detail the tentative design principles and the associated conceptual content-generic version of the PDF (design proposal).

These principles were generated on an in-time-basis throughout the previous section. The principles are gathered below.

3.3.2.1 Tentative design principles

In order to design a conceptual content-generic version of a PDF to be used in any educational setting to support the design and implementation of inquiry-based science education, the following seven principles are useful:

> *Design Principle #1.1:* Aim the PDF at enhancing the related knowledge, attitudes, beliefs and practices of teachers as this is a goal in effective teacher learning.
>
> (Elster, 2009; Fishman, Marx, Best & Tal, 2003; Loucks-Horsley, Love, Hewson, Stiles & Mundry, 2003; Rozenszajn & Yarden, 2014).
>
> *Design Principle #2.1:* Using a sociocultural or a situated learning perspective is recommended as the learning perspective for the PDF in order to allow for collective participation in professional learning communities.
>
> (El-Deghaidy, Mansour & Alshamrani, 2015; Marx & Harris, 2006; National Science Teachers Association, 2006; Ostermeier et al., 2010).
>
> *Design Principle #3.1:* Incorporate a pre-participation phase, an exploration/planning phase, an implementation phase and a post-implementation phase into the PDF with reference to studies on effective teacher learning.
>
> (Chikasanda et al., 2013; Mansour, EL-Deghaidy, Alshamrani & Aldahmash, 2014; Rozenszajn &Yarden, 2014; Yerushalmi &Eylon, 2013).
>
> *Design Principle #4.1:* Adopt a lesson study as the professional development strategy in the PDF given, for example, that the lesson study is usable across different socio-economic contexts, involves active learning in a professional learning community, and is aligned to core features of effective teacher learning.

(Desimone, Porter, Garet, Yoon & Birman, 2002; Gaible & Burns, 2005; Lewis et al., 2006; Perry & Lewis, 2009).

Design Principle #5.1: Incorporate lesson study phases into the PDF under related major phases of professional development (pre-participation, exploration/planning, implementation and post-implementation) in order to provide a sequence for planning activities within the major professional development phases.

(McKenney et al., 2006; Reigeluth, 1999).

Design Principle #6.1: Include instructional functions (such as reviewing relevant prior learning, providing overviews and learning goals, providing guidance and feedback and reviewing learning periodically) in the PDF so that professional development can be more effective, and that this may also serve as a transition between its phases.

(Mettes, Pilot & Roossink, 1981; Rosenshine &Stevens, 1986; Stolk et al., 2012; Terlouw, 2001).

Design Principle #7.1: Incorporate intrinsic and extrinsic teacher motivation into the PDF given that teachers need to be motivated to change their practice and that although improved performance is effective as an intrinsic incentive, motivation is difficult to sustain without extrinsic incentives.

(Boyd, Banilower, Pasley & Weiss, 2003; Gaible & Burns, 2005; Pintrick & Schunk, 1996; Stolk et al., 2009b).

It may be useful to clarify the designation of the above and subsequent (versions of) design principles, for example, in *Design Principle #7.1*, ‘7’ is the serial number, while ‘1’is the research cycle number. Thus, subsequent versions of this design principle will be designated the code #7.2 (in research cycle two) and #7.3 (in research cycle three).

3.3.2.2 Conceptual content-generic version of PDF

This framework to be used in any educational setting towards supporting the design and implementation of inquiry-based science education can be synthesised on the basis of the seven tentative design principles listed above. In addition, details regarding the phases of professional development (Section 3.3.1.3) and the description of lesson study in Figure 3.7 and Table 3.10 may be incorporated into the PDF. However, the backbone of the PDF comes from *Design Principle #5.1:*

> Incorporate lesson study phases into the PDF under related major phases of professional development (pre-participation, exploration and planning, implementation and post-implementation) in order to provide a sequence for planning activities within the major professional development phases.
>
> (McKenney et al., 2006; Reigeluth, 1999).

The six other tentative design principles can be implemented around *Design Principle #5.1,* for example, *Design Principle #7.1* is implemented early in the PDF in the pre-participation phase so that the ensuing professional development programme may be attractive to teachers from the beginning. This is due to the fact that a primary challenge in professional development lies in attracting teachers, in addition to sustaining their involvement so that they can receive the full dose of professional development (Boyd et al., 2003). This is in line with the definition of instructional functions as general operations or measures implemented in order to complete the phases of a learning programme (Mettes et al., 1981). Instructional functions may be incorporated into all phases of the PDF as per *Design Principle #6.1.* Thus, the professional development goal (*Design Principle #1.1)* is at the top of the PDF and phase-specific goals (required by instructional functions) are provided thereafter on an on-going basis. The other instructional functions are similarly implemented in the different phases of the PDF, as demanded by *Design Principle #6.1*. Alternatively, *Design Principle #2.1* is implemented in the PDF simply by basing the PDF on lesson study as the professional development strategy (*Design Principle #4.1).* It is in the above way that the PDF in Figure 3.8 was synthesised.

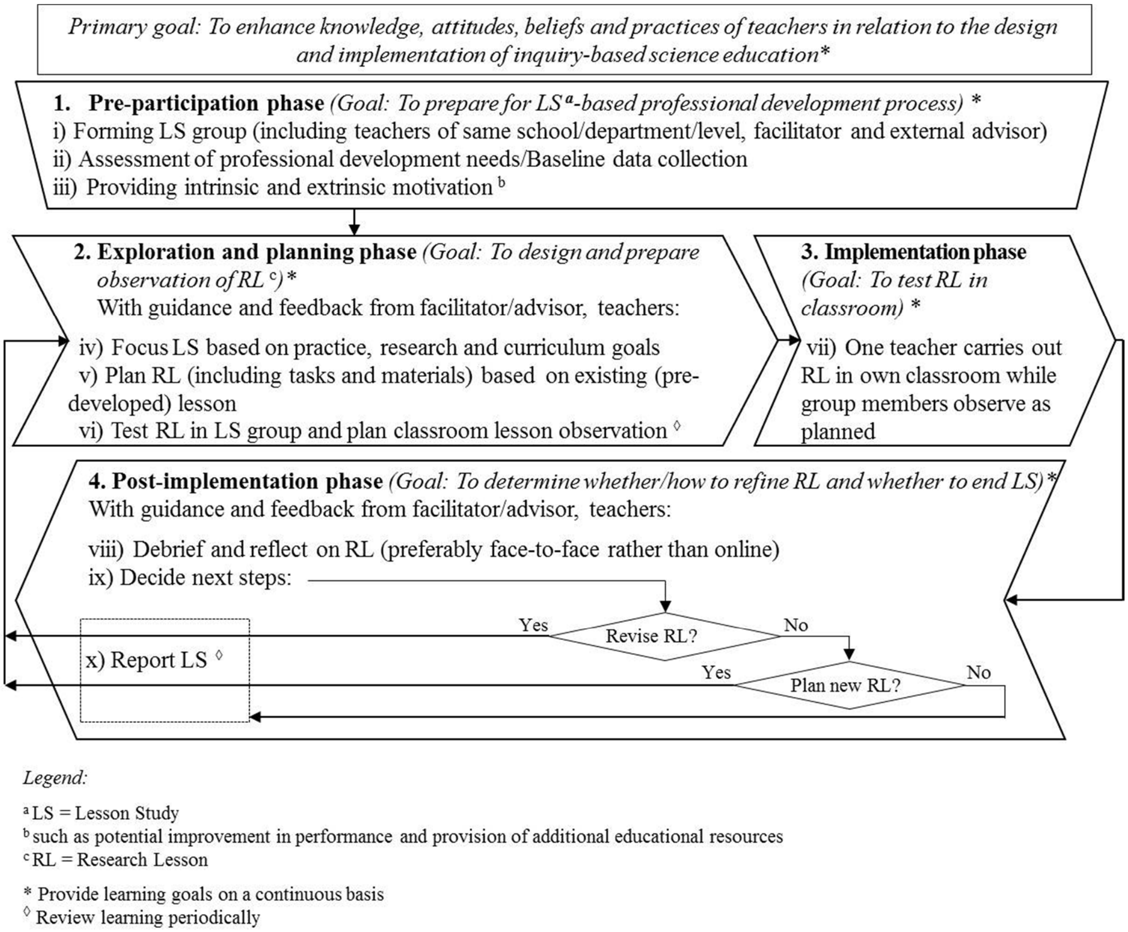


Figure 3.8 Conceptual content-generic PDF to support teachers in the design and implementation of inquiry-based science education (Source: Researcher)

Overall, the conceptual content-generic version of the PDF in Figure 3.8 reflects a cyclical professional development process due to *Design Principle #4.1.* However, as the design proposal, the PDF was only the first version of the PDF being designed (PDF v1 in Figure 3.1). Thus, the PDF with the associated tentative design principles is subject to further development, which makes the last phase of this research cycle useful in this regard.

3.4 EVALUATION PHASE 1

3.4.1 Introduction

In this phase, the design proposal (conceptual content-generic version of the PDF) undergoes a formative evaluation. Formative evaluation is "a systematically performed activity (that includes research design, data collection, data analysis and reporting), aiming at quality improvement of a prototypical intervention and its accompanying design principles" (Nieveen & Folmer, 2013, p. 158). A prototypical intervention (in this case the PDF in Figure 3.8), may be evaluated in relation to its merits or its worth. Merit refers to the inherent, intrinsic value of an object, while its worth is defined as its place-bound, contextually determined value (Lincoln & Guba, 1979). Here, the formative evaluation focuses on the merit of the intervention (PDF) which still at the conceptual level of development. For assessing the merit of the PDF, relevance (content validity) is the quality criterion in the evaluation in line with Figure 3.1. Regarding this criterion, an intervention and its design need to be based on state-of-the-art (scientific) knowledge (Nieveen, 1999, 2013). Thus, the evaluation question here was:

> *How relevant (content valid) is the content-generic version of the PDF to support teachers in the design and implementation of inquiry-based science education?*

The above question may be answered by checking the intervention design against the required design specifications or important characteristics. The core features of teacher professional development programmes and principles for designing effective teacher learning are useful in this regard (Section 3.2.1.2).

3.4.2 Data collection and analysis

As specified in Figure 3.1, screening was the formative evaluation method used in this research cycle. For this purpose, data was collected using a checklist that incorporated the characteristics that the intervention needed to have (Abdal-Haqq, 1998). On this basis, the relevance (content validity) of the content-generic version of the PDF was assessed against the core features of teacher professional development and the principles for designing effective teacher learning. A checklist for this purpose is contained in Table 3.12.

Table 3.12 Checklist for screening PDF against core features of teacher learning (Source: Researcher)

Core feature of teacher professional development (Table 3.1)	Incorporated into PDF?	
	Yes	No
1. Collective participation in professional learning communities.		
2. Content focus.		
3. Use of methods similar to those needed in the classroom.		
4. Adequate duration.		
5. Active learning.		
6. Coherence.		

In Table 3.12, the core features of teacher professional development are the design specifications or important characteristics against which to assess the relevance of the content-generic version of the PDF (Figure 3.8). In the checklist contained in Table 3.13, the specifications or characteristics are rather the principles for designing effective teacher learning.

Table 3.13 Checklist for screening PDF against principles for designing effective teacher learning (Source: Researcher)

Principle for designing effective teacher professional development programmes (Table 3.2)	Incorporated into PDF?	
	Yes	No
A. Addressing central problem areas in teaching.		
B. Introducing processes of quality development in school.		
C. Collaboration and cooperation at all levels, especially amongst teachers.		
.		
.		
.		
V. Sustaining change through a cyclical professional development process that ensures durability		

The checklists in in Table 3.12 and Table 3.13 allow the relevance (content validity) of the PDF (Figure 3.8) to be evaluated against the core features of teacher professional development and the principles for designing effective teacher learning respectively. The relative number of check marks in each case is indicative of the relevance of the PDF in relation to the aspect under consideration. It remains for the researcher to complete these checklists.

3.4.3 Results and reflection

3.4.3.1 Results

Regarding the relevance of the PDF in relation to the core features of teacher professional development programmes, the results are presented in Table 3.14.

Table 3.14 Completed checklist for screening PDF against core features of teacher learning (Source: Researcher)

Core feature of teacher professional development (Table 3.1)	Incorporated into PDF?	
	Yes	No
1. Collective participation in professional learning communities.	√	
2. Content focus.		√
3. Use of methods similar to those needed in the classroom.		√
4. Adequate duration.	√	
5. Active learning.	√	
6. Coherence	√	
Total	4	2

The relevance (content validity) of the conceptual content-generic PDF in relation to the principles for designing effective teacher learning programmes is presented in Table 3.15.

Table 3.15 Completed checklist for screening PDF against principles for designing effective teacher learning (Source: Researcher)

Principle for designing effective teacher professional development programmes (Table 3.2)		Incorporated into PDF?	
		Yes	No
A.	Addressing central problem areas in teaching.	√	
B.	Introducing the processes of quality development in school.		√
C.	Collaboration and cooperation at all levels, especially amongst teachers.	√	
D.	Supplementing the work of teachers with support from other teachers and through research on learning and instruction.	√	
E.	Attending to both the pedagogical content knowledge and educational beliefs of participants.	√	
F.	Demonstrating activities and teaching strategies linked to curricular needs and providing teachers required resources.	√	
G.	Establishing multiple opportunities for teachers to experience activities from the perspective of learners.	√	
H.	Developing a network of support for participating teachers.	√	
I.	Reflecting research on effective classroom learning and teaching.	√	
J.	Using instructional strategies that are research-based and reflect those needed in the classroom.		√
K.	Facilitating the building of a learning community of teachers.	√	
L.	Supporting teachers to serve in leadership roles.		√
M.	Aligning professional development to local and state priorities and systems.	√	
N.	Using the learning needs of learners as a basis and helping teachers to address learner difficulties in subject-matter knowledge and skills.		√
O.	Basing professional development on the needs of participating science teachers and assessing and refining professional development to meet teachers' evolving needs.	√	
P.	Engaging science teachers in transformative learning experiences that confront deeply held beliefs, knowledge, and habits of practice.	√	

Principle for designing effective teacher professional development programmes (Table 3.2)		Incorporated into PDF?	
		Yes	No
Q.	Maintaining a sustained focus over time and providing opportunities for continuous improvement.	√	
R.	Actively involving teachers in observing, analysing, and applying feedback to teaching practices.	√	
S.	Concentrating on specific issues of science content and pedagogy that are derived from research and exemplary practice.	√	
T.	Promoting collaboration among teachers in the same school, grade, or subject.	√	
U.	Providing on-going support in the form of long-term, continuous pedagogical, technical and social assistance.	√	
V.	Sustaining change through a cyclical professional development process that ensures durability	√	
	Total	18	4

3.4.3.2 Relevance of content-generic version of PDF

The PDF was considered to be largely relevant (content valid) considering that it is in line with:

- Most (four out of six) of the core features of teacher professional development programmes.
- Over 80% (18 out of 22) principles for designing effective teacher professional development programmes.

The only principles for designing teacher professional development programmes that the PDF did not directly incorporate were the following:

- Supporting teachers to serve in leadership roles;
- Introducing processes of quality development in schools;
- Using the learning needs of learners as a basis and helping teachers to address learner difficulties in subject-matter knowledge and skills; and
- Using instructional strategies that are research-based and reflect those needed in the classroom.

While the above principles for designing effective teacher professional development programmes were not incorporated directly into the PDF, the framework is not opposed to these four principles. A facilitator, for example, may be selected from among participating teachers in step 1i) in Figure 3.8. Also, the actual introduction of for example lesson study in a school can also be considered in terms of instructional quality development. On the other hand, the third principle above is not necessarily applicable here as the PDF being developed focuses on teacher learning, unlike classroom learning. The evaluation also shows that the PDF does not incorporate methods similar to those needed in the classroom. However, teaching and learning methods are not needed unless when translating a PDF into an intervention programme (Kumar, 2005).

In relation to the core features of teacher professional development programmes, the evaluation shows that the PDF was not in line with the following:

- Content focus; and
- The use of methods similar to those needed in the classroom.

The reason why the PDF does not have the last feature was provided above. Content focus is incorporated to an extent into the primary goal of the PDF. This is in terms of aiming the PDF at enhancing teacher competence in relation to knowledge, attitudes and beliefs linked to inquiry-based science education. Although the PDF was not specific in this regard, by definition this is to be expected of a conceptual content-generic PDF. However, this point highlights the need for the further development of the PDF.

The above screening results and discussion indicate that the content-generic version of the PDF is relevant (content valid) as the blueprint of a professional development programme. This supports teachers in enhancing their competences in specified domains of inquiry-based science education. These domains consist of knowledge, attitudes, beliefs and practices. In this regard, the PDF provided the data needed in clarifying the processes, means and ways through which professional development outcomes may be attained (Hewson, 2007).

It is worth noting, however, that the PDF does not provide details in relation to the domains of the competences to be enhanced in teachers. These competences need to be specified with respect to a given aspect of inquiry-based science education. According to the primary purpose of this study (PRP, Section 1.3.3), this aspect is the design and implementation of inquiry-based practical work. In this regard, while the PDF indicates in step 2 v) that the participants include tasks and materials in their research lesson, what these materials may be and what kind of tasks may be designed remains to be clarified. In a nutshell, a mechanism for designing and implementing inquiry-based practical work remains to be incorporated into the PDF. Thus, further development of the PDF and the associated tentative design principles is needed.

3.5 CHAPTER SUMMARY AND CONCLUSION

This chapter detailed the first research cycle of this design research study. The research cycle provided the first major step in the process outlined in Table 3.1 for developing a PDF. The purpose of this step was to design a conceptual content-generic PDF to support the design and implementation of inquiry-based science education based on the related tentative design principles.

The designing of the PDF was located in the context of the effective (continuous) professional development of teachers. This was based on the core features of teacher professional development and the principles for designing effective teacher professional development programmes. Based on this, it was necessary to define a PDF for the purposes of this study. In this regard, a PDF was defined as an abstract artefact serving as the blueprint of the associated professional development process and consisting of concepts, assumptions, principles, values and practices linked to the processes, means and ways through which the desired professional development outcomes can be achieved.

In order to provide data for the purpose of synthesising the content-generic version of the PDF (design proposal), a thesis literature review and a systematic literature review (Section 2.4.4.2) were used. The former type of literature review provided the core features of effective teacher professional development programmes and the principles for designing such programmes. These were useful in the formative evaluation of the content-generic version of the PDF. However, the synthesis of the PDF resulted from the systematic literature review.

Included in the systematic literature review were 23 peer reviewed articles (19 empirical studies and four literature review articles) from eleven Thomson Reuters Web of Science Core Collection (2016) database of journals for the period 2007 to 2015. The articles used multiple data collection methods and collectively included a wide range of data collection methods among which were surveys, interviews and observation. The articles presented studies carried out on five different continents that included Africa, and involved mostly science teachers. Regarding the data extraction, the method of constant comparison (Glaser & Strauss, 1967; Strauss & Corbin, 1990) was used in this study.

On the above basis, the components of a PDF are: goals, learning phases, learning theory, strategies, instructional functions, and teacher motivation. Based on these components, seven tentative design principles were generated as seen in Section 3.3.2.1. These principles have enabled the conceptual content-generic version of the PDF in Figure 3.8 to be synthesised. The PDF has been formatively evaluated for content validity (relevance) through screening with reference to the core features of teacher professional development and the principles for designing effective professional development programmes respectively. The evaluation indicated that the PDF is relevant as the blueprint of a professional development programme for supporting teachers in enhancing their knowledge, attitudes, beliefs and practices. The above outcomes are linked to the following first secondary research purpose (SRP1a) of this study:

> SRP1a: To generate tentative design principles in relation to effective teacher professional development, upon which basis a conceptual content-generic PDF to support science teachers is then designed.

As a design proposal, the conceptual content-generic PDF did not provide details in relation to the domains of competence that need to be enhanced. With reference to the primary purpose of this study (Section 1.3.3), the domains of competences need to be specified in relation to the challenges linked to the design and implementation of inquiry-based practical work. In addition, the means through which inquiry-based practical work may be design and implemented is also needed. Moreover, the PDF still has to address the challenges associated with the design and implementation of inquiry-based practical work. Overall, revised or additional design principles are needed to design a conceptual content-specific version of the PDF.

CHAPTER 4 : CONCEPTUAL CONTENT-SPECIFIC PROFESSIONAL DEVELOPMENT FRAMEWORK

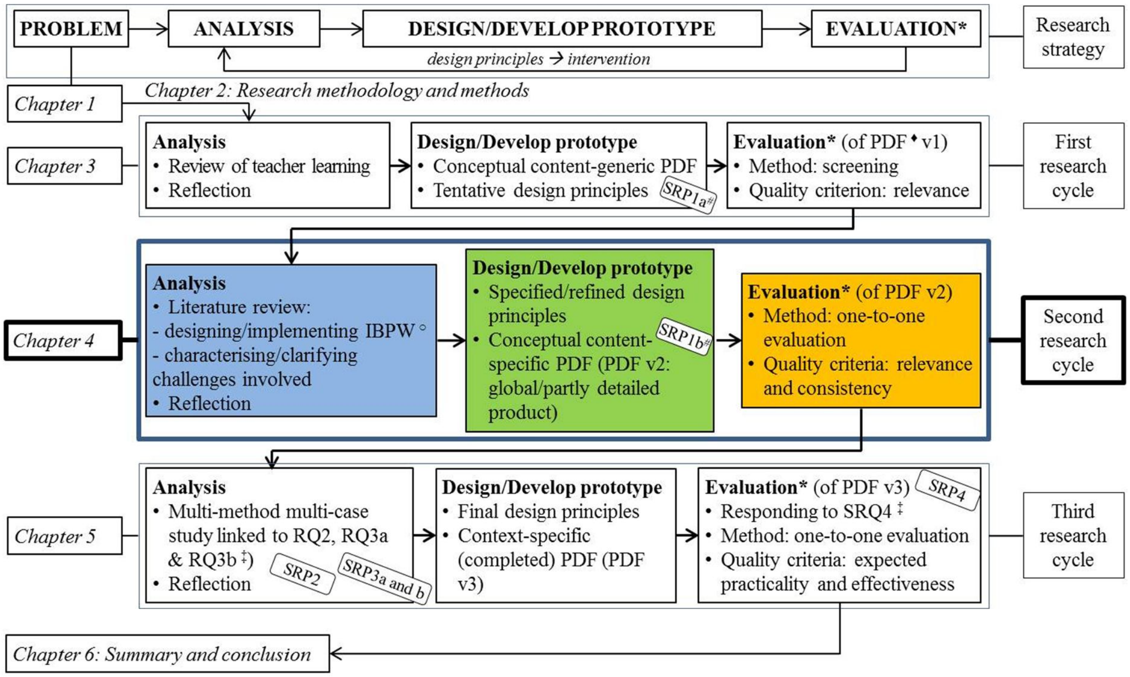
4.1 CHAPTER OVERVIEW

This chapter presents the second research cycle in this design study. This research cycle constitutes the second major step in the process used here to develop the professional development framework (PDF) to support the design and implementation of inquiry-based practical work. This was in the context of South African Physical Science classrooms in resource-constrained schools (Figure 1.1). In this regard, this research cycle builds on the previous one in terms of:

- Transforming the existing tentative design principles into the specified/refined design principles and adding three new specified design principles;
- Identifying two new professional development framework components; and
- Revising the professional development framework.

In order to achieve the above, this research cycle included a systematic literature review for the purpose of collecting the needed existing data and also a formative evaluation to gather empirical data. In reality, two systematic literature reviews (SLRs) were carried out in this chapter, although only one is presented here. The other SLR (Akuma & Callaghan, 2016) focuses on the challenges linked to the incorporation of improvised science education equipment and materials in practical work is science classrooms. This SLR is found in Appendix Q. The SLR presented in this chapter focuses on the design and implementation of inquiry-based practical work and the related teaching challenges. It is this SLR that allows for the revision of the version of the PDF from the previous chapter. For this revision, two experts in research and/or practice in teacher professional development, and also inquiry-based science education participated in the formative evaluation.

The place of this research cycle and chapter within this study as a whole is highlighted in Figure 4.1.



Legend:
* Consisting of data collection and analysis, in addition to results and reflection
♦PDF = Professional Development Framework; °IBPW = Inquiry-Based Practical Work; # SRPi = Secondary Research Purpose i (section 1.3.3)

‡SRQ1a = What are the characteristics of a conceptual content-generic PDF to support science teachers?
‡SRQ1b = What are the characteristics of a conceptual content-specific PDF to support IBPW in secondary school science classrooms?
‡SRQ2 = How inquiry-based is the way in which practical work is being designed and implemented in resource-constrained South African Physical Science classrooms?
‡SRQ3a = What specific extrinsic challenges are being faced by teachers in these classrooms in relation to the design and implementation of IBPW?
‡SRQ3b = What specific intrinsic challenges are being faced by the teachers in relation to the design and implementation of IBPW?
‡SRQ4 = What are the characteristics of a context-specific PDF to support these teachers in the design and implementation of IBPW?

Figure 4.1 Position of Chapter four within design research process (Source: Researcher)

As reflected in Figure 4.1, the second design research cycle builds on the previous cycle. It does so in relation to transforming the tentative design principles and the conceptual content-generic version of the professional development framework (PDF v1) into the specified design principles and the conceptual content-specific version of the PDF (PDF v2) respectively. In design research terms, the conceptual content-specific version of the PDF (PDF v2) incorporated the global design of the invention. It thus needed to include tentative details of all or some components of the completed intervention while reflecting how the completed intervention would appear (Section 2.4.3.2).

The PDF that was developed and the associated design principles needed to become more content-specific. This meant focusing the design principles and PDF on the design and implementation of inquiry-based practical work (IBPW), as noted at the end of the previous research cycle. More specifically, there was the need to focus the design principles and PDF on enhancing the knowledge, attitudes, beliefs and practices of teachers in relation to the challenges associated with the design and implementation of IBPW. The challenges may have been intrinsic or extrinsic, for example, teachers' knowledge and their beliefs regarding learning, teaching, and content are critical factors in determining how they teach (Putnam & Borko, 1997). Depending on their state, these factors could present intrinsic challenges to individual teachers. However, teachers may be strengthened regarding the related competences through professional development. At the same time, professional development is not complete unless the participating teachers are able to translate their new competences in teaching (e.g., Grant, 1996; Wells, 2007). In this regard, factors external to individual teachers may be important, for example, teaching is affected by the curriculum, time, and availability of supplies and facilities (National Research Council, 2005a). These factors could result in extrinsic challenges linked to the design and implementation of IBPW.

Against the above background, it is useful to clarify the notion of practical work, IBPW, and how IBPW may be designed and implemented. This allows for the identification of the associated practices and challenges. The characterisation and clarification of these challenges allows for the systematic identification of the beliefs, attitudes and knowledge to be enhanced in order to reduce specific intrinsic challenges linked to the design and implementation of IBPW. It would also be useful to gather ways of reducing specific extrinsic challenges linked to the design and implementation of IBPW. Thus, in order to make the design principles and PDF more content specific, this research cycle focused on answers to the following questions:

1. How can IBPW be understood and how can IBPW be designed and implemented?
2. What intrinsic and extrinsic teaching challenges may be faced by teachers in relation to the design and implementation of IBPW?
3. How can these challenges be characterised and clarified?
4. What are the ways in which the challenges can be reduced?

In accordance with Figure 4.1, this second research cycle, like the rest, was divided into three phases: analysis, design/develop prototype, and evaluation phase. The analysis phase started by clarifying the concept of inquiry-based practical work (IBPW), allowing a conceptual framework for designing and implementing IBPW to be compiled. This framework was, however, not the only conceptual framework that needed to be compiled. Two other conceptual frameworks compiled consisted of a conceptual framework of teaching challenges and a conceptual framework for clarifying intrinsic challenges linked to the design and implementation of IBPW. These conceptual frameworks serve in responding to the above questions and are not to be confused with the conceptual framework for this study as a whole (Section 2.4.3). The latter conceptual framework is reflected in Figure 4.1. Additionally, the analysis phase also describes the systematic literature review (SLR) based on the above conceptual frameworks and in response to the last two questions above. The literature review was conducted from an international perspective.

In the design/develop prototype phase of the research cycle, the results, especially those of the SLR, were presented and simultaneously used to generate the relevant specified design principles. It was based on these design principles that the conceptual content-specific version of the PDF was then synthesised. The above outcomes of this research cycle were subjected to a formative evaluation in the evaluation phase of the research cycle. Regarding the evaluation, the one-to-one evaluation method was used. The evaluation question was: What is the consistency and also the relevance of the conceptual content-specific version of the PDF (PDF v2)? This was in accordance with the detailed research process for the research cycle in Figure 4.1. Thus, both the extent to which the intervention (PDF) is based on scientific knowledge and the extent to which the components of the PDF were logically linked to one another were assessed and are reported on in this chapter. After a reflection on the evaluation, this chapter ends with a summary.

4.2 ANALYSIS PHASE 2

4.2.1 Practical work in secondary school science classrooms

Here, practical work is discussed in relation to its use, definition, approaches, and teaching strategies. In this regard, a stance was taken in relation to a number of debates. The different stances taken helped in clarifying the kind of IBPW considered here and how it could be designed and implemented.

4.2.1.1 Definition and use of practical work

Practical work (which includes laboratory work) is commonly implemented in schools in most countries around the world (Nivalainen, Asikainen, Sormunen, & Hirvonen, 2010; TIMSS, 1997). In fact, internationally, practical work is considered an indispensable aspect of science education by researchers, scientists, teachers and learners (e.g., Abrahams & Millar, 2008; Lee et al., 2008; Nivalainen et al., 2010). However, *Practical work is not uniquely defined.* Practical work may be considered to consist of experiences in which learners individually or collaboratively manipulate and/or observe real materials and objects (equipment),unlike simulated ones (such as interactive computer simulations) (Millar, 2011). However, practical work may not be limited to traditional laboratory activities given that in many situations, computer-based learning (for example using data-logging and simulated equipment) may be more effective (e.g. Eilks, Prins & Lazarowitz, 2013; Hodson, 1998). Alternatively, practical work includes experiences that allow learners to interact with data about the natural world that is not necessarily gathered by the learners (National Research Council, 2005a). However, learners cannot gain a complete understanding of the essence of scientific inquiry unless they are given opportunities to acquire data themselves prior to analysing this data (Sweeney & Paradis, 2004). Thus, practical work may be defined as experiences in which learners interact with materials or secondary sources of data (including computer-based sources) in order to observe and understand the natural world (Lunetta, Hofstein, & Clough, 2007).Against the above background, it can be concluded that practical work involves hands-on experiences, as well as the manipulation of computer-based (e.g. simulated) materials and equipment in addition to existing data sets.

4.2.1.2 Resources useful in practical work

The discussion in the previous paragraph is indicative of the existence of two primary categories of Science Education Equipment and Materials (SEEMs) linked to practical work: computer-based (simulated) and hands-on (real) equipment and materials. However, the latter category consists of conventional and improvised SEEMs. All three categories of SEEMs are worth discussing.

Conventional and improvised hands-on SEEMs

Conventional Science Education Equipment and Materials (SEEMs) are SEEMs commonly described as ready-made, original, standardised or ideal. The supply of these SEEMs is not always adequate, making alternative ways of accessing them useful in some schools.

Availability of conventional resources is useful in practical work. Many classrooms in industrialised and less developed countries lack essential conventional hands-on SEEMs (e.g., Childs et al., 2012; Ens, Olson, Dudley, Ross, Siddiqi, Umoh et al.,, 2012; Kriek & Basson, 2008a; Nivalainen et al., 2010; Singh & Singh, 2012). The lack of conventional SEEMs in many classrooms may be explained by the fact that even in industrialised countries such as Germany and Japan, conventional SEEMs are costly, coupled with the fact that in many industrialised and less developed countries, science education budgets have decreased (Poppe, Markic, & Eilks, 2011; Schaffer & Pfeifer, 2011; Set & Kita, 2014). This is also the case in the former Soviet Union countries of Georgia and Moldova (Kapanadze & Eilks, 2014). In many less-developed countries, including Kenya and Nigeria, conventional hands-on SEEMs tend to be imported, difficult to obtain, and expensive (Bhukuvhani, Kusure, Munodawafa, Sana, & Gwizangwe, 2010; Ezeliora, 1998; Ndirangu, Kathuri, & Mungai, 2003).

Alternative ways of accessing conventional SEEMs. Faced with a lack of conventional SEEMs in schools, various alternative ways have been utilised around the world to gain access to these. These ways include borrowing from or utilising facilities outside individual schools (such as mobile laboratories and science centres), using a small-scale (micro-scale) approach in conducting conventional experiments, in addition to the improvisation of SEEMs at a central production unit or in school (Bradley, 1999; Di Fuccia et al., 2012; Musar, 1993; Singh & Singh, 2012; Sussman, 2000; Tran, Scherpbier, Van Dalen, & Wright, 2012).

Improvisation of SEEMs. Improvised SEEMs have normally been considered as equipment used when conventional SEEMs are unavailable (Eniajeyu, 1983;

Ogoh, 2014). This strategy has been used in science education for so many years, as evidenced in the literature (e.g., Barbara & Sam, 1957; Set & Kita, 2014). Based on this strategy, resourceful science teachers design equipment (including physical models) from basic materials and use the designed equipment and basic materials in practical work in their classrooms (Gilbert, Justice, & Arsela, 2003; Ndirangu et al., 2003; Ogoh, 2014). The basic materials that have been utilised in developing and industrialised countries in designing science education equipment include syringes, scrap timber from the school workshop, plastic bottles, aluminium foil, food colouring, tin cans, baking soda, glycerine, plastic bags, cabbage juice used as a chemical indicator and straws (Ens et al., 2012; Gilbert et al., 2003; Nyaumwe & Mavhunga, 2005; Sussman, 2000; Tran et al., 2012; Wilke & Tronicke, 2007, 2008). Basic materials (such as the materials listed above) are readily available to science teachers for designing improvised SEEMs (Stephen, 2015; Wood, 1990).

Simulated SEEMs and practical work

There is value in non-traditional forms of practical work. Practical work may not be restricted to traditional laboratory experiences considering that in some cases, computer-based activities are also useful and may be even more effective in learning to do science, doing science and learning about science (Eilks, Prins, & Lazarowitz, 2013; Hodson, 1998; National Research Council, 2005a; Science Community Representing Education, 2009). Regarding the carrying out of computer-based activities, interactive computer simulations, which include Physlets, can be used. Physlets are simple, flexible and interactive applications that display physical concepts, run in-browser software and are downloadable from the internet (Lee, Nicoll, & Brooks, 2004). In general, interactive computer simulations are computer applications that enable users to interact with a computer representation of a theoretical system or the natural world in terms of teaching or learning how the system works (De Jong & van Joolingen, 1998; Roblyer & Doering, 2013; Weller, 1996). These resources allow learners to observe scientific phenomena, including those that are invisible, too large, dangerous to interact with directly, or too expensive (Fan & Geelan, 2012; Khan, 2008; National Research Council, 2005a).

ICTs may not supplant hands-on resources in practical work. Despite their value in practical work, interactive computer simulations and other ICTs may not supplant hands-on science education equipment and materials (e.g., Khan, 2011; Scheckler, 2003; Zacharia, 2007). This is due to the fact that giving learners opportunities to develop their practical (manipulative) laboratory skills is a learning goal in itself (Rutten et al., 2012). In addition, simulated and hands-on equipment have their respective merits (Scheckler, 2003)and complement each other in practical work in science classrooms (Donnelly et al., 2013; Urban-Woldron, 2009).

Based on the above discussion, conventional SEEMs may be used in practical work in combination with improvised hands-on work, as well as simulated SEEMs. This conclusion informs the earlier one to the effect that practical work may involve hands-on experiences as well as the manipulation of computer-based (e.g. simulated) materials and equipment in addition to existing data sets. Although these conclusions were useful in providing a general notion of the type of practical work considered in this study, further discussion is needed in order to clarify the notion of inquiry-based practical work (IBPW). In this regard, it is useful to consider the approaches used in practical work in relation to those used in science education in general.

4.2.2 Approaches in science education and practical work

Approaches in practical work vary along a band from an open-ended, learner-driven approach to a teacher- (worksheet-) driven approach (Hodson, 1998; Kidman, 2012). This variation is reflected in the approaches used in the teaching and learning of science in general. While various approaches can be used in the teaching and learning of science (Magnusson & Palinscar, 1995), these approaches may be categorised into the traditional approach on the one hand, and inquiry-based approaches on the other hand (Friedrichson, Van Driel, & Abell, 2010).

4.2.2.1 Traditional approach in science education and practical work

Science has traditionally been taught as a rigid collection of theories, rules and facts to be memorised and practised (De Vos, Bulte, & Pilot, 2002). In this approach, the teacher focuses primarily on content coverage, sees the learner as a knowledge reservoir (Ibrahim, 2003), and pays less attention to the methods of science (Samuel & Ogunkola, 2013). Even when using technology in the classroom, science teachers mostly employ the traditional or transmission-orientated approach

(Guzey & Roehrig, 2012). This approach is often textbook-orientated with little science inquiry (Crawford, 2007; Jones & Eick, 2007). Thus, this approach does not motivate learners (Osborne & Collins, 2001).

Practical work based on the traditional approach in science education has been referred to as recipe-type, traditional, 'cookbook', verification-based or confirmatory practical work. This approach to practical work has limitations in relation to promoting learner achievement and in enhancing their curiosity regarding the natural world (Fan & Geelan, 2012). Confirmatory practical work has also been criticised for not representing the way scientists work (McComas, 2005). The above limitations may be better understood in the light of how practical work is carried out in the traditional approach. Based on this approach, learners follow 'recipes' to perform procedures given to them by their teacher, with little thinking and purpose (Anderson, 2007; Kim & Tan, 2010). Such practical work thus involves limited active learning. Actively involving learners in the (practical) learning process requires a shift from a transmission-orientated to a more transformational (such as constructivist) teaching and learning approach (Keys & Bryan, 2001).

4.2.2.2 Inquiry-based approach in science education and practical work

The inquiry-based approach in science education is in line with a constructivist learning perspective in which learners construct meanings for themselves based on their prior learning and through social interaction (Anderson, 2007; Zion & Mendelovici, 2012). Based on the inquiry-based approach, science learners are encouraged to investigate the natural world as they pose researchable questions, investigate these questions, in addition to explaining and justifying assertions based on evidence (Hofstein & Lunetta, 2004; Quintana, Reiser, Davis, Krajcik, Fretz, & Duncan, 2004). Inquiry-based teaching enhances learner creativity and the development of the habits of mind that they need in order to question and investigate real-world phenomena (Haigh, 2007). Also, inquiry-based teaching can make science more accessible as it provides greater relevance (Songer, Lee, & Kam, 2002). Moreover, inquiry-based teaching and learning is a reflection of the practices of real scientists (Dudu & Vhurumuku, 2012). Thus, the need for inquiry-based teaching and learning in science education has been widely emphasised, coupled with curricular reforms involving the infusion of inquiry into practical work (e.g., Australian Curriculum Assessment and Reporting Authority, 2012; Department of Basic Education, 2011b; European Commission, 2007; National Research Council, 2000; Ontario Ministry of Education, 2008; Samuel & Ogunkola, 2013).

It is worth noting, however, that many people recommend that inquiry-based teaching be combined with direct instruction (traditional approach) in the teaching of science (e.g., Kennedy, 2013; Sadeh & Zion, 2012). Concerning proportion, some teachers and reformers are of the opinion that inquiry-based teaching needs to play a major role in science education (e.g., Harris & Rooks, 2010; National Research Council, 2000; National Science Teachers Association, 2007).

The above discussion supports the use of an inquiry-based approach in practical work and brings us close to the notion of IBPW as used in this study. In relation to clarifying the notion of IBPW, it remains to characterise the inquiry-based teaching approach in relation to implementation strategies.

4.2.2.3 Inquiry-based strategies in science education

There are different types of inquiry-based teaching strategies in classroom settings. One categorisation of these strategies is the levels of openness framework (Herron, 1971; Schwab, 1962). This is a widely recognised categorisation of inquiry-based strategies (McComas, 2005). The categorisation is consistent with that of Bell, Smetana, and Binns (2005b). The two categorisations of school-based inquiry have been combined in Table 4.1.

Table 4.1 Categorising school-based inquiry (Source: Bell et al., 2005; Herron, 1971; Schwab, 1962)

Level of inquiry	Question	Methods of investigation	Answers
0 (confirmation)	Given	Given	Given
1 (structured)	Given	Given	Open
2 (directed)	Given	Open	Open
3 (open)	Open	Open	Open

4.2.2.4 Defining inquiry-based practical work (IBPW)

Based on Table 4.1, we see that confirmation inquiry is in line with confirmatory practical work. This form of inquiry, however, is not of interest in this study because practical work is more effective in learning when it is used to introduce rather than confirm scientific ideas stated by the teacher or in books (e.g., Ivins, 1985; Raghubir, 1979). This leaves structured, directed and open inquiry to be considered here in relation to practical work.

Structured (Level 2) inquiry is regarded by some researchers as inadequate in enhancing the critical and scientific thinking of learners, in addition to their attitudes (e.g., Kaberman & Dori, 2009; Lord & Orkwiszewski, 2006). In this light, the European Union project, SALiS (Student Active Learning in Science), incorporated both structured and guided inquiry into teacher learning linked to practical inquiry (Kapanadze & Eilks, 2014). Alternatively, Settlage (2007) is opposed to the notion that Level 3 (Open) inquiry is the best way to teach science. Thus, science teachers who are new to inquiry may engage in more teacher-directed, inquiry-based instruction (Levels 1 and 2) until they have overcome some of the challenges (Davis, Petish, & Smithey, 2006; Donnelly et al., 2013), before moving to Level 3 (Open) inquiry.

Against the above background, IBPW is considered in this study to mean practical work that involves at least one of Levels 1 to 3 in Table 4.1. However, the above description of IBPW is limited in terms of providing information linked to the actual learner experiences involved in IBPW. The experiences are linked to inquiry-based learning practices.

Learners need to be able to generate and test ideas, generate and evaluate scientific evidence, as well as construct explanations based on evidence (National Research Council, 1999, 2007). Inquiry-based learning practices also include designing experiments, testing hypotheses, and data interpretation (Duschl, 2008).The above practices have been reformulated by the National Research Council (2012) into a number of inquiry-based learning practices rooted in the work of practising scientists. These practices include asking questions, planning and conducting investigations, analysing and interpreting data, constructing explanations, and engaging in evidence-based arguments. Based on these practices, the last three levels of inquiry in Table 4.1 can be clarified for the purposes of this study, as seen in Table 4.2.

Table 4.2 Inquiry-based practical work as considered in this study (Source: Researcher)

Level of inquiry	Question	Methods of investigation	Answers	Learning practices*
1 (structured)	Given	Given	Open	C, D, E and F
2 (directed)	Given	Open	Open	B, C, D,E and F
3 (open)	Open	Open	Open	A, B, C, D, E and F

* Including (National Research Council, 2012):
A = asking questions
B = planning investigations
C = conducting investigations
D = analysing and interpreting data
E = constructing explanations and
F = engaging in evidence-based arguments

In this study, the term IBPW is considered as practical work involving one of the levels of inquiry described in Table 4.2 in relation to various inquiry-based learning practices. In this light, the term 'inquiry' (often used in the United States) is considered equivalent to the term 'investigation' as used in the United Kingdom, for example. Considering earlier discussions as well, the following definition of IBPW is used here:

Inquiry-based practical work (IBPW) involves learners in collaboratively manipulating a combination of hands-on and computer-based SEEMs, or existing data sets, in order to gain an understanding of the natural world as they experience inquiry-based learning practices through structured, directed or open inquiry.

In the above definition, hands-on SEEMs may be conventional, improvised or both. Moreover, the types of inquiry of interest are as described in Table 4.2. While learners may also work individually during practical work, IB teaching and learning (in this case IBPW) is consistent with the popular view that learning involves not only the individual, but also the social construction of knowledge (e.g., Minstrell & Van

Zee, 2000; Vygotsky, 1978). In addition, there are many ill-equipped science classrooms, as seen earlier. This explains the word ‘collaboratively’ in the above definition. It is in the context of such practical work that the formulation of the specified/refined design principles and the synthesis of the associated content-specific version of the PDF (PDF v2) are located. It is also in the context of such practical work that the rest of this study was situated.

4.2.3 Useful conceptual frameworks

The term conceptual framework is understood here as it was described in the beginning of Section 2.4.3. That said, as noted at the beginning of this chapter, the first step towards making the design principles and PDF content-specific is to focus them on the design and implementation of IBPW. Having defined what is meant here by IBPW, the next question concerns a useful conceptual framework for designing and implementing such practical work.

4.2.3.1 Conceptual framework for designing and implementing IBPW

A framework for the design and implementation of IBPW may be compiled with reference to instructional design and instructional models respectively. These two aspects may complement each other in terms of a conceptual framework for designing and implementing IBPW. In this regard, the Science Laboratory Instructional Design Model and the so-called 5E instructional model have been considered, as explained below.

While resources are important in relation to inquiry-based teaching and learning, the most important element in effective science instruction is the teacher, who must design instruction in a way that enhances the learning process (National Research Council, 2000). This statement highlights the importance of Instructional Design (ID). ID deals with the design of instructional materials, lessons and whole systems in a manner that is consistent and systematic, with the goal being to make these products more relevant and effective (Molenda, Reigeluth, & Nelson, 2003; Reiser & Dempsey, 2007).

Designing IBPW (Science Laboratory Instructional Design model)

Many ID models exist as indicated in the literature (e.g., Dick, Carry, & Carry, 2001; Posner & Rudnitsky, 2001; Smith & Ragan, 1999). On the one hand, the model of Dick et al. (2001) incorporates such major components common to other models as analysis, design, development, and evaluation (Balta, 2015). On the other hand, the Analysis, Design, Development, Implementation and Evaluation (ADDIE) model (Peterson, 2003) has been widely and traditionally used (Kallio, 2008; Magliaro & Shambaugh, 2006; McGurr, 2008). By fusing the ADDIE model and the model of Dick et al., Balta (2015) designed the Science Laboratory Instructional Design (SLID) model. This ID model, which was favourably evaluated by 34 science teachers, consists of five phases: Initiation, Planning, Execution-Guidance-Evaluate (hereafter Implementation), Evaluation, and Feedback. These phases of the model are briefly discussed below as a basis for the designing of the IBPW.

Initiation. This phase of the SLID model involves setting goals, and analysing learners and content, in addition to selecting a delivery strategy in relation to a learning theory (Balta, 2015). Inquiry-based teaching and learning (in this case IBPW) is consistent with the popular view that learning involves not only the individual, but also the social construction of knowledge (e.g., Minstrell & Van Zee, 2000; Vygotsky, 1978). Considering the definition of IBPW used here (Section 4.2.2.4), the practical work strategy is limited to structured, directed or open inquiry. Regarding the selection of learning methods (in this case the specific delivery strategy), the characteristics of the content, the prior learning of learners, their prior experiences, as well as their needs and interests are important (Hodson, 2014). That said, practical work is confusing and unproductive without clear, thought-out goals (Hodson, 1990). Thus, it is vital for teachers to be explicit regarding the goals that they want to attain in the classroom (Hofstein & Lunetta, 2004).

Planning. In this phase of the SLID model, safety precautions and the formation of learner groups are considered (Balta, 2015). In inquiry-based learning, learners work in groups (Harlen, 2010). In relation to safety, the actions of learners can sometimes be unpredictable and dangerous (Kim & Tan, 2010). On these grounds, teachers sometimes prefer using interactive computer simulations in practical work (Scaife & Wellington, 1993). However, this cannot be consistently the case, as seen earlier (Section4.2.1.2). Thus, the prior formation of learner groups is in line with the fact that there is limited time available for most practical lessons, and that IBPW demands more time than recipe-type practical work (Abrahams & Millar, 2008; Hofstein & Lunetta, 2004). In addition to group formation and safety considerations, Balta includes the assessment of needs, the development of assessment instruments, in addition to the designing and production of materials in this phase of the SLID model. While the materials normally include worksheets, and SEEMs, these may be selected among the existing ones where available. The SEEMs include not only hands-on (conventional and improvised) SEEMs, but also the relevant ICTs (e.g. data loggers and interactive computer simulations). In terms of simulations, science teachers typically limit their use to situations that include when conventional equipment is not available or too complicated to use; the activity is dangerous; and when there are serious time constraints (Kirschuner & Huisman, 1998). In addition, the use of interactive computer simulations should be limited to situations where there are better options in relation to enabling learners to understand scientific concepts (Lee et al., 2008).

Implementation. Unlike in the last two phases, learners are active in this phase of the SLID model, which involves the conduct of practical work in the classroom with teacher guidance and feedback (Balta, 2015). This phase of the model thus involves formative evaluation. This may be defined as assessment *for* learning, unlike the assessment *of* learning (Black, 1993), which is summative evaluation.

Evaluation. This phase of the SLID model responds to the fact that during the last phase, there is usually insufficient time for learners to prepare a laboratory report (Balta, 2015). The report that learners prepare at home is usually used for summative evaluation purposes. However, practical work is also often reported orally in some classrooms (Ottander & Grelsson, 2006).

Feedback. In this last phase of the SLID model, the teacher may revise the delivery strategy, carry out needs assessment, group formation and evaluation instruments, depending on the evaluation of the practical work (Balta, 2015). The teacher may also evaluate the materials used in the lesson in order to enhance them (Seel & Glasgow, 1998).

As evidenced by the discussion, the 'designing' of IBPW includes its 'implementation'. However, the phrase 'design and implementation,' and alternatively 'designing and implementing' in IBPW is used here in order to emphasise the point that 'implementation' is also involved.

Implementing IBPW (5E instructional model)

Regarding a basis for considering the implementation of IBPW, the implementation phase of the SLID model may be expanded with reference to Instructional Models (IMs). IMs can assist teachers in sequencing and organising inquiry-based learning experiences in their classrooms (National Research Council, 2000).A learning cycle is the IM often employed by many teachers in the conduct of their lessons and is useful in providing learners opportunities to engage in inquiry (e.g., Dogru-Atay & Tekkaya, 2008; National Research Council, 2000). Contemporary learning cycles include the original Exploration, Invention, and Discovery model (Karplus & Thier, 1967), the resulting Engagement, Exploration, Explanation, Elaboration and Evaluation (5E) instructional model (Bybee, 1997), and its extension, the Elicit, Engagement, Exploration, Explanation, Elaboration, Evaluation and Extension (7E) instructional model (Eisenkraft, 2003).

The 5E instructional model has achieved widespread success in education (Bybee, Taylor, Gardner, Van Scotter, Powell, Westbrook et al.,, 2006; Zuiker & Whitaker, 2014), for example, the model is used in designing the instructional modules (SciPacks) developed by the National Science Teachers Association (Sherman, Byers, & Rapp, 2008). Also, the phases of the 5E instructional model are reflected in the five phases considered by the National Research Council (2000) as common to instructional models and useful as a general guide to inquiry-based teaching. Thus, the 5E instructional model is used in professional development programmes in order to enable science teachers to design their own inquiry-based lessons (Zwiep & Benken, 2013). In this case, the lessons are practical lessons. The phases of the 5E instructional model are thus described and discussed below as a basis for the implementation of IBPW.

Engagement phase. This phase of the 5E instructional model consists of short and simple activities (physical or mental) designed to assess the prior learning of learners, promote curiosity, and identify any misconceptions that they possess (Bybee et al., 2006). The activities need to connect prior learning and intended learning outcomes (Bybee, 2009). These outcomes (goals) need to be made explicit and clear to learners (Hodson, 2014). The formulation of a "what do you think" question at the outset of a lesson is a popular way of eliciting the prior knowledge of learners (Eisenkraft, 2003). In addition to asking a question, ways of engaging learners include defining a problem that learners have to solve, enacting a problematic situation and demonstrating a discrepant event (Bybee et al., 2006). Discussions around misconceptions can also serve as stimulus (Naylor, Keogh, & Downing, 2007). In this regard, the teacher may set the procedures and rules for formulating the task (Bybee et al., 2006) or question. Encouraging learners to ask questions fosters inquiry-based learning practice A in Table 4.2. The question (or task) should be centred on events, objects and organisms in the natural world and linked to the science concepts specified in the content standards (National Research Council, 2000). However, when learners formulate their own questions (or tasks), the teacher needs to ensure that these are clear and can be investigated (Ramnarain, 2011a).

Exploration phase. In this phase, the process of equilibration is initiated in response to the disequilibrium established in the last phase (Bybee et al., 2006). In the equilibration process, learners explore questions and possibilities as they use their prior knowledge to develop hypotheses in addition to designing and planning preliminary investigations, for example (Bybee, 2009). The involvement of learners in the presentation and discussion of alternative hypotheses and ways through which a task may be resolved are useful in this regard (Kind et al., 2011). Facilitating the above equilibration process is a teacher practice that allows learners to engage in the inquiry-based learning practices B and C in Table 4.2. Although learners may investigate their own questions through analysing the data that they collect by themselves, practical work can still be inquiry-based when the questions and data are given, provided that learners go on to conduct the analysis and draw their own conclusions (Bell, Smetana, & Binns, 2005a). Either way, learners get an opportunity to engage with inquiry-based learning practice D in Table 4.2. As they work in small groups, the role of the teacher is that of a coach (facilitator). Thus, instead of responding to the questions of learners using direct answers, the teacher rather provides learners with guidance using indirect questions, hints, and suggestions (e.g., McComas, 2005; Urban-Woldron, 2009). In addition, the teacher needs to avoid long periods of contact with a single group and has to share concerns in individual groups rather than stopping the entire class (McComas, 2005).

Explanation phase. This phase of instruction is aimed at making concepts, skills and processes clear and comprehensible to learners (Bybee et al., 2006). While the phase is teacher-led and involves direct instruction (Bybee, 2009), the teacher first gives learners the opportunity to provide their own explanations and portray their own understanding and skills before introducing scientific terminology and explanations (Bybee, 2009; Bybee et al., 2006). This allows learners to engage in inquiry-based learning practice E in Table 4.2. This is consistent with Hodson (1990), who notes that in order to promote meaningful learning during practical lessons, learners need opportunities to construct their own understanding of the scientific concepts associated with the phenomena that they explore. This can be facilitated by open questions that elicit evidence-based justifications and evaluate the reasoning of and explanations from learners (Bybee et al., 2006; Chin & Osborne, 2008; Jiménez-Aleixandre, Lopez Rodriquez, & Erduran, 2005). The posing of such questions may encourage learners to engage in inquiry-based learning practice F in Table 4.2.

Elaboration phase. The primary goal of this phase is to enable learners to reach generalisations of concepts, skills and processes (Bybee et al., 2006) or to broaden and deepen their understanding and skills in relation to new, but closely related situations (Bybee, 2009). Learners sometimes understand a concept only in relation to their exploratory experience or are still left with misconceptions (Bybee et al., 2006). Thus, they are encouraged during this phase to apply their learning to explore further, carry out a new activity, or solve a numerical problem (Bybee, 2009). Teachers are encouraged to allocate a bigger proportion of time during practical work to assisting their learners in applying ideas linked to the phenomena they have experienced (Abrahams & Millar, 2008).

Evaluation phase. In the evaluation phase, learners are persuaded to reflect on their new understandings and abilities while the teacher provides feedback (Bybee, 2009; Bybee et al., 2006), which involves formative evaluation. However, such informal evaluation runs across all the phases of instruction (Bybee et al., 2006). In this regard, the teacher may use guiding and probing questions, in addition to suggestions in order to correct the errors of learners (Ramnarain, 2011b). However, in this last phase of the 5E instructional model, the teacher also formally evaluates the progress of learners towards the attainment of the intended learning outcomes (Bybee, 2009). This involves summative evaluation, which often takes place after a period of instruction (Boston, 2002). The period may be a single lesson as the SLID model entails.

As seen above, the 5E instructional model may be used to expand the implementation phase of the SLID model as a basis for designing and implementing IBPW, as defined in this study (Section 4.2.2.4). The above basis for designing and implementing IBPW may be summarised as shown in Figure 4.2.

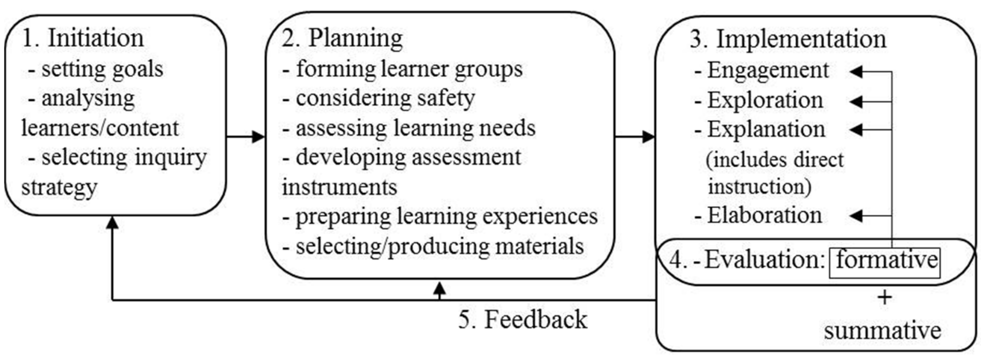


Figure 4.2 Conceptual framework for designing and implementing IBPW (Source: Researcher)

The conceptual framework in Figure 4.2 for designing and implementing IBPW provides a basis for enhancing the related learning and teaching practices. This concerns teacher and learner practices during inquiry-based teaching and learning (Vhurumuku, Holtman, & Mikalsen, 2004). That said, it is in relation to the practical work designed and implemented, as reflected in Figure 4.2, that the specified design principles were generated below and used to synthesise the content-specific version of the PDF. It is also with reference to the design and implementation of such practical work that some teachers face challenges. Therefore, a basis is needed.

4.2.3.2 Conceptual framework of teaching challenges

The international literature appears to contain different kinds of challenges faced by science teachers in relation to IBPW, for example, some curricula emphasise the mastery of science content by learners, unlike the development of inquiry skills (e.g., Childs et al., 2012; Ottander & Grelsson, 2006). Such curricula constrain science teachers in relation to practical work. The constraint is independent of the individual competences of the teachers. This is, however, not the case with certain other challenges linked to IBPW, for example, some teachers face difficulties when deciding when and how to utilise interactive computer simulations in practical work(Urban-Woldron, 2009). This challenge is linked to the competencies of individual teachers. The above two examples suggest that science teachers may experience different types of challenges regarding IBPW. For the purpose of characterising these challenges, a framework of teaching challenges linked to IBPW may be compiled with reference to existing categorisations of teaching challenges.

Researchers and teachers have used a number of characterisations of teaching challenges in different pedagogical contexts. These contexts include that of the integration of ICTs (such as interactive computer simulations) in learning, as well as in problem-based and inquiry-based teaching and learning. On the basis of these categorisations, a conceptual framework of teaching challenges can be compiled.

With reference to elementary science classrooms, Lee, Tan, Coh, Chia, and Chin (2000) categorise the challenges encountered by teachers in relation to inquiry-based and problem-based teaching and learning as internal challenges (such as attitudes and lack of knowledge) and external challenges (e.g. time constraints). Alternatively, the British Educational Communications and Technology Agency (2004) categorises teaching challenges in relation to ICT integration in learning into teacher-level challenges (such as deciding when and how to use simulations) and institutional-level challenges (such as lack of time). Nonetheless, another categorisation divides challenges into extrinsic challenges (e.g. related to an organisation) and intrinsic challenges (i.e., linked to an individual, Ertmer, 1999). We see that although emanating from different instructional contexts, the above categorisations of teaching challenges largely agree with one another. In this regard, the categorisations yield two primary categories of challenges linked to teaching:

extrinsic (external) challenges and intrinsic (internal) challenges. These broad categories of teaching challenges may be broken down into smaller categories.

Case of extrinsic teaching challenges. While not apparent in the British Educational Communications and Technology Agency (2004) categorisation, extrinsic challenges are not limited to institutional-level challenges. This is because teachers may also experience system-level teaching challenges, which are challenges associated with the broader educational framework (Balanskat, Blamire, & Kefala, 2006). Thus, extrinsic teaching challenges may be grouped into system- and institutional-level challenges. However, with reference to ICT integration in the classroom, the teaching challenges are either linked to a material condition or to a non-material condition (Pelgrum, 2001). Examples of these conditions are a shortage of computer devices and time constraints on teachers, respectively. Similarly, teachers may face challenges regarding the supply of conventional SEEMs as well as they may lack an adequate amount of time to design and produce their own SEEMs. Thus, in general, extrinsic teaching challenges may be broken down into challenges linked to a material condition and those not linked to such a condition.

Case of intrinsic challenges. By definition, these challenges may not be categorised in relation to challenges linked to a material condition and those not linked to a material condition. The same is true of the system-level versus institutional-level categorisation of challenges. However, intrinsic teaching may be categorised into planning-, implementation- and evaluation-phase challenges (Akuma & Callaghan, 2016). In a similar light, the conceptual framework for designing and implementing IBPW in Figure 4.2 offers a possible framework for categorising intrinsic teaching challenges. In this way, the challenges can be categorised as Initiation-, Planning-, Implementation-, Summative evaluation- and Feedback-phase challenges. In relation to Figure 4.2, implementation-phase challenges can be broken down into Engagement-, Exploration-, Explanation-, Elaboration- and Evaluation (formative)-phase challenges.

Based on the above discussion, the conceptual framework of teaching challenges in Figure 4.3 has been compiled.

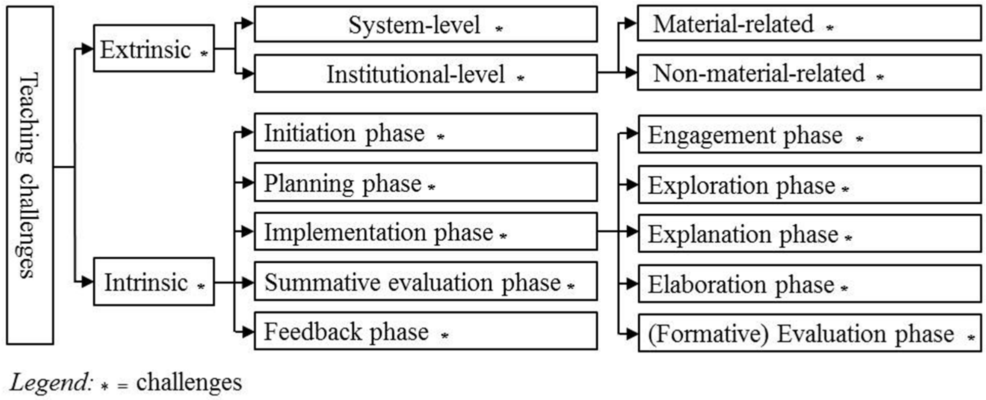


Figure 4.3 Conceptual framework of challenges linked to designing and implementing IBPW (Source: Researcher)

In relation to categorising teaching challenges as intrinsic versus extrinsic, and breaking down the extrinsic challenges, the framework in Figure 4.3 is based on the existing categorisations of teaching challenges in the contexts of ICT integration in learning, as well as in inquiry-based and problem-based learning. However, the framework also draws on the SLID model and the 5E instructional model to provide categories of intrinsic teaching challenges. In this last regard, the conceptual framework in Figure 4.3 is similar to the categorisation of intrinsic teaching challenges used by Akuma and Callaghan (2016).

The framework in Figure 4.3 may be used to characterise teaching challenges linked to the design and implementation of IBPW. The framework also allows ways of reducing specific challenges to be systematically juxtaposed with the related challenges. Although the above conceptual framework allows challenges and ways of reducing them to be gathered in a systematic manner, the clarification of intrinsic challenges would allow for the identification areas for enhancement of competences in the domains of knowledge, beliefs, and values in relation to the design and implementation of IBPW. The next conceptual framework is also useful in linking competences and classroom practices.

4.2.3.3 Conceptual framework for clarifying intrinsic challenges

A basis for clarifying intrinsic teaching challenges may be compiled with reference to the competences required of teachers. Competences are skills and cognitive abilities that individuals possess, or can acquire, with which they solve certain problems, in addition to abilities linked to volition, motivation and social willingness (Weinert, 2001). These competences permit an individual to responsibly and successfully implement the solutions to problems in variable situations.

The two broad perspectives on competence consist of an attributes- (outcome) based perspective and an activity-based perspective (Eraut, 1998). In the outcome-based perspective, what a person does to yield a result determines how competent the person can be considered to be. On the contrary, in the attributes-based perspective, competence is based on the attributes that contribute to the ability of a person to act. The latter perspective is widely used by organisations as the basis of their professional development or competency frameworks (Lester, 2014).

Based on the attributes-based perspective, competences include skills, knowledge, understandings, attitudes, motivations and values (Chong & Cheah, 2009; Eraut, 1998; United Nations Educational Scientific and Cultural Organisation, 2011). The skills component includes reflective, pedagogical, personal and management skills (Chong & Cheah, 2009). Regarding the production of improvised SEEMs, practical skills are also needed (Bhukuvhani et al., 2010). The values required of teachers include care and concern for learners, commitment and dedication to their practice, collaboration and team spirit, in addition to the desire for continuous learning, innovation and excellence (Chong & Cheah, 2009). The knowledge base of teachers is worth discussing in detail.

Pedagogical Content Knowledge (PCK) framework. The first framework of teacher knowledge was put forth by Shulman (1986), who stated that teachers need Pedagogical (P) and Content (C) Knowledge (K). This knowledge base is now popularly referred to simply as PCK. In science education research, the PCK concept has been interpreted in several ways and used for different purposes (Appleton, 2003; Park & Oliver, 2008). However, the PCK model of Magnusson, Krajcik, and Borko (1999) has been predominantly used and widely accepted (Großschedl, Mahler, Kleickmann, & Harms, 2014; Kind, 2009).

Based on the PCK model of Magnusson et al. (1999), science teachers need knowledge in four primary domains comprising knowledge of context, Content

Knowledge (CK), Pedagogical Knowledge (PK) and Pedagogical Content Knowledge (PCK). Knowledge of context covers factors such as grade level and learner background (Doering, Veletsianos, Scharber, & Miller, 2009; Koehler & Mishra, 2009). The CK domain includes knowledge of concepts, ideas, theories, organisational frameworks, established approaches to developing such knowledge in addition to knowledge of evidence (Shulman, 1986). In this way, the CK domain includes knowledge of scientific and classroom inquiry (National Research Council, 2000). Conversely, PK includes knowledge of teaching and learning processes, as well as teaching methods and practices (Koehler & Mishra, 2009; Mishra & Koehler, 2006). In this case, the practices include inquiry-based teaching and learning practices allowed for in the 5E instructional model. Also included in this primary domain of teacher knowledge is knowledge about learning objectives, how learning occurs, learner assessment, as well as instructional planning and implementation (Koehler & Mishra, 2009). The planning and implementation may be consistent and systematic by combining the SLID and 5E models, as reflected in Figure 4.2.

Unlike the above primary domains of knowledge, the PCK domain has five secondary domains, the first of these secondary domains being *orientation towards science teaching*. This is knowledge of the goals and purposes of science teaching at a given grade level. *Knowledge and beliefs about the science curriculum* is the second PCK component, and it consists of knowledge about specific curricular materials and programmes of relevance to science teaching, in addition to prescribed goals and objectives. The third secondary PCK domain is *Knowledge of instructional approaches* in science education. This knowledge includes the knowledge and beliefs of a teacher regarding instructional approaches. The fourth secondary domain of PCK is beliefs and knowledge about the *understandings of science learners* about specific topics. Included in this PCK domain are learner misconceptions, required prior knowledge, and topics that pose difficulties to learners. The fifth and last secondary domain of PCK is *knowledge and beliefs about the assessment of learning*. This knowledge includes the aspects of learning that require assessment and how the assessment can be carried out.

Technological Pedagogical Content Knowledge (TPACK) framework. With the advent of technology in education, Mishra and Koehler (2006) extended the PCK concept to the TPCK (later, TPACK) framework shown in Figure 4.4.

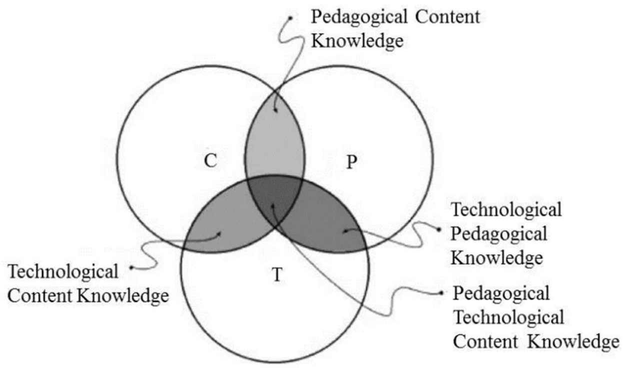


Figure 4.4 Framework of teacher knowledge (Source: Mishra &Koehler, 2006)

The introduction of Technology into the PCK concept led to four new primary domains of teacher knowledge, as seen in Figure 4.4. An outline of the domains added into the PCK framework to make the TPACK framework is provided below with reference to Mishra and Koehler (2006).

On the one hand, the TK domain consists of knowledge about standard technology (such as books) in addition to more advanced technology (e.g. data loggers and interactive computer simulations). However, TK also includes the skills needed in order to use particular technology. On the other hand, the TCK domain contains knowledge linked to the reciprocal relationship between C and T, for example, science teachers need knowledge not only about the content to teach, but also how the content may be influenced by technology. Concerning TPK, this includes knowledge about various forms of technology used in the classroom. This includes knowledge about their existence, constituents and capabilities in addition to how teaching may be influenced by the use of particular technology. Finally, TPACK, which transcends the primary domains of teacher knowledge (T, C and P), is the basis of effective teaching using technology. TPACK includes how technology may be used in teaching content in constructive ways.

The above framework for clarifying intrinsic teaching challenges from an attribute-based perspective may be represented as shown in Figure 4.5.

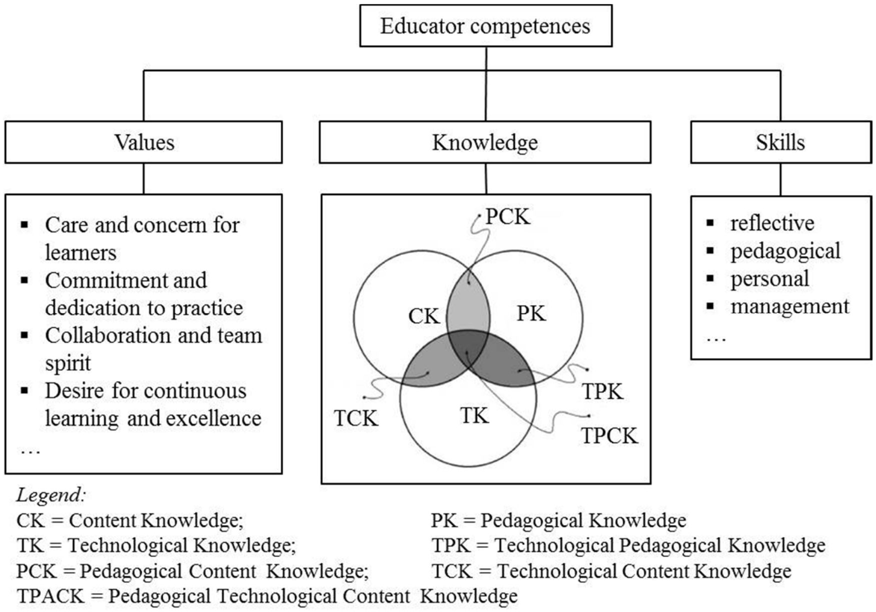


Figure 4.5 Framework for clarifying intrinsic teaching challenges (Source: Researcher)

Link between teaching and teacher competences. It is a commonly held view that the knowledge of teachers affects their classroom practices (Cochran-Smith & Lytle, 1999), for example, science teachers need adequate CK, general PK and PCK in order to be effective in preparing practical activities for their learners (National Research Council, 2000). Thus, the lack of CK in general, and especially an understanding of inquiry, seriously limits the ability of many teachers to implement an inquiry-based strategy in their teaching (Capps & Crawford, 2013b). However, other domains of competence (such as skills and value) also affect teaching. For instance, science teachers also experience difficulties linked to inquiry as a result of a shortfall in their skills (Zion, Cohen, & Amir, 2007). Conversely, inadequate motivation presents challenges for some teachers in relation to the production of their own SEEMs (Stephen, 2015; Tsuma, 1998). In summary, teacher competences affect their teaching, making these competences useful in clarifying teaching challenges.

Conceptual frameworks have thus been compiled to clarify intrinsic teaching challenges and to characterise these challenges in addition to extrinsic challenges. The latter framework may be used to juxtapose ways of reducing specific challenges. Also, a conceptual framework for designing and implementing IBPW is also now available. It remains in this analysis phase of the current research cycle to consider how, based on these conceptual frameworks, data can be gathered and analysed in order to formulate the specified design principles and to synthesise the content-specific version of the PDF.

4.2.4 Systematic review in the process of creating a content-specific PDF

Considering the description of the global design of an intervention (Section 2.4.3.2) to be incorporated into the content-specific version of the PDF, an international perspective was used in conducting the systematic literature review involved here. In this regard, the principles for conducting a systematic literature review (Section 2.4.4.3) are applicable as a general guide.

4.2.4.1 Purpose

In many countries, including South Africa, inquiry-based teaching (thus IBPW), remains new to most science teachers (Capps & Crawford, 2013a; Kapanadze & Eilks, 2014; Kim & Chin, 2011; Onwu & Stoffels, 2005). However, regarding the success of curricular reforms, teachers have a central role to play (Anderson & Helms, 2001; European Commission, 2007; Hattie, 2009). At the same time, the literature is replete with challenges being experienced by science teachers regarding inquiry-based teaching (e.g., Breslyn & McGinnis, 2012; Ritchie, Tobin, Sandhu, Sandhu, Henderson, & Roth, 2013; Van Rens et al., 2010). A challenge is understood here as a condition that presents a difficulty to the teacher in his/her efforts when moving towards or attaining a goal (Schoepp, 2005). The challenges teachers often experience in an effort to provide their learners with inquiry-based experiences causes these teachers to avoid or to resist curriculum reforms involving inquiry (Ritchie, Tobin, et al., 2013).

Against the above background, it useful to gather the teaching challenges associated with IBPW that are scattered in the international literature. However, instead of gathering these challenges in the form of a laundry list, it is useful to characterise the challenges in addition to clarifying them. The clarification of the intrinsic challenges allows for the identification of gaps in the related knowledge, beliefs and attitudes of teachers. In relation to addressing the gaps, it is useful ingathering ways of reducing specific intrinsic challenges. However, ways of reducing extrinsic challenges are useful in the creation of conditions that are favourable towards teacher learning and practice in the design and implementation of IBPW. Such data is applicable to the formulation of specified design principles and the content-specific version of the PDF. In this regard, the following three questions listed in the beginning of this chapter can serve as a guide:

1. How can IBPW be understood and how can IBPW be designed and implemented?
2. What intrinsic and extrinsic teaching challenges may be faced by teachers in relation to the design and implementation of IBPW?
3. How can these challenges be characterised and clarified?
4. What are the ways in which the challenges can be reduced?

Regarding this last question, parties with a role to play in the reduction of specific challenges are also of interest.

4.2.4.2 Data collection

Databases searched. A combination of electronic educational and journal databases has been searched in light of previous systematic literature reviews (e.g., Capps, Crawford, & Constas, 2012; Schneider & Plasman, 2013). The databases, which include three of the five used by Capps et al. (2012), consist of ERIC (Education Resources Information Center), Wiley Online Library, and four Thomson Reuters Web of Science Core Collection (2016) database of journals. These journals, which are all in the field of science and technology education research, consist of the *International Journal of Science Education,* the *Journal of Research in Science Teaching,* the *Journal of Science Education* and *Technology and Research in Science Education*. These journals were selected as leaders both in relation to the scope of this review and in science education research. A similar approach was used by Davis et al. (2006). This gives a total of six electronic databases. Similar to Ward (2016), a database of articles from previous systematic literature reviews has also been searched.

Search terms, limiting criteria and results. The search terms used in the full text of articles consisted of:

"practical work" OR "laboratory work" AND "investigative" OR "inquiry-based" AND "science education" AND "secondary school"

These search terms follow from the discussion in Section 4.2 that limits the type of practical work considered here to be inquiry-based (investigative) practical work in science classrooms in secondary schools. Alternatively, the terms 'challenges', 'intrinsic challenges 'and 'extrinsic challenges' have not been used as search terms because, based on previous literature reviews, various terms including 'impediments', 'constraints', 'not straightforward', 'not easy', 'hinder 'and 'difficult 'have been used to describe the experiences of teachers in relation to the design and implementation of IBPW. Thus, not using the terms 'challenges', 'intrinsic challenges 'and 'extrinsic challenges 'as search terms ensured that more articles were included in the search results. That said, the search results were limited to the past decade, more or less (2007 to 2016). Where more results were obtained, only the first 25 in order of relevance were considered. In the above way, 67 articles were found based on the individual online searches and 21 from the database of articles from previous systematic literature reviews. This gives a total of 88 articles from the individual databases. However, 10 articles were duplicates, leaving 78 unique articles.

Screening and augmenting search results. A preliminary review of the 78 articles revealed that a few had limited data in the sense that only one or two teachers were involved in the study (e.g., Ebenezer, Columbus, Kaya, Zhang, & Ebenezer, 2012). While, alternately, some articles focus mostly or entirely either on learners (e.g., Kawalkar & Vijapurkar, 2015), pre-service science teachers(e.g., Crawford, 2007) or elementary (primary) science teachers (e.g., Martin & Hand, 2009). Also, the search results were screened in relation to whether subjective judgment, such as a feedback questionnaire, was the only instrument used. Regarding the overall quality of the journal articles, the inclusion of the journal in the Thomson Reuters Web of Science Core Collection (2016) database was considered. Based on the above criteria, 50 articles were excluded. This leaves 27 of the initial 78 articles. However, based on the reference lists of the remaining articles, additional sources meeting the inclusion criteria, but missed by the search can be found (Capps et al., 2012; Pickering & Byrne, 2014). In this way, nine articles that were not duplicates have been found, taking the total number of articles initially included in this literature review to 36. The above screening and augmentation process is summarised in Figure 4.6.

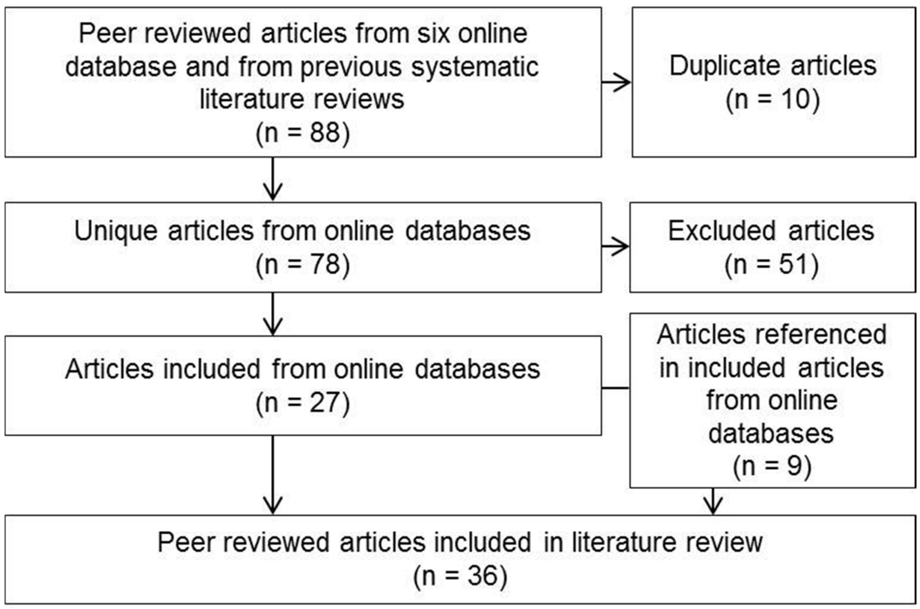


Figure 4.6 Process of finding articles on inquiry-based practical work (Source: Researcher)

The 36 articles included in the systematic literature, as indicated in Figure 4.6, all involved more than two established secondary school science teachers as participants. Also, these articles were all peer reviewed articles from the Thomson Reuters Web of Science Core Collection (2016) database of journals. However, it is useful to know more about the comprehensiveness of the included articles.

4.2.4.3 Coding

While the initial 36 peer reviewed articles included in this systematic literature review focused on science teachers, the articles varied across a number of journals and publication dates during the period 2007 to 2015. Additionally, the articles varied in relation to the location of the study.

Distribution of articles in relation to the location of study. The distribution is shown in Figure 4.7.

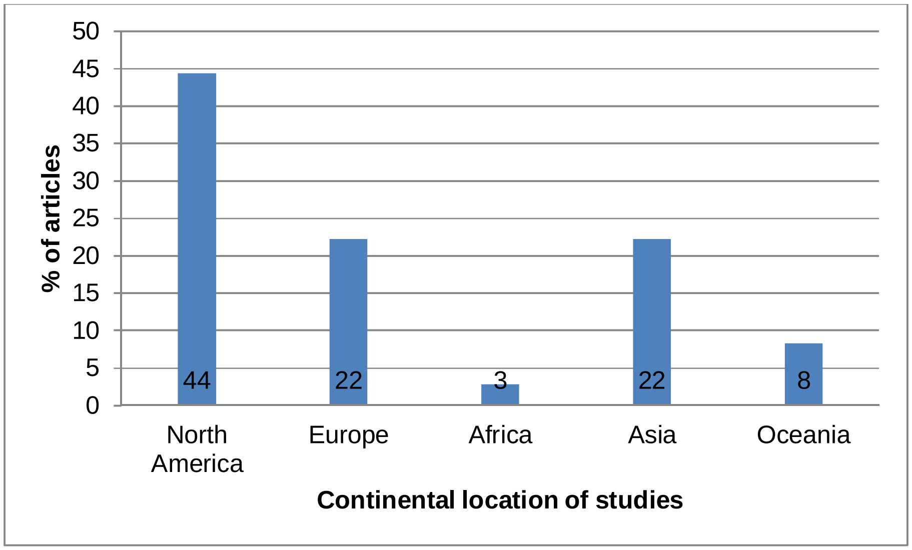


Figure 4.7 Distribution of articles on inquiry-based practical work per continent (Source: Researcher)

Figure 4.7 indicates that no articles were included from South America. However, studies from all of the other continents were included, although to varying extents. The distribution of articles per year of publication is shown in Figure 4.8.

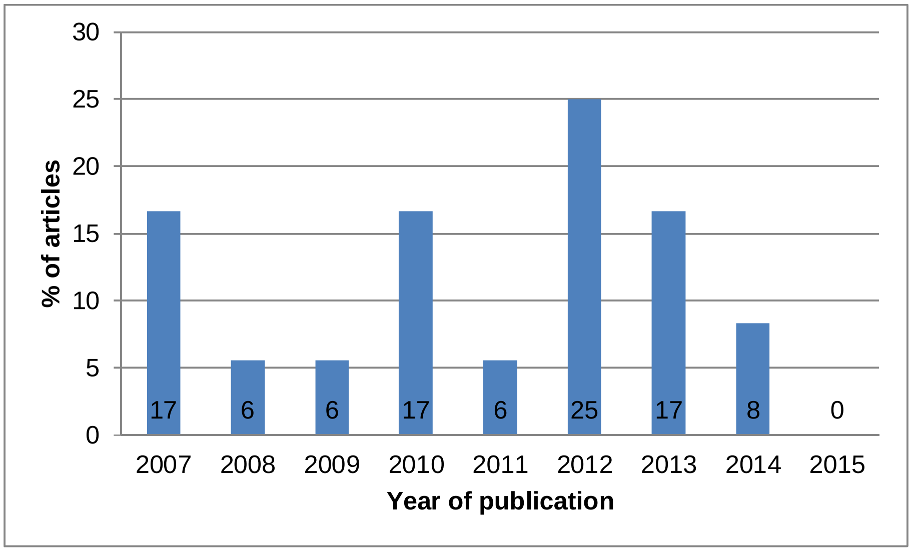


Figure 4.8 Distribution of included articles on inquiry-based practical work per year of publication (Source: Researcher)

Figure 4.8 indicates that there is continued interest among researchers in inquiry-based practical work in the period studied (2007 to 2015), although no articles were included in this literature review from 2015.

Distribution of articles in relation to data collection methods. Among the initial 36 articles, 10 were literature reviews. These review articles provided quality data from previous studies outside the other articles included in this literature review. Thus, each of the remaining 26 research articles used multiple methods of data collection. Table 4.3 shows the frequency of individual data collection methods in the research articles.

Table 4.3 Data collection methods in research articles on inquiry-based practical work (Source: Researcher)

Method of data collection	Frequency
Interview	21
Observation	16
Artefacts	9
survey (questionnaire)	8
learner assessment	4
field notes	1

Table 4.3 indicates that the use of subjective judgment, such as feedback questionnaires, is relatively low in the studies presented in the 26 research articles. This is coupled with the fact that where this is the case, at least one other data collection method has also been used. This is due to the screening criterion with respect to the data collection methods used in the search results.

Distribution of articles across different journals. As seen in Table 4.4, the articles included come from 11 journals included in the Thomson Reuters Web of Science Core Collection (2016) database of journals.

Table 4.4 Distribution of included articles on inquiry-based practical work per journal (Source: Researcher)

	Journals	Number of Articles
	Journal of Research in Science Teaching	10
	International Journal of Science Education	9
	Science Education	4
	Research in Science Education	4
	Eurasia Journal of Mathematics, Science & Technology Education	3
	Other journals (6)	6
Total	11	36

The above coding results show that the 26 research articles among the 36 peer reviewed articles initially included in this literature review come from various Thomson Reuters Web of Science Core Collection (2016) database of journals (Table 4.4), and used multiple data collection methods from a range of methods (Table 4.3). The articles also came from studies carried out in the past decade approximately (Figure 4.8) on five continents (Figure 4.7). The articles thus constitute a comprehensive source of good quality data on inquiry-based practical work. In addition to this data, more literature has been consulted, in some cases regarding ways of reducing specific challenges linked to the design and implementation of inquiry-based practical work.

Regarding this systematic literature review, the results are presented as part of the next phase of this design research cycle. As the last aspect of the current analysis phase, it remains to consider the data analysis.

4.2.4.4 Data extraction, synthesis and writing

Due to the deductive approach involved in this study, *a priori* categories of challenges linked to the design and implementation of IBPW were defined based on the conceptual framework of teaching challenges in Figure 4.3. By reading the 36 included peer articles in detail, specific challenges linked to IBPW can be identified based on the earlier given definition of a challenge from Schoepp (2005). The challenges can be identified in relation to conditions in teacher experiences described using terms that include ‘impediments’, ‘constraints’, ‘not straightforward’, ‘not easy’, ‘hinder’ and ‘difficult’. In this way, the challenges were extracted per article for all the 36 articles and assigned to the appropriate *a priori* category of teaching challenges. This allowed the data analysis within each *a priori* category to proceed inductively. In this regard, the method of constant comparison (Glaser & Strauss, 1967; Strauss & Corbin, 1990) was useful. Thus, each challenge in an *a priori* category was coded as a category. The codes were then compared within the category, leading to inductively-determined categories of teaching challenges within certain *a priori* categories of teaching challenges. In the above manner, the gathered challenges linked to the design and implementation of IBPW were deductively and inductively characterised.

This systematic literature review was also aimed at clarifying the intrinsic teaching challenges and at gathering ways of reducing specific intrinsic and extrinsic challenges. Regarding the clarification of the intrinsic challenges, the conceptual framework for clarifying intrinsic challenges reflected in Figure 4.5 was useful. It is based on this clarification that gaps in the knowledge, beliefs and attitude of teachers were identified. On this basis, the initial 36 articles included in this literature review were read in detail in order to identify ways useful in reducing specific intrinsic teaching challenges. Ways of reducing extrinsic challenges were also gathered. Additional sources (including Lederman & Lederman, 2012; National Research Council, 2005a; Osborne & Hennessy, 2003; Slovinsky, 2012) were used, where ways of reducing specific challenges could not be found in the initial 36 articles. Though, these sources consist mostly of peer-reviewed journal articles (such as Hofstein & Lunetta, 2004; Kapanadze & Eilks, 2014), they also include conference proceedings (e.g., Slovinsky, 2012), science education documents (e.g., National Agency for Education, 2000; National Research Council, 2005a) and books (including Lederman & Lederman, 2012). As seen, the sources pre-date 2007 in some cases. Once identified, each way of reducing a teaching challenge was then juxtaposed with the related teaching challenge in the different categories. In relation to the writing of the results of this literature review, this was done in the next phase of this research cycle in order to simultaneously apply them in the generation of the needed specified/refined design principles.

4.3 DESIGN/DEVELOP PROTOTYPE PHASE 2

The results of the literature review described above are presented here. The results exclude the ensuing embedded design principles and the conceptual content-specific version of the intervention (PDF). Specifically, two new professional development framework components were added to those identified in the previous research cycle (Section 3.3.1). The tentative design principles from the previous research cycle were refined here, and specified design principles corresponding to the new PDF components were generated.

4.3.1 PDF component linked to instructional design and related design principle

These tentative outcomes are embedded in the results of the literature review described above. However, embedded in the results in a just-in-time basis are design principles and the content-specific version of the PDF.

Component: Instructional design perspective. The discussion in Section 4.2.3.1 shows that a framework was needed to design and implement practical work in a manner that is consistent; systematic; more relevant and effective; in addition to being adequately sequenced and organised. Thus, the PDF that was developed needed to incorporate a conceptual framework for designing and implementing inquiry-based practical work (IBPW) as one of its components. In this regard, a new specified design principle was needed. In this regard, and in relation to the revision or generation of other new design principles, it was useful here to recall the format of a design principle (Van den Akker, 1999):

> If you want to design <intervention X> for the <purpose/function Y> in <context Z>, then you are best advised to give <that intervention> the <characteristics A, B, and C>, because of <arguments P, Q, and R>

In this research cycle, the following aspects of the above format of a design principle remained the same for all design principles:

<intervention X> = the PDF (specifically the global design of the PDF (content-specific version of PDF)

<purpose/function Y> = supporting the design and implementation of IBPW

<context Z> = any educational setting

Thus, in revising existing design principles and in generating new principles, the above components of the design principles may be assumed. On this basis, the design principles may be generated in the following format:

Give <intervention X> the <characteristics A, B, and C>, because of <arguments P, Q, and R>

Design principle linked to instructional design perspective. Against the above background, and considering the conceptual framework for designing and implementing IBPW (Section 4.2.3.1), the following new specified design principle may be generated:

> *Design Principle #8.2:* Combine the SLID [a] model and the 5E [b] instructional model in order for the PDF to reflect practical work that is consistent, systematic, adequately sequenced and organized, as well as more relevant and effective.
>
> (Balta, 2015; Bybee, 1997; Dick et al., 2001; Dogru-Atay & Tekkaya, 2008; Kallio, 2008; National Research Council, 2000; Peterson, 2003; Reiser & Dempsey, 2007).
>
> [a] SLID = Science Laboratory Instructional Design
>
> [b] 5E = Engagement, Exploration, Explanation, Extension and Evaluation

Having generated the additional specified design principle, the seven previously generated design principles (Section 3.3.2.1) were considered regarding specificity. Based on the above format of a design principle, the existing tentative design principles necessarily differed from the specified design principles generated in this research cycle in relation to two fields of the above format of a design principle. These fields are<intervention X> and <purpose/function Y>. While <intervention X> is the conceptual content-generic PDF regarding the tentative design principles, in the specified design principles, <intervention X> is the content-specific version of the PDF (PDF v2). This difference necessarily affects the <purpose/function Y> field of tentative design principles. However, this may or may not be the case regarding the <characteristics A, B, and C> field.

4.3.2 Extrinsic challenges linked to IBPW, related PDF and related design principle

This section sheds light on factors that are external to science teachers and which help in creating an environment that does not favour the design and implementation of IBPW. The usefulness of considering these factors lies in the fact that an improved understanding of the circumstances that facilitate or impede change is useful in the designing and sustaining of educational improvement

(Goldman, 2005). In this case, the improvement involved the infusion of inquiry in PW. In this regard, and in line with the conceptual framework for teaching challenges (Figure 4.3), the circumstances here were linked to extrinsic challenges at the system and institutional levels.

4.3.2.1 System-level extrinsic challenges

Content-intensive curricula. In some countries, including Ireland, the inquiry-based strategy may be seen as implausible due to the congested nature of the science syllabus (Donnelly, McGarr, & O'Reilly, 2011). Science curricula often focus on the mastery of science content by learners, unlike the development of their investigative skills (Childs et al., 2012; Dai, Gerbino, & Daley, 2011). When a school system encourages a content-intensive approach in science teaching, it discourages inquiry-based activities, which demand more time as teachers struggle to present large amounts of information to their learners (Blanchard, Southerland, & Granger, 2009; Donnelly et al., 2013; Qhobela & Moru, 2014). Thus, it is difficult for teachers using such curricula to encourage inquiry-orientated questions from learners (Chin & Osborne, 2008). This is contrary to the inquiry-based teaching and learning practices advocated by the National Research Council (2012). These practices include engaging learners in posing researchable questions, planning and conducting investigations, as well as analysing and interpreting data, formulating explanations in addition to engaging in evidence-based arguments. As a result, there have been changes in some curricula with a shift in emphasis from the teaching of science content towards teaching about science (Osborne & Hennessy, 2003). For instance, the Swedish science curriculum states that practical work should include inquiry skills such as formulating researchable questions, planning and conducting investigations, in addition to the formulation, communication and justification of explanations (Hofstein & Lunetta, 2003; National Agency for Education, 2000). In fact, in order to effectively implement inquiry-based activities, it is helpful to even established science teachers to have a curriculum in which such activities have been embedded across the different grade levels (Lederman & Lederman, 2012).

Pressure from high-stakes assessments. Many teachers wishing to implement inquiry, experience the pressure of accountability resulting from the heavy focus on high stakes assessment (Lin, Hong, Yang, & Lee, 2013; Lotter, Harwood, & Bonner, 2006). Some teachers, for instance, are restricted from engaging their learners in analysing and critiquing their results by the need to cover the syllabus in a timely manner prior to high-stakes assessments (Donnelly et al., 2013). In addition, IBPW is being restricted to a few tested investigations, detached from routine science teaching due to the high stakes assessment culture (Toplis & Allen, 2012). There may thus be the need for a discussion in the science education community on the level of emphasis that is currently given to the high stakes assessment of science learning. Also, Chin and Osborne (2008) call for a redefinition of success criteria linked to teaching and learning.

Inadequate recognition and assessment of IBPW outcomes. Some teachers face difficulty resulting from the fact that the skills that learners gain based on open-ended tasks lack sufficient recognition in assessment criteria, or are not assessed (Abrahams & Reis, 2012; Higgins, 2009). However, some curricula include assessment criteria linked to such process skills as planning investigations and interpreting the results thereof (Hofstein & Lunetta, 2004; National Agency for Education, 2000). An example is the Swedish national science curriculum, which identifies five assessment criteria that are mostly linked to practical work (National Agency for Education, 2000). The criteria include planning and conducting experiments, interpreting and evaluating the results, and presenting a report. Nevertheless, the National Research Council (2005a) proposed that researchers, teachers, scientists and curriculum developers collaborate in relation to addressing the issue of assessing the learning of science during practical work. This should be in relation to the specific learning goals and most appropriate ways of measuring these goals, both in large-scale and school-based learning assessments. Examination bodies may be added to the above list as they are also role players in the assessment of science learners.

Quality of curriculum materials. Reformers have stated that materials (e.g. textbooks and learner manuals) focused on curricular goals play a critical role in the success of curricula (National Research Council, 2007, 2010). However, the activities found in practical work manuals are normally limited to structured inquiry (Zion et al., 2007). This level of inquiry is regarded by some researchers (e.g., Kaberman & Dori, 2009; Lord & Orkwiszewski, 2006) as inadequate in relation to enhancing the attitudes of learners towards science, as well as their critical and scientific thinking. It is thus useful for authors to include inquiry-based activities with a variety of levels of inquiry in practical work manuals.

Inadequate quality of teacher learning experiences. Teachers' professional development experiences often provide little or no direct experience in developing their content and pedagogical knowledge in addition to the skills that they need to organise and facilitate meaningful practical activities for learners (Sweeney & Paradis, 2004). One exception is the European Union project, SALiS (Student Active Learning in Science), which incorporated structured and guided inquiry into teacher learning linked to practical work (Kapanadze & Eilks, 2014).

4.3.2.2 Institutional-level extrinsic challenges linked to IBPW

Material-related challenges

Lack of facilities. Hands-on practical work requires adequate facilities for learning activities and for the safe storage of SEEMs (National Research Council, 2005a). Thus, in many countries, practical lessons take place in purpose-built science laboratories or classrooms (Childs et al., 2012; Ramnarain, 2011b; Toplis & Allen, 2012). However, researchers have observed limitations in laboratory facilities and the lack of science laboratories in school especially in rural areas (Childs et al., 2012; Kriek & Grayson, 2009; VanBalkom & Sherman, 2010). Due to these limitations, science teachers face considerable pressure in relation to gaining access to laboratories for conducting the required practical work (Higgins, 2009). Thus, in line with a new curriculum, the government of Georgia in 2006 invested in laboratories and science education equipment for inquiry-based science education (Slovinsky, 2012). However, the acquisition of laboratory facilities is not the only option where they are lacking. This is because in some cases, facilities or equipment may be available for practical work from the surrounding community. This includes mobile laboratories, science centres and local museums, as well as centralised laboratory facilities (National Research Council, 2005a; Singh & Singh, 2012). These facilities may be utilised by science learners and teachers in schools that have limited facilities. However, some researchers (Abrahams & Millar, 2008; Abrahams &

Reis, 2012) hold that what matters is how practical work is done and not where it is carried out.

Inadequate science education equipment and materials. IBPW involving physical manipulation depends heavily on the availability of SEEMs (Donnelly et al., 2013; Lin et al., 2013). However, SEEMs are in short supply in many classrooms in developing and industrialised countries (Kapanadze & Eilks, 2014; Kidman, 2012; Qhobela & Moru, 2014; Singh & Singh, 2012). At the same time, improvised hands-on SEEMs (such as self-created models, small-scale experiments) are useful in providing learners with inquiry-based experiences (Schmidt, 2003) in schools with limited science education equipment and a small budget (Poppe et al., 2011). For producing such equipment, some required basic materials are freely available in the local environment, at home and in school (Ezeasor, Opara, Nnajiofor, & Chukwukere, 2012; Pimpro, 2005; Singh & Singh, 2012; Wilke & Tronicke, 2008). In Germany, for instance, the use of improvised SEEMs in practical work is an increasing trend (Di Fuccia et al., 2012). At the same time, interactive computer simulations and other technological tools allow learners to gain inquiry-based practical experiences in addition to analysing data (Higgins & Spitulnik, 2008; Urban-Woldron, 2009). Some simulations, such as the Virtual Chemistry Laboratory simulations developed by the Chemcollective at the Chemistry Department in Carnegie-Mellon University, Pittsburgh and the Physics Education Technology (PhET) project simulations, are freely available to download or run from the internet (Donnelly et al., 2013; Perkins, Adams, Dubson, Finkelstein, Reid, Wieman et al.,, 2006).

Non-material-related challenges

Lack of time. Some teachers have concerns linked to the longer time requirements of IBPW (Anderson, 2007). In reality, IBPW demands more time than scripted laboratory work (Abrahams & Reis, 2012; Trumbull, Scarano, & Bonney, 2006). Thus, some teachers blame the use of recipe-type tasks, unlike unstructured and more open-ended tasks on the inadequate time available for most practical lessons (Abrahams & Millar, 2008). Other reasons for the lack of time include content overload and the lack of laboratory assistants in school, in addition to the time needed for preparing and cleaning the laboratory (Childs et al., 2012; Donnelly et al., 2011; Higgins, 2009). In order to support time-starved science teachers, some schools use Laboratory Technicians, Science Technicians or Teacher Aids (often special needs teachers) in the classroom (e.g., Higgins, 2009; Royal Society (The) & Association For Science Education, 2001). In the UK, 27% of Science Technicians frequently take part in practical work (Moor, Jones, Johnson, Martin, Cowell, & Bojke, 2006), while in Australia, some schools using an inquiry-based programme allow Laboratory Technicians to participate in practical work (Kidman, 2012).

Technology-rich classrooms may offer other options for dealing with the lack of time for IBPW. In such classrooms, time-starved teachers may use interactive computer simulations instead of real SEEMs, given that issues such as limited resources, safety, and cleaning are absent (Donnelly et al., 2013; Kirschuner & Huisman, 1998; Scalise, Timms, Moorjani, Clark, Holtermann, & Irvin, 2011). Due to the removal of characteristics such as limited resources, physicality and the cleaning of equipment by simulations (Scalise et al., 2011), learners can reach the findings stage of practical work much faster (Donnelly et al., 2013). Also, a Wireless Technology Enhanced Classroom (WiTEC, Liu, Wang, Liang, Chan, Ko, & Yang, 2003), permits a teacher to focus on teaching rather than spending time on time-consuming tasks such as having learners demonstrate their work on a whiteboard, as well as giving out and collecting worksheets. In addition, computer-aided practical work reduces the time that learners need for data collection (Barton, 2005). We see that time may be created for IBPW based on the choices that teachers make, and also by collaborating with other science teachers in addition to school managers.

Difficulty monitoring group learning. During practical work (in this case involving inquiry), learners normally work collaboratively in small groups or in pairs (Kind et al., 2011), making such practical work liable to issues relating to the monitoring of group learning. This is because learners normally interact verbally most of the time, leaving the teacher with little access to the interchange of ideas within the group (Liu et al., 2003). However, in order to monitor the performance of group work, some teachers use peer assessment (Wheater, Langan, & Dunleavy, 2005). In addition, in a technology-rich classroom, science teachers may use ICT tools to monitor the ideas and work of learners. Examples of ICTs useful for this purpose include Progress Portfolio, which is software designed to support inquiry-based learning (Loh, Reiser, Radinsky, Edelson, Gomez, & Marshall, 2001), and Wireless Technology Enhanced Classroom (WiTEC), which allows learners in a group to share information or ideas through their mobile learning devices in a way that is accessible to the teacher (Liu et al., 2003). Science teachers may consider the above ways of dealing with the issue of monitoring the group learning during IBPW.

Learner-related difficulties. Inquiry-based teaching and learning is quite alien to some learners (Donnelly et al., 2013). This fact can pose certain challenges for science teachers, for example, Bell, Urhahne, Schanze, and Ploetzner (2010) note that it is difficult for learners to pose questions that are relevant and researchable. However, learners become more capable when provided instruction on the definition, essential features, in addition to examples and non-examples of researchable questions (Cuccio-Schirripa & Steiner, 2000). Also, teachers need to encourage their learners through different ways of eliciting questions (Chin & Osborne, 2008; Dillon, 1988). One way to do so is to set up a cognitive conflict (Chin & Osborne, 2008; Piaget, 1985). In this regard, computer simulations are useful as they can be used to provide learners with discrepant events (Tao & Gunstone, 1999). Chin (2004) provides a review of the different ways to encourage learners to formulate researchable questions. These ways include creating an atmosphere in the classroom in which learners feel free to ask questions, modelling the posing of questions, providing learners suitable stimuli for asking questions, in addition to providing question stems or prompts.

Lack of support. Some teachers encounter a negative stance relating to inquiry-based pedagogy from their peers (Crawford, 2007). Additionally, it is difficult for teachers to reach the standards of inquiry-based instruction that reformers expect of them without strong institutional support (Lin et al., 2013). Thus, managerial and collegial support is useful in fostering IBPW.

Teaching outside area of specialisation. Curricula that place emphasis on inquiry constitute a challenge to teachers who, despite teaching science, are not trained for this role (Harris, Jensz, & Baldwin, 2005). In particular, engaging learners in inquiry introduces much more uncertainty and unpredictability into the classroom than exercises that are strongly structured (Trumbull et al., 2006). As a result, teachers who teach outside their subject specialism may rely more on routine and controllable activities (Hacker & Rowe, 1985). Such activities include recipe-type practical tasks (Abrahams & Millar, 2008), unlike inquiry-based tasks. However, science technicians can offer non-specialist teachers support in relation to practical work (Helliar & Harrison, 2011), for example, in Ireland, 11% of junior secondary schools use science technicians (Higgins, 2009), while in England, 27% of science technicians frequently assist in practical work (Moor et al., 2006).

The above discussion on the extrinsic challenges linked to IBPW, ways of reducing these challenges, and the actors with a role to play in this regard are summarised as follows in Table 4.5.

Table 4.5 Extrinsic challenges linked to IBPW, in addition to ways and actors useful in their reduction (Source: Researcher)

Category		Major challenge	Way (s) of reducing challenge	Role player (s)
System level	Non-material-related	Content-intensive curricula.	- Shift in curriculum emphasis from science content to teaching about science/ - Incorporating IB activities in science curricula.	Curriculum developers.
		Pressure from high-stakes assessments.	- Discussion on reducing the degree of emphasis on high-stakes assessment.	Various actors in the science education sector.
		Inadequate recognition and assessment of IBPW outcomes.	- Curricula incorporation of assessment criteria relating to IBPW. - Inclusion of assessment of practical investigations in national test scores. - Broad-based discussion between role-players.	Science teachers, researchers, scientists, curriculum developers, and examination boards (councils).

Category		Major challenge	Way (s) of reducing challenge	Role player (s)
		Quality of curriculum materials.	- Portraying science as certain and invariant in textbooks and lab manuals. - Manuals continue to emphasise procedures, unlike conceptual learning. - Activities in manuals typically limited to structured inquiry.	Authors.
		Inadequate quality of teacher/ learning experiences.	- Lack of practical experiences. - Lack of focus on the content and pedagogical knowledge and skills for planning and facilitating practical work.	Teachers, professional development providers.
Institutional level	Material-related	Lack of facilities.	- Utilisation of alternative facilities (e.g. mobile laboratories, local museums and science centres).	Science teachers, school managers.
		Lack of science education equipment and materials.	- Complementing interactive computer simulations. - Supplementing improvised equipment.	Science teachers.
	Non-material-related	Lack of time	- Use of teacher aids or laboratory technicians in the classroom. - Using simulated equipment and time-saving technology (e.g. WiTEC).	Science teachers, school managers.

Category		Major challenge	Way (s) of reducing challenge	Role player (s)
		Difficulty monitoring group learning.	- Use of peer assessment. - Employing relevant technology.	Science teachers.
		Learner-related difficulties (e.g., asking researchable questions).	- Training learners in questioning, modelling questioning, using different ways of eliciting questions, creating atmosphere in which learners are free to ask questions.	Science teachers.
		Teaching outside the area of specialisation.	- Using the support of laboratory or science technicians in practical work.	Laboratory/science technicians.
		Lack of support.	- Provision of strong, collegial and institutional support.	Other teachers and school managers.

4.3.2.3 Additional PDF component and related design principle

Component: Attending to contextual factors: The contents of Table 4.5 indicate that extrinsic challenges may not be ignored in the synthesis of a PDF to support the design and implementation of IBPW. In fact, the process of educational change is context specific to the extent that it will take place differently in each individual school (Rogan & Grayson, 2003). Here, the context is not only at an institutional level, but also at the level of the broader educational framework, given the institutional- and system-level challenges. The above discussion indicates that a second PDF component needs to be added to the other six identified in the previous research cycle. This additional component concerns contextual factors. The addition of this component raises the number of PDF components to seven, as listed below:

1. Professional development phases.

2. Professional development strategy.
3. Learning goals.
4. Instructional functions.
5. Teacher motivation.
6. Learning perspective.
7. Instructional design perspective.
8. Attending to contextual factors.

There is more support for the inclusion of this seventh component among the other components than is provided by the discussion summarised in Table 4.5. A multi-faceted approach, for example, is needed in curriculum improvement and implementation (Fullan, 1992).

Design principle linked to the PDF component. Having said that, with the inclusion of a new professional development framework component comes the need for an additional design principle. The design principle is as follows:

s

Design Principle #9.2: Incorporate the reduction of system-level as well as material- and non-material-related institutional-level challenges into the PDF in order to create circumstances that are more favourable towards teacher learning and practice.

(Abrahams & Reis, 2012; Chin, 2004; Goldman, 2005; Higgins, 2009; Kapanadze & Eilks, 2014; Lederman & Lederman, 2012; Lin et al., 2013; Poppe et al., 2011; Toplis & Allen, 2012; Wheater, Langan, & Dunleavy, 2005)

4.3.3 Intrinsic challenges linked to IBPW and related design principle

Here, specific intrinsic challenges linked to IBPW are presented and clarified before considering one or more ways of reducing each challenge. The conceptual framework of teaching challenges (Figure 4.3) is useful in framing this discussion.

4.3.3.1 Planning phase

The challenges in this phase of instructional design are linked to the preparation of learning experiences and the selection and/or production of SEEMs.

Preparation of learning experiences

Situating practical work in the flow of science instruction. In order for practical experiences to be effective in meeting science education goals, teachers need to integrate the learning of both the process and content of science (National Research Council, 2005a). However, this is not the case, as observed by Childs et al. (2012),in lessons in which learners were asked to determine which ball would bounce the highest. Although the learners successfully designed and carried out their investigation, the teachers struggled thereafter to link the activity to any key scientific concepts. Thus, when interviewed, the teachers were uncertain about the concepts that could be developed using the activity. This is evidence of a lack of adequate PCK relating to instructional approaches. Integrating practical work into the flow of science instruction aimed at teaching both the content and process of science is useful in making practical work effective (National Research Council, 2005a).

Finding open-ended research questions. Finding genuinely open-ended problems suitable for investigations in school classrooms may be difficult (Kind et al., 2011). This difficulty arises from the lack of adequate pedagogical skills and also PCK with respect to curricular materials. While open-ended problems may be established with reference to course materials (Kind et al., 2011), models or frameworks exist for designing problems and also inquiry-based procedures (tasks) to carry out practical work (Girault, d'Ham, Ney, Sanchez, & Wajeman, 2012; Hung, 2006). Also, for guidance, assessment bodies may provide problems for use in practical activities (Donnelly, Buchan, Jenkins, Laws, & Welford, 1996). At the same time, instead of a single open-ended problem, teachers may select or design a series of smaller problems leading to the development of particular prescribed concepts and skills (Davis, 1999).

Production of materials

Lack of equipment improvisation skills. There are shortages, hazards and adverse environmental effects linked to some conventional science education equipment and materials (Ens et al., 2012; Poppe et al., 2011; Singh & Singh, 2012). There are, however, a number of impediments in the planning of practical work involving improvised science education equipment. These comprise a lack of motivation, lack of creativity, and inadequate practical skills in relation to producing such equipment, in addition to knowledge on how to use these in practical work (Bhukuvhani et al., 2010; Kadzera, 2006; Stephen, 2015). These challenges result from a shortfall in the TK about standard technology and/or PCK relating to curricular materials, in addition to the inadequate skills and values (for example commitment) of the teachers. In this regard, however, Akuma and Callaghan (2016) provide a framework that can be used to strengthen teachers.

4.3.3.2 Implementation phase

Engagement phase

From a socio-cultural perspective, learners construct new knowledge on the basis of their prior learning (Garbett, 2011). However, teachers generally do not give learners the opportunity to situate their learning experiences in the context of their prior learning during practical work (Abrahams & Millar, 2008; Lunetta et al., 2007). Thus, most science teachers possess inadequate PCK of learners' understanding. Eisenkraft (2003) notes that a popular way of eliciting prior knowledge is formulating a "what do you think" question at the outset of lessons. In general, ways of engaging learners include defining a problem that learners have to solve, performing a problematic situation, demonstrating a discrepant event, and asking a question (Bybee et al., 2006). Discussions around misconceptions can also serve as a stimulus (Naylor et al., 2007). Teachers can be prepared to recognise ideas in the repertoire of their learners and to identify ways of building on these ideas through effective professional development (Gerard et al., 2010).

Exploration phase

Difficulties persuading learners to engage in inquiry. The need for teachers to give learners opportunities to pose questions, formulate hypotheses and design experiments to seek answers to their questions has been highlighted by many researchers (e.g., Neber & Anton, 2008; Ottander & Grelsson, 2005). However, teachers seldom engage their learners in formulating the questions and the hypothesis to investigate and plan the experimental procedure needed (e.g., Chin & Osborne, 2008; Ottander & Grelsson, 2006). Thus, Kind et al. (2011) observe that more than 80% of the time, the learners involved in practical work focus on data gathering. In reality, teachers often face difficulties in relation to helping learners in the asking of thoughtful (researchable) questions and in designing their own investigations (Marx, Freeman, Krajcik, & Blumenfeld, 1998; Schneider, 2013). Teachers are bound to face challenges in this regard if they lack adequate PCK linked to instructional approaches. Such teachers need to develop the capacity of their learners to ask questions that may be investigated, in addition to being knowledgeable in ways of eliciting and evaluating these questions. According to Cuccio-Schirripa and Steiner (2000), the ability of learners to ask researchable questions increases when they are taught the definition, essential features, and examples and non-examples of questions that can be investigated. Chin and Kayalvizhi (2002) provide further information on this aspect. There is also evidence that involving IBPW enables learners become capable of asking investigable questions in addition to hypothesising (Hofstein, Shore, & Kipnis, 2004). In terms of persuading learners to participate in the development of procedures for their investigations, one way of doing so noted by Di Fuccia and Ralle (2010) is to provide a procedure with blanks in it that learners complete prior to the practical work lesson. Also, Girault et al. (2012) provide a model for use by learners and teachers in designing inquiry-based laboratory procedures.

Providing adequate learner support. Teachers find it challenging to decide when to provide support and when to hold back information in order to promote authentic inquiry learning (Crawford, 2007; Furtak, 2006). In this regard, it may be useful for the teacher to first of all keep in mind the particular type of IBPW (structured, directed or open) being implemented (Table 4.2), for example, in directed IBPW, learners may not be given the procedure to follow although they may be supported as needed. However, while teachers need to refrain from answering learners' questions using direct answers, they may provide learners guidance using hints, indirect questions and suggestions (Blake & Pope, 2008; McComas, 2005; Urban-Woldron, 2009). Whatever the method employed, support of learners in the form of feedback or prompts needs to be immediate (Lee et al., 2008). In fact, teachers need to be able to respond quickly and appropriately, even to the unexpected concerns and interests of their learners (Van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001).

Explanation phase

Persuading learners to reflect on their observations. In order to guide learners in their inquiry efforts, teachers need to press them to explain, justify, critique, and revise their ideas as they examine their experiences with phenomena (Schneider, Krajcik, & Blumenfeld, 2005). However, teachers seldom challenge learners to reflect on their observations (Abrahams & Millar, 2008) or engage in manipulating the data that they have collected (Ottander & Grelsson, 2006). Donnelly et al. (2013), for example, observed in a case study of four science teachers that three considered the analysis and critiquing of the findings of an experiment as an add-on to practical work and not an integral part of it. Supporting science learners in making sense of their experiences is difficult, especially for teachers new to inquiry-based pedagogy (Schneider, 2013). This indicates a shortfall in CK about inquiry and/or PCK linked to instructional approaches. Science teachers need to be aware of the need to engage their learners in sharing ideas and in reflecting on and debating what they observe or experience about the phenomena that they produce during practical work (Kind et al., 2011; Schneider, 2013). Questioning plays a role in eliciting explanations, evaluating evidence and in justifying reasoning (Chin & Osborne, 2008). However, unsuitable questioning methods can limit opportunities for learners to construct and revise scientific explanations to the phenomena that they are investigating (McNeill & Pimentel, 2010). It is also useful for teachers to demonstrate good scientific practices such as engaging in debate and posing open questions that elicit justification (Jiménez-Aleixandre et al., 2005). Thus, Minstrell and Kraus (2005) note the importance of preparing science teachers to elicit and address the ways that learners reason about phenomena.

Elaboration phase

The elaboration and application of learning leads to enhanced learner understanding (Hofstein & Lunetta, 2004; Hofstein, Navon, Kipnis, & Mamlok-Naaman, 2005). However, teachers generally do not give learners the opportunity to apply their learning experience to other phenomena (Lunetta et al., 2007). This may be attributed to a lack of adequate PK. Teachers need to allocate a greater proportion of class time for practical work to assist learners in the application of ideas related to the phenomena they produce (Abrahams & Millar, 2008). For instance, science teachers may engage their learners in developing explanations of the science involved in real life (Schneider, 2013). In an inquiry-based learning context (in this case during practical work), teachers always need to pose questions to extend learners' ideas (e.g., Chin, 2007). However, teachers need to consider their questioning methods given that this can limit opportunities for learners to elaborate on scientific explanations of the phenomena that they are investigating (McNeill & Pimentel, 2010).

Evaluation phase

Formative evaluation. On-going formative assessment may assist in enhancing teacher awareness of the science needs and capabilities of their learners (National Research Council, 2005a). The questions that learners ask are potentially useful in this regard (Bell & Cowie, 2001) as these questions provide insight into their puzzlement, knowledge and understanding, thus acting as a window into their minds (Chin & Osborne, 2008). However, teachers often do not encourage their learners to ask questions (Chin & Osborne, 2008). Despite being beneficial to learners, formative assessment is still rare in most classrooms (Ruiz-Primo & Furtak, 2007). However, a sound CK and how it is constructed is needed for formative interactions between a teacher and learners (Moreland, Jones, & Northover, 2001). Thus, some teacher education courses focus on enabling students to develop an understanding of the structure of physics in addition to conceptual understanding (Nivalainen et al., 2010). In fact, teachers need to develop content knowledge that is rich, adequate and flexible (Nivalainen et al., 2010; Windschitl, 1999). That said, Campbell, Abd-Hamid, and Chapman (2010) developed two instruments for measuring the perceived extent to which learners experience inquiry in science classrooms from the perspective of learners and teachers respectively. These instruments are based on the principles of scientific inquiry outlined by the National Research Council (2005b). The principles comprise framing research questions, designing investigations, conducting investigations, collecting data, and drawing conclusions. These instruments are thus useful in the formative assessment of IBPW.

Summative evaluation. Many science teachers either have concerns about the grading of learners involved in inquiry-based learning (Anderson, 2007), in this case during practical work, or they actually find the assessment of IBPW difficult (Higgins, 2009). At the same time, although ways exist for doing so, these are rarely used (Di Fuccia & Ralle, 2006, 2010). This may be due to a gap in the PCK linked to assessment. In order to be able to focus practical learning experiences on clear goals, teachers need to understand assessment methods (National Research Council, 2005a)**.** A number of methods exist for carrying out the summative assessment of IBPW. These include assessing the understanding of learners by asking them to draw experimental setups (Schmidkunz, 2011) and concept maps linking the practical activities carried out and the underlying scientific concepts (Sager & Ralle, 2011). Also, learners may be asked for possible observations during an experiment and exactly why they expect these observations to occur (Reif & St. John, 1979). When used as a written assessment, this allows the teacher to assess whether learners have understood the experiment and whether they are able to link it to the underlying theory. Similarly, the teacher may present learners with an open-ended problem to resolve as a written task (Witteck & Eilks, 2006). The learners are asked to devise ways of solving the problem by experiment. Based on the written report, the teacher can assess the learners on such aspects as the formulation of hypotheses, the planning and conduct of the experiment, in addition to the falsification or verification of the hypothesis.

4.3.3.3 Related revised design principles

The above discussion indicates that intrinsic challenges linked to the design and implementation of IBPW can be associated to a shortfall in various domains of teacher knowledge (CK, PK, TK, and especially PCK), skills (e.g. creativity, pedagogical and practical skills) in addition to values (such as commitment). In a similar light, one of the extrinsic challenges in Table 4.5 is linked to teacher competences. This is a system-level, non-material-related challenge regarding the inadequate quality of teacher learning experiences. This is in the sense that teacher learning experiences linked to practical work need to focus on enhancing the content and pedagogical content knowledge, as well as the skills of teachers linked to the planning and facilitation (design and implementation) of meaningful practical work. Against this background, and considering earlier discussions, Design Principle #1.1 may be revised as follows:

> *Design Principle #1.2:* Aim the PDF at enhancing the related knowledge [a], skills [b], attitudes, beliefs [c], values [d] and practices [e] of teachers as effective teacher learning in general and in relation to practical work in particular. This focuses on these areas of competence, which are linked to various specific intrinsic teaching challenges.
>
> (Elster, 2009; Fishman, Marx, Best & Tal, 2003; Loucks-Horsley, Love, Hewson, Stiles & Mundry, 2003; Magnusson et al., 1999; Mishra & Koehler, 2006; Rozenszajn & Yarden, 2014; Sweeney & Paradis, 2004)
>
> [a] Consisting of CK, PK, TK and PCK.
>
> [b] Consisting of pedagogical skills, creativity and practical skills.
>
> [c] Including about the science curriculum and the understanding of science learners.
>
> [d] Which include care and concern for learners, commitment and dedication to their practice, collaboration and team spirit, in addition to the desire for continuous learning, innovation and excellence.
>
> [e] In relation to the IB learning practices in Table 4.2.

The above design principle is in line with the fact that teachers need to change their viewpoints (beliefs), attitudes, and teaching methods (including practices) if they are to implement educational changes such as reform-based practical science (Guskey, 2003; Vannatta & Fordham, 2004). This change is important considering, for example, that changes in attitude influence behaviour (Jones & Carter, 2007).

Considering *Design Principles #1.2* and *Design Principles #9.2*, we see that a broad-based approach is needed regarding the design and implementation of inquiry-based practical work. This is in line with the multi-faceted approach recommended by Fullan (1992) in curriculum improvement and implementation. In this case, the approach entails reducing both intrinsic and extrinsic challenges linked to inquiry-based practical work. In the reduction of these two categories of challenges linked to IBPW, as contained in these two design principles, the Ecological Theory of Development (Bronfenbrenner, 1979) is useful. According to this theory, the environment consists of five structures, the inner most of which is the individual and factors linked to the personal attributes of the individual (in this case intrinsic challenges). The most immediate of the remaining four structures in the environment consist of cultural, physical, and social factors in the immediate settings in which people live. Extrinsic challenges linked to inquiry-based practical work can arise from these factors. For example, teaching is affected limited learner ability and exposure to inquiry, and large classes (Ramnarain, 2014; Ramnarain & Schuster, 2014). Based on this theory, efforts to reduce intrinsic challenges linked to IBPW need to be nested within efforts towards reducing extrinsic challenges linked to IBPW. Hence, the following design principle:

> *Design Principle #10.2:* Locate efforts in reducing intrinsic challenges within efforts aimed at reducing extrinsic challenges. This is done in order to align the PDF with the Ecological Theory of Development and the multi-faceted approach needed in curriculum implementation and improvement.
>
> (Bronfenbrenner, 1979; Fullan, 1992).

4.3.4 Specified design principles and conceptual content-specific PDF

4.3.4.1 Specified design principles

Based on the above discussion, ten specified design principles are available for synthesising the content-specific version of a PDF to support the design and implementation of IBPW in any educational context. The design principles are as follows:

> *Design Principle #1.2:* Aim the PDF to enhance the related knowledge [a], skills [b], attitudes, beliefs[c], values[d] and practices[e] of teachers as effective teacher learning in general, and in relation to practical work in particular. This focuses on

these areas of competence, which are linked to various specific intrinsic teaching challenges.

(Elster, 2009; Fishman, Marx, Best & Tal, 2003; Loucks-Horsley, Love, Hewson, Stiles & Mundry, 2003; Magnusson et al., 1999; Mishra & Koehler, 2006; Rozenszajn & Yarden, 2014; Sweeney & Paradis, 2004).

[a] Consisting of CK, PK, TK and PCK.
[b] Consisting of pedagogical skills, creativity and practical skills.
[c] Including about the science curriculum and the understanding of science learners.
[d] Which include care and concern for learners, commitment and dedication to their practice, collaboration and team spirit, in addition to the desire for continuous learning, innovation and excellence.
[e] In relation to the IB learning practices in Table 4.2.

Design Principle #2.2: Use a socio-cultural or a situated learning perspective as the learning perspective for the PDF in order to allow for collective participation in professional learning communities.

(El-Deghaidy, Mansour & Alshamrani, 2015; Marx & Harris, 2006; National Science Teachers Association, 2006; Ostermeier et al., 2010).

Design Principle #3.2: Incorporate a pre-participation phase, an exploration/planning phase, an implementation phase, and a post-implementation phase into the PDF with reference to studies on effective teacher learning.

(Chikasanda et al., 2013; Mansour, EL-Deghaidy, Alshamrani & Aldahmash, 2014; Rozenszajn & Yarden, 2014; Yerushalmi & Eylon, 2013).

Design Principle #4.2: Adopt lesson studyas the professional development strategy in the PDF given, for example, that lesson study is usable across different socio-economic contexts, involves active learning in a professional learning community, and is aligned to core features of effective teacher learning.

(Desimone, Porter, Garet, Yoon & Birman, 2002; Gaible & Burns, 2005; Lewiset al., 2006; Perry & Lewis, 2009).

Design Principle #5.2 (#3.2 revised): Incorporate lesson study phases into the PDF under related major phases of professional development (pre-participation, exploration/planning, implementation, and post-implementation) in order to provide a sequence for planning activities within these major professional development phases.

(McKenney et al., 2006; Reigeluth, 1999).

Design Principle #6.2: Include instructional functions (e.g. reviewing relevant prior learning, providing overviews and learning goals, providing guidance and feedback, and reviewing learning periodically) in the PDF in order for professional development to be more effective and also to serve as a transition between its phases.

(Mettes, Pilot & Roossink, 1981; Rosenshine & Stevens, 1986; Stolk et al., 2012; Terlouw, 2001).

Design Principle #7.2: Incorporate intrinsic and extrinsic teacher motivation into the PDF given that teachers need to be motivated in order to change their practice and that although improved performance is effective as an intrinsic incentive, motivation is difficult to sustain without extrinsic incentives.

(Boyd, Banilower, Pasley & Weiss, 2003; Gaible & Burns, 2005; Pintrick & Schunk, 1996; Stolk et al., 2009b).

Design Principle #8.2: Combine the SLID [a] model and the 5E [b] instructional model in order for the PDF to reflect practical work that is consistent, systematic, adequately sequenced and organised, as well as more relevant and effective.

(Balta, 2015; Bybee, 1997; Dick et al., 2001; Dogru-Atay & Tekkaya, 2008; Kallio, 2008; National Research Council, 2000; Peterson, 2003; Reiser & Dempsey, 2007)

[a] SLID = Science Laboratory Instructional Design
[b] 5E = Engagement, Exploration, Explanation, Extension and Evaluation

Design Principle #9.2: The PDF needs to incorporate the reduction of system-level, as well as material- and non-material-related institutional-level challenges in order to create circumstances that are more favourable for teacher learning and practice.

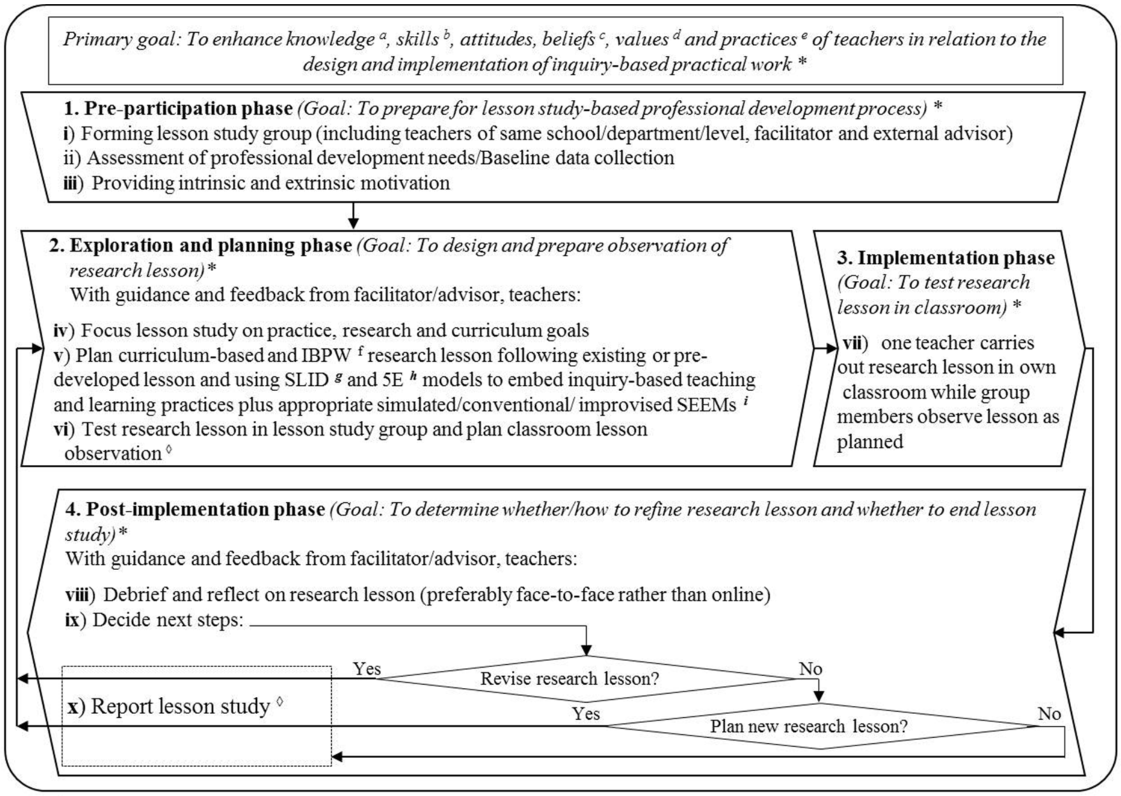
(Abrahams & Reis, 2012; Chin, 2004; Goldman, 2005; Higgins, 2009; Kapanadze & Eilks, 2014; Lederman & Lederman, 2012; Lin et al., 2013; Poppe et al., 2011; Toplis & Allen, 2012; Wheater, Langan & Dunleavy, 2005).

Design Principle #10.2: Locate efforts in reducing intrinsic challenges within efforts aimed at reducing extrinsic challenges, in line with the Ecological Theory of Development and the multi-faceted approach needed in curriculum implementation and improvement.

(Bronfenbrenner, 1979; Fullan, 1992).

4.3.4.2 Content-specific version of professional development framework

Based on the above 10 specified design principles, the content-generic version of the Professional Development Framework (PDF) from the previous research cycle (Figure 3.8) can now be revised. The result is the content-specific version of the PDF. This version of the PDF contains tentative details of all the components of the completed intervention. The version thus reflects how the completed PDF looks. This result is shown in Figure 4.9.



Legend:
[a] consisting of content knowledge, pedagogical knowledge, technological knowledge and pedagogical content knowledge
[b] consisting of pedagogical skills, creativity and practical skills
[c] including about the science curriculum and the understandings of science learners
[d] including care and concern for learners, commitment and dedication to practice, collaboration and team spirit, in addition to desire for continuous learning, innovation and excellence
[e] linked to inquiry-based learning (e.g., asking questions, planning and conducting investigations, analysing and interpreting data, constructing explanations and engaging in evidence-based arguments)
[f] IBPW = Inquiry-Based Practical Work
[g] SLID = Science Laboratory Instructional Design model (Phases: Initiation, Planning, Implementation (based on 5E [h] instructional model in this case), Evaluation and Feedback)
[h] 5E instructional model (Phases: Engagement, Exploration, Explanation, Extension and Evaluation)
[i] SEEMs = Science Education Equipment and Materials

* Providing learning goals on a continuous basis (Primary goal lies in enhancing teacher competences in order to reduce intrinsic challenges regarding the design and implementation of IBPW. For example, teachers not giving learners opportunity to link new learning to prior learning (intrinsic challenge) is reduced by enhancing pedagogical content knowledge linked to the understanding learners through the use of the SLID and 5E instructional models (way of reducing intrinsic challenge)

◊ Reviewing learning periodically

▢ = Learning and practice environment where various specific system-level and institutional-level extrinsic challenges are reduced (For example, in relation to inadequate quality of teacher learning experiences (extrinsic challenge), professional development providers (role players) provide more practical learning experiences involving either structured, guided or open inquiry (way of reducing extrinsic challenge)

Figure 4.9 Content-specific PDF to support teachers in the design and implementation of IBPW (Source: Researcher)

Due to the implementation of the specified design principles, the conceptual content-specific version of the PDF in Figure 4.9 is significantly different from the conceptual content-generic version from the previous research cycle (Figure 3.8). For example, the primary goal of the PDF has become more specific. The three new specified design principles have also contributed in transforming the PDF through the addition of two professional development components. Design principle #8.1 has been used to provide the PDF an instructional design perspective. Through design principle #9.2, the PDF now responds to contextual factors (extrinsic challenges). Due to design principle #10.2, an outer box has been added to the PDF and described in the legend of the PDF.

The content-specific version the PDF in Figure 4.9 is the second version (PDF v2) of the PDF that was developed. This version of the PDF, together with the preceding ten specified design principles on which the PDF was based, are the outcomes of this phase of the present research cycle. The outcomes are based on existing data gathered using the systematic literature review described in Section 4.2.4. However, the PDF in Figure 4.9 may be improved based on formative evaluation. It is this evaluation that allows the outcomes of this research cycle to also be informed by empirical data.

4.4 EVALUATION PHASE 2

4.4.1 Introduction

The purpose of this phase of the current research cycle is to formatively evaluate the above conceptual content-specific version of the Professional Development Framework (PDF v2). In the evaluation, the quality criteria used are consistency and relevance. This is in accordance with the detailed research process (conceptual framework) in Figure 4.1.

On the above basis, data is needed regarding the extent to which the PDF is based on scientific knowledge, as well as the extent to which its components are logically linked to one another. In this regard, the identification of shortcomings in the conceptual content-specific version PDF may be accompanied by the generation of suggestions on how the shortcomings may be resolved or how the PDF may otherwise be improved (Nieveen & Folmer, 2013; Van den Akker, 1999). Thus, participants in the evaluation may evaluate not only the consistency and relevance of the PDF, but also other aspects deemed to need improvement. This includes expected practicality and expected effectiveness.

4.4.2 Data collection and analysis

Unlike the previous phase, this phase of the current research cycle involved the collection and analysis of empirical data. In this regard, the phase was driven by the discussion of the techniques of empirical data collection and analysis in Section 2.7. It is thus necessary to consider the sampling of participants, techniques of data collection, data analysis, as well as ethical issues.

4.4.2.1 Sampling

In a development study (such as this one), participants need to be selected that can assist in answering the research (in this case evaluation) question (Nieveen & Folmer, 2013). Thus, a purposive sample of experts was needed in the formative evaluation. The participants considered in the formative evaluation need to be experts in inquiry-based science education research and/or practice. They also need to be teacher professional development researchers and/or providers. This is in line with design research in the sense that these are among the users of the completed PDF. On this basis, two experts were identified.

4.4.2.2 Techniques of data collection

As per the research process for this study contained in Figure 4.1, the method of data collection used in this formative evaluation was one-to-one evaluation. The instrument on which basis the formative evaluation was carried out is provided in Appendix B. The instrument consists of four sections: biographical information, general introduction, introduction of the PDF, and formative evaluation of the framework.

The formative evaluation section of the instrument contains five open-ended items to evaluate the consistency and relevance of the PDF: two on relevance and consistency each, and one on any other aspect of the PDF. The administering of this instrument was different for the two experts. In the case of Expert 2 (E2), the instrument was sent by email following a formal introduction email to which the expert responded positively. In this case, the general introduction section of the instrument was more detailed in order to provide ample information that includes the background of the research, problem statement, and intentions of the PDF.

Following the initial response of E2 to the instrument, the researcher asked clarification questions over several emails until the comments of this reviewer were fully understood and their implementation found suitable to the expert. This is exemplified in the following excerpt:

> Researcher: Would the step above be adequate as an addition to phase 2 of the PDF? Did I understand your suggestion adequately?
> E2: I am afraid, but I might have not succeeded in clarifying the point I wanted to make. I will try to reach you tomorrow on the phone.
>
> Researcher: I realise that I read your last comment too quickly. The point you make is rather that …
>
> E2: Your new interpretation is the correct one. That's the point I wanted to make…

The interaction between E2 and the researcher described above lasted over a period of one week.

In the case of Expert 1 (E1), two face to face sessions lasting one hour each took place. The first session focused on the introduction of the conceptual content-specific version of the PDF. However, the researcher first briefly presented the purpose of the research before describing each component of the PDF. In addition, the researcher indicated where/how each component was incorporated into the PDF. While doing so, the researcher asked the expert several times whether there were any questions. The expert also spontaneously asked questions to check whether they had understood the intent, composition and arrangement of the PDF components, as well as the purpose of the evaluation. For instance, E1 asked if the term *relevance* refers to *content validity.* In response, the researcher agreed. In the course of the presentation and discussion of the PDF, the expert made comments linked to the evaluation questions, which the researcher took note of. However, it was in the second session that the discussion focused on the evaluation questions. In addition to the specific comments and advice, E1 provided literature that the researcher could consult in relation to improving the relevance of the PDF. The literature covered both teacher professional development and inquiry-based science education (Beauchamp & Thomas, 2009; Beijaard, Verloop, & Vermunt, 2000; Clarke & Hollingsworth, 2002; Gaigher, Lederman, & Lederman, 2014b; Walkington, 2005). Thus, in reality, the formative evaluation of the PDF involved both existing and empirical data from two experts.

4.4.2.3 Data analysis

This aspect was carried out in line with the deductive-inductive approach involved in this study. In the case of relevance, each concept in the data was assigned first to one of the components (such as a goal) of the PDF. Following this, the data was analysed inductively using the thematic technique of data analysis based on the data-driven inductive approach (Boyatzis, 1998).

4.4.2.4 Ethical considerations

The data collection, data analysis and reporting linked to this formative evaluation were carried out while observing certain ethical principles. These principles, which include safety in participation, informed consent, voluntary participation, and guaranteeing confidentiality are discussed in Section 2.8, for example, letters of informed consent were sent by email to potential experts prior to their participation in the data collection. The data collection was scheduled when participants became available and was broken down into multiple sessions at the convenience of the experts. Moreover, in presenting the results as seen below, the identity of the experts and their host institutions are not provided.

4.4.3 Outcomes and reflection

Before presenting and using the results of the formative evaluation, it is useful to firstly present a profile of the experts who participated in the formative evaluation. This can be seen in Table 4.6.

Table 4.6 Profile of experts involved in evaluation of conceptual content-specific PDF (Source: Researcher)

Aspect	Expert 1	Expert 2
Highest qualification	D Ed, PhD	Dr. rer. nat. (PhD)
University/Institution	"Research intensive university."	"Foreign governmental development cooperation service."
Position	Professor Emeritus.	Programme manager (recently in-service programme coordinator).
Country of origin	South Africa.	Germany.
Years of experience in teacher professional development research	20	0
Years of experience in delivering teacher professional development	5	12
Years of involvement in inquiry-based science education research	15	12
Years of involvement in inquiry-based teaching	15	12

Based on Table 4.6, the two experts (E1 and E2) involved in the evaluation were qualified professionals with considerable experience in research and/or practice in both teacher professional development and in inquiry-based science education and/or research. The experience of E2 spanned four different countries - Cameroon, Germany, Kenya and South Africa. The results from the analysis of the empirical data from these experts and the literature recommended by E1 are presented below. The results are presented in two aspects: relevance and the consistency of the PDF.

4.4.3.1 Relevance of the PDF

E2 noted that the components of the PDF are all relevant. However, based on the comments of E1 and the literature that this expert recommended, the relevance of the PDF can be improved. This is discussed below for the components of the PDF framework that need improvement.

Professional development goal. The formative evaluation revealed two ways of improving the goal of the PDF. Firstly, E1 advised that in order to make the PD goal more complete, the development of teacher identity may be included. This request is in line with the literature in that identity development is important in teacher professional development (Hoban, 2007). While teacher identity is not easy to define (Beauchamp & Thomas, 2009), this concept involves how a teacher sees themself as being a teacher (professional perspective) and how they feel about being a teacher (viewed from an individual perspective) (Beauchamp & Thomas, 2009; Meyer, 1999). While this indicates the multi-faceted nature of teacher identity, this identity is also dynamic and influenced by internal factors (such as emotion) and external factors (such as professional experiences in a particular context) (Beauchamp & Thomas, 2009; Flores & Day, 2006; Rodgers & Scott, 2008). The importance of developing teacher identify is evidenced, for example, by the fact that teachers' perceptions of their professional identity has an effect on their professional development and efficacy (Beijaard et al., 2000). Also, this perception affects teachers' capacity and willingness to handle educational change and to incorporate innovations in their classrooms. In this case, the change or innovation is the infusion of inquiry in practical work. The professional dimension of teacher identity is linked to teacher knowledge such as content and pedagogical knowledge (Beijaard et al., 2000). This knowledge includes instructional planning and implementation (in this case using the SLID and 5E models), and classroom inquiry (in this case, during practical work). Thus, the development of teacher identity involves enabling teachers to understand their practice and themselves (Ministère de L'Éducation, 2001). This can be achieved through the provision of learning contexts involving conflict and the challenging of beliefs (Smagorinsky, Cook, Moore, Jackson, & Fry, 2004). Reflection and practice (Freese, 2006), in addition to the use of a school-based teacher education (Beauchamp & Thomas, 2009) is useful in this regard. The above means of developing teacher identity are already incorporated into the current version of PDF. However, the development of teacher identity is not reflected in the primary goal of the PDF.

In addition to not reflecting the development of teacher identity, the current goal of the PDF reflects a different professional development model than the actual one involved in the PDF. This model is the deficit model (Clarke & Hollingsworth, 2002), which, based on training, is limited to the enhancement of teacher knowledge and skills (Guskey, 1986). The demonstration of specific competences is no longer adequate in teacher professional development (Walkington, 2005). Actually, professional development needs to enhance the practice of participants (Clarke & Hollingsworth, 2002). Although this is involved in the PDF through the implementation phase, for example, the enhancement of practice is not reflected in the PD goal, which is deficit orientated.

Based on the above discussion, the goal of the PDF needs to reflect the enhancement of practice and teacher identity. As a result, the corresponding design principle is revised as follows:

Design Principle #1.2b: Aim the PDF to enhance the related competences*in addition to the professional identity and practice of teachers as these are important in effective teacher learning in relation to the intrinsic challenges linked to IBPW.

(Clarke & Hollingsworth, 2002; Elster, 2009; Fishman, Marx, Best & Tal, 2003; Hoban, 2007; Loucks-Horsley, Love, Hewson, Stiles & Mundry, 2003; Magnusson et al., 1999; Mishra & Koehler, 2006; Rozenszajn & Yarden, 2014; Sweeney & Paradis, 2004).

* Consisting of knowledge[a], skills[b], attitudes, beliefs[c], values[d] and practices[e]

[a] such as CK, PK, TK and PCK.

[b] Consisting of pedagogical skills, creativity and practical skills.

[c] Including information about the science curriculum and the understanding of science learners.

[d] This includes care and concern for learners, commitment and dedication to their practice, collaboration and team spirit, in addition to the desire for continuous learning, innovation and excellence.

[e] This is in relation to the IB learning practices in Table 4.2.

Learning theory. E1 noted that the sociocultural and situated cognition perspectives are appealing learning perspectives in relation to the PDF. However, he added that the Social Cognitive Theory would be more useful. This opinion is in line with Clarke and Hollingsworth (2002), who note that if professional development is to simultaneously enhance teacher knowledge and practice, then the cognitive and situative learning perspectives need to be combined. The situative perspective holds that learning results from participation in socially-organised practices involving cognitive apprenticeship (Brown et al., 1989; Rogoff, 1990). Similarly, the Social Cognitive Theory (Bandura, 1986, 2001) holds that people acquire knowledge, skills, beliefs, attitudes, strategies and attitudes by observing other people (vicarious learning), as well as through actual performance (enactive learning) (Schunk, 2012). However, teachers may also be enhanced by engaging in reflection (Teacher Professional Growth Consortium, 1994). Reflection involves looking back at thoughts and practices in relation to their value or effectiveness (Beauchamp & Thomas, 2009). Reflection, enactment and observation are all involved in the existing PDF in the exploration/planning, implementation, and post-implementation phases. However, unlike the case with reflection, the PDF does not ensure that most, if not all participants can experience both observation and enactment as a means of learning in the course of their professional development. This is in the sense that the existing PDF does not call for rotation among participants in serving as observers (thus learning vicariously) and serving as the teacher (enactive learning). Based on the above discussion, the corresponding design principle may be revised as follows:

> *Design Principle #2.2b:* Use the Social Cognitive Theory as the learning perspective for the PDF in order to allow for collective participation in a professional learning community involving the enhancement of the competences, professional identity, and practice of each teacher through observation, enactment and reflection.
>
> (Bandura, 2001; El-Deghaidy, Mansour & Alshamrani, 2015; Marx & Harris, 2006; National Science Teachers Association, 2006; Ostermeier et al., 2010; Schunk, 2012; (Teacher Professional Growth Consortium, 1994).

Teacher motivation. Based on the Social Cognitive Theory, people learn from the consequences of the actions that they undertake (Schunk, 2012). These consequences are sources of motivation. E1 cited the incorporation of motivation in the existing PDF as one reason why the PDF needs to be based on the social cognitive learning perspective. Contemporary theories consider motivation in cognitive terms as most motivation processes have a cognitive component (Schunk, 2012). A teacher is motivated by the observation of the success of peers (extrinsic motivation) as well as finding that their efforts yield success (intrinsic motivation) (Schunk, 1995, 2012). Intrinsic motivation can be sustained over long periods in the absence of external incentives based on given- or self-formulated goals (Schunk, 2012). However, these examples of ways of creating and sustaining motivation are not included in the PDF in Figure 4.9. Thus, E1 noted that the PDF needed to be specific in relation to both intrinsic and extrinsic teacher motivation. While motivation is a very broad concept, the specification of intrinsic and extrinsic motivation may be limited here to the provision of examples. The related design principle may be revised accordingly as follows:

> *Design Principle #7.2b:* Incorporate intrinsic and extrinsic teacher motivation into the PDF given that teachers need to be motivated in order to change their practice. Although goal-setting and improved performance is effective as an intrinsic incentive, motivation is difficult to sustain without extrinsic incentives (such as access to additional resources and observing the success of peers).
>
> (Boyd, Banilower, Pasley & Weiss, 2003; Gaible & Burns, 2005; Pintrick & Schunk, 1996; Stolk et al., 2009b; Schunk, 1995, 2012).

4.4.3.2 Consistency of the PDF

Regarding the integration of the components of the PDF, E2 noted that "[t]he logical flow of the framework is adequate. It is not overloaded and the backflow allows for improving single lessons and lesson sequences". However, E1 made two suggestions about the consistency of the PDF. The first one was that external factors that influence the design and implementation of inquiry-based practical work (IBPW) may be added in the body of the PDF if there is room. This suggestion indicates that Design principle #9.2 can be better implemented. E1 also noted that the arrangement of the components of the PDF reflected a linear professional development process to an extent. The expert then suggested that an integrated matrix be used instead. A multi-linked conceptual framework is needed in teacher identity development (Hoban, 2007). In this case, the conceptual framework is embedded in the exploration/planning phase where the Science Laboratory Instructional Model (SLID) and 5E (Engagement, Exploration, Explanation, Elaboration and Evaluation) models, in addition to the curriculum and a pre-developed lesson were the basis for designing and implementing inquiry-based practical work. However, Clarke and Hollingsworth (2002) argue in favour of the Interconnected Model of Teacher Professional Growth (Teacher Professional Growth Consortium, 1994). This model is shown in Figure 4.10.

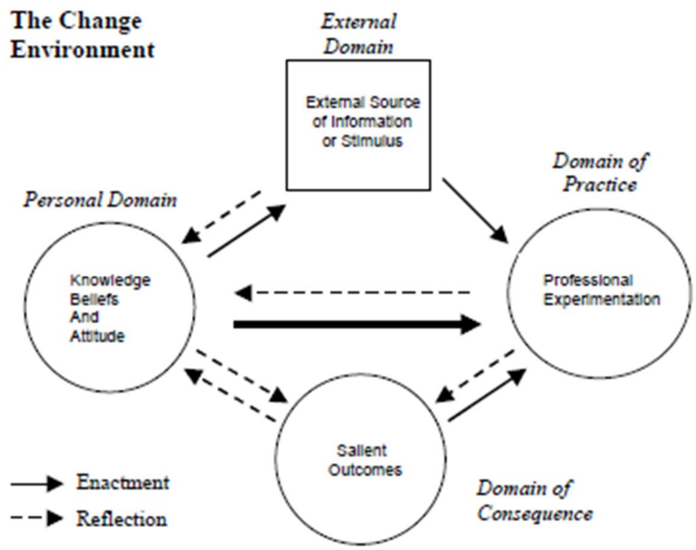


Figure 4.10 Interconnected model of professional growth (Source: Teacher Professional Growth Consortium, 1994)

Based on the model in Figure 4.10, effective teacher development occurs through enactment and reflection. These mechanisms of change are part of the PDF, which also uses observation (modelling). In the model in Figure 4.10, enactment and reflection are ways of effecting change in four domains consisting of the external domain, personal domain, domain of practice and domain of consequence. In the PDF, the external domain is present through the use of an external lesson study advisor (secondary phase i), external motivation (secondary phase iii), and research input (secondary phase iv). The other three domains make up the professional world of practice of teachers (Clarke & Hollingsworth, 2002). In this world, the acquisition of a new belief recedes in the personal domain, while experimenting with a new teaching strategy (in this case IBPW) takes place in the domain of practice. In the PDF, the domain of practice is in the implementation phase. The personal domain and the domain of consequence may not be localized. Due to the outcomes of experimenting with a new strategy (domain of practice), a change in perception may occur in the domain of consequence. The model contains multiple pathways of teacher development between the four domains. Along these pathways, change in one domain leads to change in another domain. These changes occur within the affordances and constraints of the surrounding change environment (Hollingsworth, 1999). It is these constraints that E1 suggested should be made explicit in the PDF. Having said that, we see that that though not arranged in the form of an integrated matrix, the PDF reflects all domains of the interconnected model of teacher professional development.

The presentation of the PDF as an integrated matrix may lead to an outcome that reflects a model more than a framework. A model is a conceptual construct representing variables, processes and relationships without providing specific guidance on or practices linked to its implementation (Tomhave, 2005). Contrary to a model, the intervention needed here was one that provides guidance in the implementation of lesson study towards supporting teachers in the design and implementation of inquiry-based practical work. A framework is more useful in this regard. This is because this construct contains guidance in relation to its implementation (Tomhave, 2005).

4.4.3.3 Other aspects of the PDF to improve

E2 noted that the PDF needs to allow for the engagement of teachers in reflecting on their understanding of scientific principles and how they acquire this understanding. In order to do so, this expert suggested the addition of a new step, or the incorporation of the above aspect in especially the existing steps 2 vi and 3 vii-viii. In this light, a new secondary phase of professional development may be introduced at the beginning of primary professional development phase two as follows:

iv) Reflection on their understanding of scientific principles and how they acquire this understanding.

4.4.4 Revised outcomes of research cycle

4.4.4.1 Design principles

All design principles contained in Section 4.3.4.1 remained unchanged except for three. The three revised design principles are the following:

Design Principle #1.2b: Aim the PDF to enhance the related competences* in addition to the professional identity and practice of teachers as these are important in effective teacher learning in general, and in relation to the intrinsic challenges linked to IBPW in particular.

(Clarke & Hollingsworth, 2002; Elster, 2009; Fishman, Marx, Best & Tal, 2003; Hoban, 2007; Loucks-Horsley, Love, Hewson, Stiles & Mundry, 2003; Magnusson et al., 1999; Mishra & Koehler, 2006; Rozenszajn & Yarden, 2014; Sweeney & Paradis, 2004).

* Consisting of knowledge[a], skills[b], attitudes, beliefs[c], values[d] and practices [e]

[a] such as CK, PK, TK and PCK,

[b] consisting of pedagogical skills, creativity and practical skills,

[c] including about the science curriculum and the understanding of science learners,

[d] which include care and concern for learners, commitment and dedication to their practice, collaboration and team spirit, in addition to the desire for continuous learning, innovation and excellence

[e] in relation to the IB learning practices in Table 4.2.

Design Principle #2.2b: Use the Social Cognitive Theory as the learning perspective in the PDF in order to allow for collective participation in a professional learning community in which the competences and practice of each teacher are enhanced through observation, enactment and reflection.

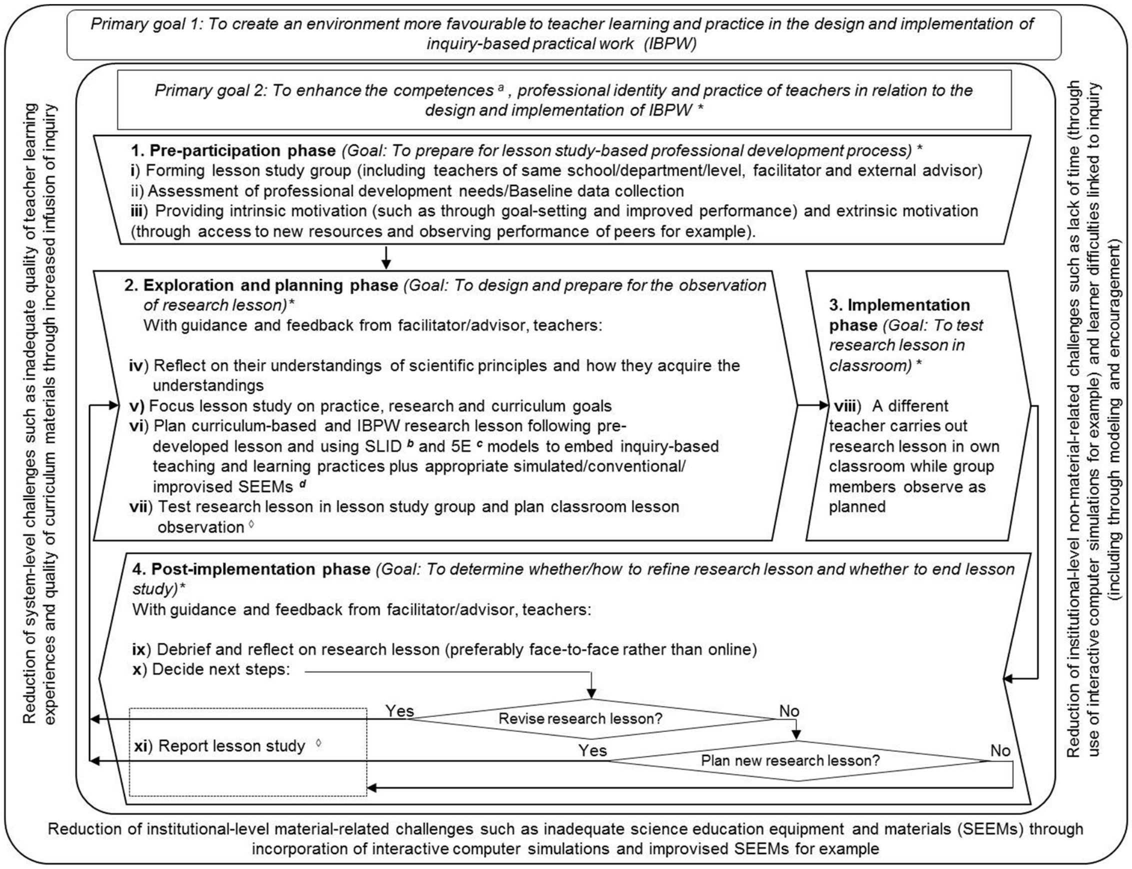
(Bandura, 2001; El-Deghaidy, Mansour & Alshamrani, 2015; Marx & Harris, 2006; National Science Teachers Association, 2006; Ostermeier et al., 2010; Schunk, 2012; Teacher Professional Growth Consortium, 1994).

Design Principle #7.2b: Incorporate intrinsic and extrinsic teacher motivation into the PDF given that teachers need to be motivated in order to change their practice. Although goal-setting and improved performance are effective as an intrinsic incentive, motivation is difficult to sustain without extrinsic incentives (such as access to additional resources and observing the success of peers).

(Boyd, Banilower, Pasley & Weiss, 2003; Gaible & Burns, 2005; Pintrick & Schunk, 1996; Stolk et al., 2009b; Schunk, 1995, 2012).

4.4.4.2 Conceptual content-specific version of PDF

Design principle #2 simply reflects the PDF better than its predecessor #2.2. However, this design principle has no effect on the PDF in Figure 4.9. Alternately, the evaluation indicates that Design principle#9.2 needs to be implemented in a specific way to make the addressing of contextual factors more explicit. Also, to be applied on the PDF in Figure 4.9 are Design principles #1.2b, #2.2b and #7.2b. The above considerations are based on the relevance (content validity) of the PDF. Regarding its consistency, the discussion in Section 4.4.3.2 indicates that the PDF may not be presented as an integrated matrix. Based on the entire evaluation, the conceptual content-specific PDF may be revised, as shown in Figure 4.11.



Legend:
[a] *competences = knowledge* [e]*, skills* [f]*, attitudes, beliefs* [g]*, values* [h] *and practices* [i]
[e] consisting of content knowledge, pedagogical knowledge, technological knowledge and pedagogical content knowledge
[f] consisting of pedagogical skills, creativity and practical skills
[g] including about the science curriculum and the understandings of science learners
[h] including care and concern for learners, commitment and dedication to practice, collaboration and team spirit, in addition to desire for continuous learning, innovation and excellence
[i] linked to inquiry-based learning (e.g., asking questions, planning and conducting investigations, analysing and interpreting data, constructing explanations and engaging in evidence-based arguments)

[b] SLID = Science Laboratory Instructional Design model (Phases: Initiation, Planning, Implementation (based on 5E [c] instructional model in this case), Evaluation and Feedback)
[c] 5E instructional model (Phases: Engagement, Exploration, Explanation, Extension and Evaluation)
[d] SEEMs = Science Education Equipment and Materials

* Providing learning goals on a continuous basis (Primary goal 2 lies in enhancing teacher competences and professional identity in order to reduce intrinsic challenges regarding the design and implementation of IBPW. For example, teachers not giving learners opportunity to link new learning to prior learning (intrinsic challenge) is reduced by enhancing pedagogical content knowledge linked to the understanding learners through the use of the SLID and 5E instructional models (way of reducing intrinsic challenge)

◊ Reviewing learning periodically

Figure 4.11 Revised conceptual content-specific PDF to support teachers in the design and implementation of IBPW (Source: Researcher)

Due to the better implementation of Design principle #9.2, and the implementation of Design principles #2.2b and #7.2b, the PDF in Figure 4.11 is different from the PDF in Figure 4.9 in three ways. Firstly, the PDF now has a shell addressing contextual factors. Associated with this shell is primary goal 1, which is concerned with the reduction of extrinsic challenges, linked to the design and implementation of inquiry-based practical work. What was previously the primary goal of the PDF is now primary goal 2. This goal is linked to the reduction of intrinsic challenges associated with the design and implementation of inquiry-based practical work. The appearance of the shell and the second primary goal of the PDF arise from the better implementation of Design principle #9.2. Secondly, the previous (lone) primary goal of the PDF (now primary goal 2) changed to reflect the enhancement of not only teacher competences, but also their professional identity and practice. This change resulting from Design principle #1.2b is the most profound change in the PDF. Thirdly, illustrative examples were added to clarify the teacher motivation component of the PDF (step iii). This arose from Design principle #7.2b. Finally, a new secondary phase of professional development was added at the beginning of the exploration and planning phase of the PDF.

4.5 CHAPTER SUMMARY AND CONCLUSION

The second research cycle contained in this chapter allowed the second major step in the process considered here for developing a PDF (Figure 1.1), which was carried out. The purpose of this research cycle was to revise the conceptual content-generic version of the Professional Development Framework (PDF v1) from the previous research cycle. This was done to yield a conceptual content-specific version of the PDF (PDF v2). Specifically, the research cycle responded to the following primary research purpose (Section 1.3.3):

> SRP1b: To generate refined/specified design principles in relation to the design and implementation of inquiry-based practical work and the associated challenges, and then design a conceptual content-specific PDF to support science teachers.

In the above regard, seven pre-existing tentative design principles were revised and three new specified design principles generated. The revision or generation of the design principles were based partly on a systematic literature review of the international literature on the design and implementation of inquiry-based practical work. The literature review focused on the associated intrinsic and extrinsic challenges based on conceptual frameworks compiled for the purpose of characterising and/or clarifying these challenges (Figure 4.2, Figure 4.3 and Figure

4.5). The ensuing ten specified design principles (Section 4.3.4.1) allowed the conceptual content-generic PDF from the previous research cycle (Figure 3.8) to be revised in favour of the conceptual content-specific PDF in Figure 4.9. However, this version of the PDF underwent formative evaluation based on one-to-one evaluation (walkthrough) involving two experts with the primary evaluation criteria being relevance (content validity) and consistency (construct validity). On this basis, four design principles were either revised or better implemented. The result is the revised conceptual content-specific PDF in Figure 4.11. This outcome and its associated ten design principles (#1.2b, #2.2b, #3.2, #4.2, #5.2, #6.2, #7.2b, #8.2, #9.2, and #10.2) were the outcomes of the content analysis associated with this design research. These outcomes enabled SRP1b (Section 1.3.3) to be achieved.

The above outcomes of this research cycle may be considered by science teacher professional development researchers and providers internationally. This could be especially considered in the elaboration of programmes towards supporting science teachers in the design and implementation of inquiry-based practical work. However, in doing so, an analysis of the actual context and needs of participants is useful. This is attempted in the next and last research cycle (Chapter 5) from the perspective of South African Physical Science classrooms in resource-constrained schools.

CHAPTER 5 : CONTEXT-SPECIFIC PROFESSIONAL DEVELOPMENT FRAMEWORK

5.1 CHAPTER OVERVIEW

This chapter contains the third and last design research cycle in this study. This research cycle allowed for the completion of the process considered for developing a Professional Development Framework (PDF) (Figure 1.1). Specifically, the research cycle enabled a needs and context analysis to be carried out on the basis of a multi-method, multi-case analysis. It is on this basis that the content-specific version of the PDF (Figure 4.11) was revised in favour of the context-specific version. Based on the development process, this research cycle also involved a formative evaluation of the PDF. The evaluation involved two South African experts in teacher professional development practice and research in relation to inquiry-based science education.

On the above basis:

- The ten existing specified/refined design principles were revised, and
- The conceptual content-specific version of the PDF was transformed into a context-specific version of the PDF.

In South Africa, like elsewhere, professional development needs to equip teachers to deal with actual classroom situations (Department of Basic Education, 2011a). By becoming context-specific, the PDF becomes complete as a PDF to support South African Physical Science teachers in resource-constrained schools, in the design and implementation of inquiry-based practical work. Figure 5.1 situates this chapter and research cycle within this design research.

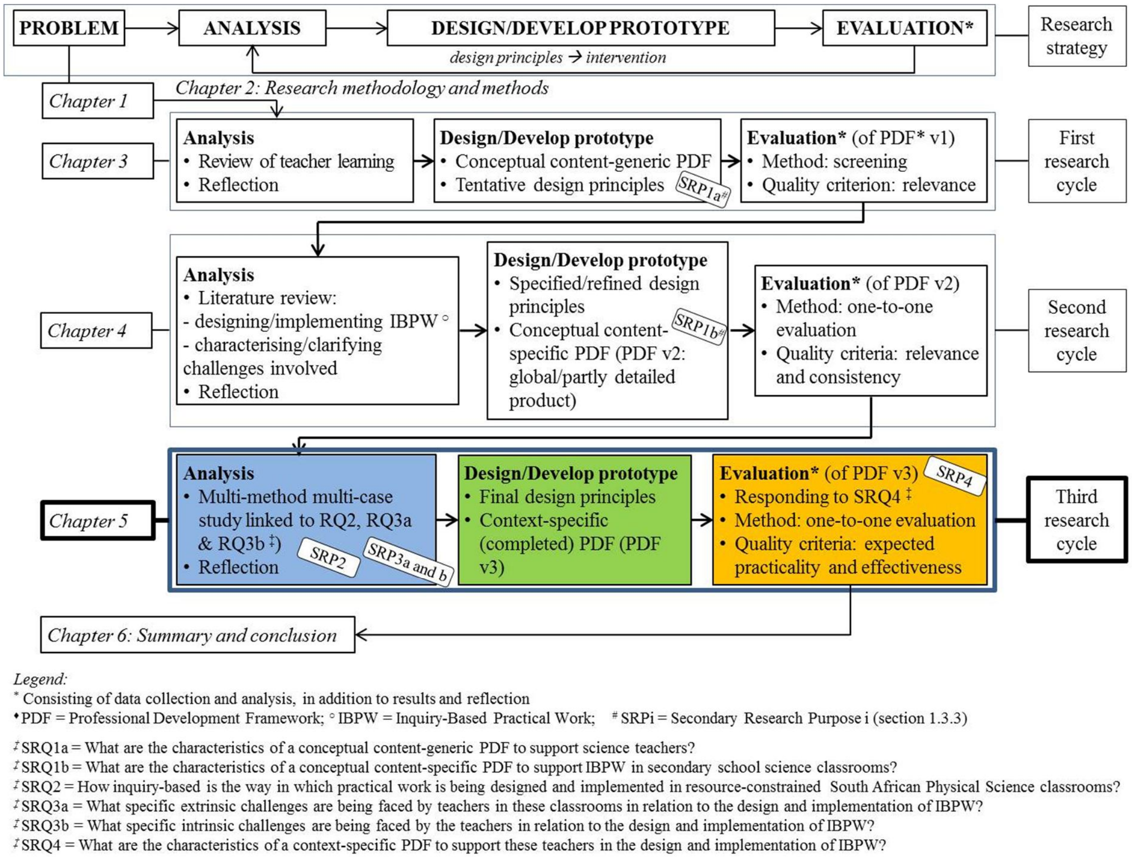


Figure 5.1 Position of Chapter five in study (Source: Researcher)

As indicated in Figure 5.1, this research cycle builds on the secondary research purposes SRP2, SRP3a and SRP3b (Section 1.3.3) in order to attain the last research purpose (SRP4). This purpose was to design a context-specific version of a PDF to support South African Physical Science teachers in resource-constrained schools, in the design and implementation of inquiry-based practical work.

In line with in Figure 5.1, the design research process broken down into three phases was used. The phases were analysis, designing/development, and evaluation. The analysis phase began by considering the usefulness of analysing the actual context and needs of the participants. It then described how the analysis could be achieved. In other words, this section describes how SRP2, SRP3a and SRP3b were attained. It then led to the designing/development phase in which SRP4 was achieved. The outcomes of this phase were the final design principles and the associated context-specific PDF. This PDF was a revised version of the conceptual content-specific version from the previous research cycle. In the third and last phase of this last research cycle, the context-specific PDF was subjected to formative evaluation. In this regard, the method used was, again, one-on-one evaluation. However, unlike in the last research cycle, in this case, the evaluation question was: What is the expected practicality and expected effectiveness of the conceptual content-specific version of the PDF (PDF v2)?

5.2 ANALYSIS PHASE 3

An improved understanding of the circumstances that facilitate or impede change is useful in designing and sustaining educational improvements (Goldman, 2005). This aspect of teacher professional development was considered in the previous research cycle from an international perspective. However, teacher professional development processes take place within the affordances and constraints of the surrounding environment (Hollingsworth, 1999). This enveloping environment can significantly affect the professional development of teachers in a number of ways (Clarke & Hollingsworth, 2002). The ways include the availability of professional development opportunities, restriction or support for particular types of participation, discouragement or encouragement of experimentation with new ideas, as well as restriction or support for the long-term application of new ideas. Thus, professional development is not effective unless it is context-specific (Girvan, Conneely, & Tangney, 2016; Wells, 2007). For instance, teachers are more likely to gain content knowledge, improve their skills and thus improve their classroom practices when their professional development is directly linked to their routine pedagogical experiences, in addition to being aligned with curriculum standards and assessments (Holland, 2005). In fact, the process of change is so context specific that it can play out differently in individual schools (Rogan & Grayson, 2003).

The above discussion supports the designing of a context-specific PDF to support South African Physical Science teachers in resource-constrained schools, in the design and implementation of inquiry-based practical work. The discussion also highlighted the usefulness of a context and needs analysis. These analyses were directed at the attainment of the secondary research purposes SRP2, SRP3a and SRP3b. In this regard, it was useful to return to the research process union (model) in

Figure 2.1 for guidance. The research paradigm (pragmatism) and approach (applied, exploratory and deductive-inductive research) remained as discussed in Sections 2.2 and 2.3 respectively. For the purpose of the context and needs analyses, it was adequate to begin in the strategies layer of the research process onion. However, the same ethical considerations described in Section 2.8 were involved in the data collection and analyses here.

5.2.1 Strategy and choice of methods

Teachers struggle with the design and implementation of inquiry-based practical work (IBPW) internationally, as seen at the beginning of the problem statement (Section 1.3.1). However, data collection in design research is usually limited to small (and purposive) samples (Van den Akker, 1999). Thus, a case study research strategy is useful. Specifically, the data collection strategy used here was a multi-case, multi-method study. The multi-method aspect is discussed later in order to focus here on the multi-case dimension in the data collection. This is in relation to the selection of cases and participating Physical Science teachers.

Selection and description of cases. The income level of the surrounding community, grade level, and possible access to a range of resources useful in IBPW were the criteria used in the selection of participants. The last criterion was used in order to be able to capture how practical work is designed and implemented, in addition to the related challenges regarding different resources used in practical work. The resources included improvised and conventional hands-on resources, as well as simulations and other ICTs. Reformers encourage the use of hands-on practical investigations coupled with the use of technological tools that include interactive computer simulations, to enhance learners' understanding of important scientific concepts (National Research Council, 2005a; Schneider et al., 2005). In order to simultaneously meet this and the other two selection criteria above, this context and needs analysis could be conducted in the Paperless Classroom project of the South African Department of Education in the province of Gauteng. This project involves the donation of tablets to learners and Smart Interactive Boards and Internet access in participating classrooms (Government Communication and Information System, 2016).

Among the seven secondary (high) schools in the above project, there are three Quintile 3 secondary schools. Ordinary public schools in South Africa are categorised nationally based on infrastructural factors and the poverty of the surrounding community (Grant, 2013). Specifically, the schools are categorised in quintiles from Quintile 1 to 5, where Quintile 5 schools are the ‘least poor’, while Quintile 1 schools are the ‘poorest’. Quintile one to three schools have been declared as non-fee paying schools, as opposed to Quintile four and five schools which are fee-paying schools. Here, we thus consider Quintile one to three schools as resource-constrained schools. While principals of all three of the Quintile 3 schools accepted to participate in this study, only two schools were retained. The two schools were in close proximity, making it easier for the Physical Science teachers from the schools to jointly participate in professional development at a later stage. Thus, the case study involved two schools.

The focus of the case studies was on the practical component of Physical Science education in the two schools (referred to here as School O and School P). In this regard, there were two major differences between Schools O and P. School O had a functional science laboratory, which was not the case in School P. The other difference was that in School P, the Physical Science teachers were assisted in the planning and implementation of practical work by a demonstrator from ____ (name of partner institution). Among other activities, the institution ran a centre that served as a platform for the borrowing of science education equipment (The Skills Portal, n.d). The equipment included conductivity probes, light sensors and motion detectors. Also, the institution ran mobile laboratories that served schools that were located in rural areas or that were severely resource-constrained. The involvement of a demonstrator in practical work in School P was different to School O, where the Physical Science teachers took full responsibility for designing and implementing practical work in their classrooms.

Selection and description of participants. After selecting the participating schools as described above, the Physical Science teachers of each school were then approached regarding informed consent to participate in the data collection. The demonstrator of School P was also approached. Resulting from these contacts, six Physical Science teachers (four in School P and two in School O), as well as the demonstrator in School P consented to participate in the data collection. All of the teachers were fully qualified in terms of having at least a first degree in education, or in a science major in addition to a certificate in education. The teaching experience of the teachers ranged from two to 20 years.

5.2.2 Time horizons

In this regard, this study was a cross-sectional study. Such studies involve a 'snapshot' of the phenomenon under study at a given point in time (Cohen et al., 2011), unlike measuring change. The usefulness of a cross-sectional study here is linked to the fact that a context and needs analysis was being conducted. Thus, only data about the existing state of the design and implementation of inquiry-based practical work in Physical Science classrooms in resource-constrained schools was needed. However, the data collection lasted six weeks in order to allow the researcher to carryout classroom observation and be immersed in the context of the two schools.

5.2.3 Data collection techniques and instruments

Below, the data collection instruments are discussed and linked to the various secondary research purposes (SRP2, SRP3a and SRP3b). However, the techniques used in the data collection are first stated and discussed.

5.2.3.1 Techniques of data collection

The data collection techniques often used in carrying out context analysis include interviews, focus groups, lesson observations and document analysis (Nieveen & Folmer, 2013). The context analysis here was in relation to the extrinsic challenges that participating physical science teachers faced in the design and implementation of inquiry-based practical work (SRP3a). However, the above techniques were also useful in identifying the professional development needs of the participants concerning how they designed and implement practical work (SRP2), and the intrinsic challenges that they faced (SRP3b).

Individual interviews were used with the demonstrator and the six participating teachers. However, relying on what teachers say is inadequate for understanding what they do due to the issue of self-protection and/or a lack of sufficient understanding of expectations and definitions (O'Sullivan, 2006). This effect was countered partially in School P, which had the majority of participating teachers. This meant that the interview with the demonstrator was aimed to assess the participating Physical Science teachers of the school and not the demonstrator. Also, certain aspects of practice cannot be examined without observing the interactions between teachers and learners in the classroom (Burstein et al., 1995). Thus, the interviews were augmented with an observation of the actual classroom practices of the teachers, in addition to field notes and the collection of learner worksheets for analysis (document analysis). This expanded the number of sources and techniques of data collection, allowing the participants' practices and challenges linked to IBPW to be better captured. The use of multiple sources and techniques in the data collection partly gave the context and needs analysis its multi-method dimension. Before this dimension is expounded in the description of the data analysis, it is necessary to further discuss the data collection.

5.2.3.2 Data collection instruments

In order to carry out the observations and interviews, an observation schedule in addition to two individual interview schedules were used. These instruments and techniques of data collection are listed in Table 5.1, per the related secondary research question in Section 1.3.2.

Table 5.1 Data collection techniques and instruments in the context and needs analysis (Source: Researcher)

Secondary research purpose	Data collection technique(s)	Data collection instrument (s)
SRP2	• Observation. • Document analysis, field notes and reflection.	• Observation schedule (Appendix C).
SRP3a and SRP3b	• Individual interview with: - Teachers;	• Individual interview schedule; - Teachers (Appendix D).

	- Demonstrator. • Field notes and reflection.	- Demonstrator (Appendix E).

The Interview Schedules (ISs) and Observation Schedules (OSs) were semi-structured and open-ended. These instruments were designed with reference to the literature review carried out in the previous chapter. This concerned the conceptual framework for designing and implementing inquiry-based practical work reflected in Figure 4.2, and the conceptual framework of challenges (Figure 4.3). Details regarding the contents of each of the above instruments are provided below.

Observation Schedule (OS). Exemplar items on the OS are: 0) Topic of practical work____. Lesson taught prior to practical work ____. Lesson scheduled after this practical work ____; 1c) What is the nature of the simulation (if involved)? (e.g. interactive/a passive demonstration, how does it reflect the real world); 2) What is the intended learning outcome as specified to learners (orally or in written form); 3) How are the following phases achieved (by teacher, learners or on worksheet): a) engagement, b) exploration, c) explanation, d) elaboration and e) evaluation. These phases of the 5E instructional model were tabulated in order that observation notes could be recorded against each phase during classroom observation.

Item 0) allows for the determination of the role (confirmatory or not) of the practical work. The role a teacher accords to practical work is indicative, for instance, of the pedagogical content knowledge of the teacher regarding instructional approaches in science education. Item 1c) reveals the state of the pedagogical knowledge of a teacher regarding instructional planning. Using item 2), the provision, or lack thereof, of the goal of practical work can be determined. This indicates whether or not a goal was set by the teacher in the initiation phase of designing of practical work. This item can also reveal the quality of the teacher's pedagogical content knowledge regarding orientation towards science teaching. Item 3) allows for the assessment of the pedagogical knowledge of the teacher regarding instructional implementation (in this case of inquiry-based practical work). Also included is the pedagogical content knowledge associated with instructional approaches (in this case models) useful in inquiry-based practical work. The OS thus described was used in both schools in the classroom during practical work.

Document analysis (Worksheets). In addition to observing the practical lesson based on the OS, the worksheet (artefact) used was also collected and included in the data analysis. An example is shown in Appendix G. In one case, the teacher wrote the practical task on the chalkboard. In this case, a snapshot of the task was taken and added to the worksheets for analysis. Thus, eight artefacts were available for document analysis. These artefacts carried such evidence regarding the design of practical work as the provision of a driving question, the intended practical work strategy and the intended level of inquiry in the practical work.

Field notes. In addition to the formal classroom observation, the researcher spent at least eight hours per week, especially in the office used by three of the four participating teachers from School P, and which was also used by the two teachers from School O. This time was partly used in holding meetings with the teachers. In School O, some of the time was also spent in the science laboratory with the participants. The research also examined this laboratory and the participating classrooms in School P regarding the display of safety procedures and practices. In addition, the researcher observed, in a non-intrusive manner, what materials and equipment the participants returned with or took to the classroom. The time spent in the above way enabled the researcher to interact with participating teachers on many occasions and as a result, helped to gain an understanding of the school context. Specifically, the rather informal observation partly enabled the researcher to find out about the practical work being prepared by the participants and the inherent challenges in this regard. The data gathered on this basis was kept in the form of detailed field notes. Excerpts are provided in Appendix F.

The above described immersion in the school context also served a methodological purpose in addition to allowing for informal data collection. This was due to the fact that in a study in real-world settings (such as this one), the researcher may become a ‘cultural stranger’ (Thijs, 1999). Also, participants may hesitate to open up to a researcher coming from outside the research context. In this case, it was useful for the researcher to engage in collaborative and mutually beneficial activities so as to gain the trust of participants and to understand the research context (i.e. insider perspective) (McKenney et al., 2006). However, an outsider perspective may allow the researcher a degree of objectivity and honesty that is not allowed to members of the group being investigated. As a result, the six weeks of immersion in the research setting were useful for subsequent data collection.

Interview Schedules (ISs). These consisted of the IS for teachers and the IS for the demonstrator. The IS for teachers contained twelve items, which included the following: 2) Tell me what you consider when designing or selecting practical work exercises so that learners can learn best, and 7) Some people believe that learners' prior knowledge and experiences are enough at the beginning of practical work? What is your opinion? 8) What do you think about allowing learners to design experiments to test their own ideas?

Item 2) could reveal the content and pedagogical content knowledge of a teacher in relation to the initiation and planning of inquiry-based practical work (see the TPACK framework and SLID model). The knowledge is linked to the preparation of appropriate learning experiences and the selection of a practical work strategy (structured, directed, or open). Item 7) allows for the assessment of the knowledge of a teacher regarding the sequencing of the implementation of inquiry-based practical work. This may be seen in the discussion above regarding the phases of the 5E instructional model. Item 8) could reveal the pedagogical knowledge of a teacher regarding inquiry-based teaching and learning practices.

The IS for the demonstrator contained ten items, which reflected corresponding items on the IS for the six teachers. However, the questions on IS for the demonstrator were not directed at the demonstrator, but rather at the Physical Science teachers of School P. This was designed to counter self-protection on the part of participating teachers. Examples of the items are: 1) What are the phases (steps), if any, that teachers of this school follow when carrying out practical work? What usually happens during each phase (step)? 2) Tell me how these teachers usually use interactive computer simulations (simulated equipment) during practical work. The other items on both ISs were designed to gather data on the experiences of teachers in the use of different resources in practical work, as well as in the production and selection of these resources. Also included is how these teachers routinely responded to learners during practical work and how they interacted with their learners during group learning.

We see that data was collected using multiple methods and sources on several occasions over a six-week period. The use of multiple methods (as in this case), increases the trustworthiness and credibility of studies (Burian et al., 2010; Samaras, 2011).

5.2.4 Data collection procedures

The classroom observation (formal observation) coupled with the collection of worksheets for analysis, as well as field notes (informal observation) lasted the entire duration of the data collection. However, the interviews were conducted only at the end of this period. The reason for positioning the interviews as such, in addition to details about the classroom observation, is provided below.

5.2.4.1 Classroom observation

This method was used on many occasions during the six week period. During this period, a total of eight practical lessons in School O and School P were observed. The observation of more lessons was made difficult due to a number of cancellations. During the observation period, ten practical lessons were cancelled by teachers for various reasons that included learners going on a trip, inadequate resources, as well as a learner involvement in a tree planting exercise. However, given that lesson observation was on an appointment basis, the teachers were either well prepared for the observed lessons or at least comfortable with its observation. The observations were of the complete observer type (non-intrusive) in order not to influence the practices and experiences being assessed.

5.2.4.2 Interviews

These were individual interviews conducted by the researcher using the two Interview Schedules (ISs) referred to above. Each of the individual interviews lasted about half an hour. These interviews were all audio recorded so that they could be fully transcribed. The interviews were conducted only at the end of the observation period based on Abrahams and Millar (2008), who noted that the responses that interviewees provide are less likely to be ‘rhetorical’ in nature and more effectively linked to realities when interviewees consider that the interviewer has observed the practice under discussion. However, researcher bias and social desirability effects can play a role in data collection using interviews (Creswell, 2006). Being aware of this is important for the researcher in relation to being careful to avoid it. However, it can only be assumed that the participants' responses to interview questions were always sincere. In cases where this was not always the case, this effect was reduced by the use of multiple sources of data collection and the fact that the interview items for the demonstrator were directed at teachers.

5.2.5 Analysis of the data

The data analysis commenced with preparation and organisation. Concerning preparation, verbatim transcripts of all seven individual interviews were produced prior to the data analysis. These transcripts (Appendix P), were then given to the participants for verification.

Data organisation involved sorting the interview transcripts, completed observation schedules, worksheets, and field notes per case (School P and School O). Further analysis of the data was based on thematic analysis. This conformed to the argument that inductive and deductive reasoning cannot be meaningfully separated (Blaikie, 2007). Thus, two approaches to thematic analysis were combined. These consist of the data-driven inductive approach (Boyatzis, 1998) and the deductive *a priori* template of codes approach (Crabtree & Miller, 1999). In line with the latter approach, code books were used in this study. As an example, Table 5.2 shows the code book used in assessing how inquiry-based (IB) is the way the participants designed and implemented practical work (PW). The code book is based on the framework for designing and implementing inquiry-based practical work (Figure 4.2). On the basis of Figure 4.3, two other code books were used with reference to the intrinsic and extrinsic challenges being experienced by the participants in relation to the design and implementation of IBPW.

Table 5.2 Code book used in assessing practices linked to design and implementation of IBPW (Source: Researcher)

Aspect		*A priori* code	Code description	Data source
Designing practical work	Initiation	- Goal/problem /key question	Availability of the question/problem driving the practical work	OS2[1], WS[2], ISE2
		- Strategy	- Strategy selected for implementing practical work: confirmatory (recipe-type) or inquiry-based (investigative). Including whether practical work precedes or follows concept development. - If inquiry-based, the degree of openness (Herron, 1971; Schwab, 1962) offered by the task.	ISE2[3], ISE11, WS, OS0 OS Just before 0, WS ISD2[4]
	Planning	- Safety	Whether safety is considered during planning, if precautions are provided on practical work sheets and whether safety rules and safe laboratory practices are displayed in the classroom or in the laboratory.	- WS, ISE2
		- Group formation	Use or not of pre-existing learner groups during practical work.	- OS
		- Preparing materials	- Deciding on when to use simulations and discriminating between them. - Whether hands-on SEEMs are selected and/or designed and produced for use.	- OS1b and c, ISE3a, b, ISD3a, b - ISE4, ISD4,
Implementing PW	Engagement	- Inclusion - Execution	- Whether phase is included in the implementation of practical work. - How phase is implemented in terms of accessing prior learning, identifying learner misconceptions, promoting curiosity and capturing attention.	- ISE5; ISD5 - OS3a
	Exploration	- Inclusion - Execution	- Whether a phase is employed during practical work. - Role of learners (e.g. to develop hypotheses and participate in planning investigations). - Teachers role (e.g. provides only essential procedures, serves as facilitator/provides	- ISE5, 9 and 10; ISD5,7 and 8 - OS3b, 4b and c

		guidance).	
Explanation	- Inclusion - Execution	- Whether phase is included in practical work. - Learners' actions (e.g. provide their own explanations of exploration). - Teachers' role (e.g. eliciting learners' explanations/understandings, leads to scientific terminology and explanations).	- ISE5; ISD5 - OS3c, ISE5; ISD5
Elaboration	- Inclusion - Execution	- Whether phase is used in practical work. - How teacher encourages learners to reach generalisations and to transfer learning.	OS3d; ISE5; ISD5; WS
Evaluation	- Inclusion - Execution	- Whether phase is involved in the conducting of practical work. - How learner reflection is encouraged (formative assessment). - Formal assessment of learning goal.	OS3e; ISE5; ISD5; WS

[1]OSX = Observation Schedule item number X, [2]WS = Work Sheet, [3]ISEX = Interview Schedule Teacher item X, [4]ISDX= Interview Schedule Teacher item number X

The first two columns of the code book in Table 5.2 reflect the conceptual framework for designing and implementing inquiry-based practical work (Figure 4.2). This and the other code books provided the deductive component of the data analysis. Based on each code book, the in-depth data analysis could proceed based on the data-driven inductive approach. For this purpose, the method of constant comparison (Glaser & Strauss, 1967; Strauss & Corbin, 1990) was used. Thus, each concept (such as a practice or extrinsic/intrinsic challenge) in the data was coded as a category. Each code was compared to the previous codes belonging to the same *a priori* category in order to identify similar and different practices and challenges in the data. This procedure has been repeated across the different data sources and methods of data collection as seen, for example, in the last column of Table 5.2. A similar procedure has been followed in the cross-case data analysis.

5.3 DESIGN/DEVELOP PHASE 3

This phase involved a presentation of the results of the context and needs analysis described in the previous phase of this research cycle. Embedded in the results is a reflection on the design principles from the previous research cycle. As a result, the design principles were revised and used to revise the PDF. In relation to revising the design principles, it was necessary to reconsider their structure (Van den Akker, 1999):

If you want to design <intervention X> for the <purpose/function Y> in <context Z>, then you are best advised to give <that intervention> the <characteristics A, B, and C>, because of <arguments P, Q, and R>

In this research cycle, X, Y and Z are as follows:

<*intervention X*> = completed PDF

<*purpose/function Y*> = supporting the design and implementation of IBPW

<*context Z*> = South African Physical Science classrooms in resource-constrained schools

Throughout this research cycle, X, Y and Z will remain the same. Thus, in revising the design principles these elements of the design principles may be assumed. On this basis, the design principles may be revised in the following format:

> Give the PDF the <characteristics A, B, and C>, because of <arguments P, Q, and R>

It is in the above light that the ten design principles from the previous research were considered against the results of the context and needs analyses.

5.3.1 Results linked to how PW is designed and implemented

These results respond to SRP2. As revealed by the interviews with participants, teachers mostly limit themselves to practical work that is prescribed or recommended in the curriculum. Although the prescribed practical work is mandatory, teachers are allowed to choose among the recommended practical work. However, two participants reported modifying existing practical activities to suit their needs or the curriculum. Nevertheless, as noted by a participant, the practical work carried out by teachers may be as few as three activities in a year. This makes the design of the limited number of activities used all the more important.

5.3.1.1 Designing practical work

Initiation phase

Problem or question

School O. In two of three instances, the practical activities observed in the classroom included an aim (goal), although it was only in one of these cases that the goal embodied a problem. In line with this observation, neither of the two teachers mentioned the inclusion of a question or problem to be investigated when asked about what they took into consideration when selecting or designing practical activities.

School P. Similarly, while the majority of practical lessons observed included a goal, none were based on a specified question. This is congruent with the fact that the teachers of this school did not mention considering the question or problem to be investigated when selecting practical activities.

We see that the practices of the participants in both schools were similar regarding the initiation aspect of the designing of inquiry-based practical work (IBPW). This meant that although the majority of practical activities used in the classroom included a goal, a central question or problem was hardly included. In line with this observation, the teachers did report considering a driving question or problem when selecting practical activities.

Strategy

School O. A teacher from this school reported sometimes using interactive computer simulations to investigate the predictions of learners. However, all three lessons observed in this school were taught after a theory lesson involving the central concept in the practical lesson. One of these lessons was designed as structured inquiry in which a central problem was provided at the outset of the worksheet. However, two of the lessons observed were either confirmatory in design or lacked a central question or problem. In one case, the worksheet asked for the hypothesis investigated not at the outset of the activity, but rather as part of the post-exploration questions. These observations are congruent to the fact that the strategy involved was not among the aspects that the participating teachers of this school considered when selecting practical activities, as confirmed in the different interviews.

School P. The use of interactive computer simulations was not reported, however, three of the practical lessons observed in this school were taught after the associated theory lesson. Four of the five practical lessons observed were confirmatory in their design. In line with this observation is the fact that while one of the participating teachers from this school reported using only a confirmatory strategy in practical work, two others did not consider a strategy when selecting practical activities. The fourth teacher, in fact, reduced the inquiry level of practical activities noting that, “It can’t be just open-ended.”

Inherent in the above results are similarities and differences in the practices of the teachers in the two schools regarding the strategy component of designing practical work. One similarity was that at least half of the practical lessons observed in each school were taught following a theory lesson involving concept development. At the same time, at least two in three lessons observed in each school were confirmatory in design or lacked a driving question or problem. This is consistent with the fact that the two teachers in School O and two of those in School P did not consider the strategy involved when selecting practical activities as revealed by the interviews. In contrast to School O, half of the teachers of School P either reported using only a confirmatory strategy in practical work or reduced the inquiry level in practical activities. Conversely, it was only in School O where the use of computer simulations to support inquiry-based practical work was reported, although not observed.

Planning phase

Safety

One teacher (from School P) mentioned safety as an aspect considered in relation to the selection of practical activities for use in the classroom. In one case observed, a teacher provided rubber gloves to learners working with chemicals. However, the worksheets used by these and other learners in both schools were found to lack safety precautions. Based on the field notes, safety rules and safe laboratory practices were also not displayed in the laboratory (School O) and in the classroom (School P).

We see that in both schools, safety precautions and safety rules or safe laboratory practices were not provided on worksheets or displayed in the classroom. However, unlike in School O, a teacher at School P considered safety when selecting practical activities, while another teacher provided safety equipment during a practical activity.

Group formation

The data from the field notes indicate that during practical lessons in School O and School P, the teachers used learner groups formed before the lesson. However, in School P, these learner groups could contain as many as 10 to 11 learners. In two cases observed, there were only two groups in a classroom consisting of 40 and 44 learners respectively. Such group numbers and sizes were not observed in School O.

Preparing materials

The use of interactive computer simulations in practical work has not been observed in any of the participating classrooms. In the case of School P, this observation was confirmed by the demonstrator, who noted that these simulations were not used in practical work in the school. At the same time, one teacher noted that she did so only in the absence of a laboratory. This means that the usage of interactive computer simulations the teacher referred to was not done at that school, which had a science laboratory. Also, this teacher did not provide any criteria that she used in discriminating between potentially useful interactive computer simulations. However, in both Schools O and P, the production and use of improvised equipment was observed and/or reported.

School O. Improvised equipment observed in the classroom consisted of steel nails used in the place of carbon rods, which were unavailable. While the teacher did not report using improvised resources in practical work, this was not the case with the other teacher from the same school. This second teacher reported using disposable cups to produce beakers and the rather unsuccessful use of a commercially available washing agent containing ammonium nitrate in allowing learners to experience endothermic reactions.

School P. Here the use of small-scale experiments and a runway intended for a different experiment by two different teachers was observed. Regarding the reported selection or production of improvised equipment, the participating teachers of this school were split down the middle. Examples given include the acquisition of balloons for use in collecting hydrogen gas and the use of a rubbed plastic ruler against a jet of water to allow learners to observe the effects of an electrostatic force.

The use of interactive computer simulations in practical work was neither observed nor was it reported in both schools. However, in both schools, half the teachers were observed to use improvised resources in practical work. Similarly, half of the teachers in both schools reported selecting and/or producing improvised equipment and materials for practical work.

5.3.1.2 Implementing practical work

Instructional phases used by teachers

School O. One of the teachers in this school did not identify any phases of a practical lesson. However, this was not the case with the other teacher, whose phases of a practical lesson included the gathering of requirements by learners, in addition to the formulation of hypotheses and carrying out instructions.

School P. One of the participating teachers from this school further did not identify any phases used in practical work, however, this was not the case with the other three. What they provided as phases in their practical lessons consisted of demonstrating the task in the beginning of a lesson (one teacher), grouping learners (another teacher), checking prior learning, providing the aim of the lesson, and moving through the different groups or stations (a third teacher). However, the demonstrator noted in relation to how the participating teachers implemented practical work that, “There is no sort of scientific way in terms of moving … from the known to the unknown.”

At least half of the teachers in each school reported using certain phases (e.g. demonstrating the task and the formulation of hypotheses by learners) in their practical lessons. However, in School P, the demonstrator noted the generalised lack of a logical sequence of phases in practical work.

The above were the reported practices of participating teachers in relation to the instructional sequence used in the implementation of practical working the classroom. Below, these practices are projected against the 5E instructional model.

Engagement phase

This phase was missing from all the practical lessons observed at both schools. However, one teacher of School P reported checking prior learning and the provision of the aim of the lesson as what they called phases of a practical lesson.

Exploration phase

Unlike the previous one, this phase of the 5E model was present in all practical lessons observed at both schools.

School O. In each practical lesson, the teacher engaged learners in small group work while moving around and interacting mostly briefly with different groups. Regarding the contents of the teacher-learner interaction during group activities, the interviews with the individual teachers revealed that this included monitoring progress, ensuring learner safety, in addition to checking what learners were struggling with and then telling them what to do, mostly without demonstrating this. Other practices reported or observed teacher practices consisted of ensuring that leaners strictly carried out the procedure for the practical activity and the teacher stayed a relatively long period of time with certain groups.

School P. Some observed activities carried out by the teachers in this phase of the lesson included putting learners in groups, as well as interacting with individual groups. Based on the interviews with the individual teachers, the contents of these interactions included overhearing conversations, telling learners what they may do (without demonstrating this), providing feedback using guiding questions and indirect answers, as well as scaffolding struggling learners. One of the teachers noted that he refrained from providing answers that "give away the whole point of the experiment." Other teacher practices included ensuring that learners followed the procedure closely so that they "can at least achieve near to the required result." Also, in two observed cases, the time spent by the teacher in one group was relatively long. As observed and also reported, teachers sometimes stop the entire class during group work in order to provide additional information or to persuade learners to do what they want them to do.

Common teacher practices in these schools consisted of using small groups all the time and only brief teacher-learner interaction during group work half of the time. However, there were differences in the contents of these interactions. On the one hand, specifically in School O, the teachers reported ensuring learner safety and checking whether learners were struggling, which was not reported in the case in School P. On the other hand, the teachers in the latter school reported providing feedback through guiding questions, indirect answers and scaffolding, which was not reported in School O. Another reported observed difference is that in School P, unlike in School O, the teachers sometimes stopped the entire class during group work in order to provide information.

Explanation phase

School O. This phase was used in two of the three practical lessons observed in this school. In one case, the teacher asked different learner groups to interpret their observations for the class. In another case, another teacher held a questioning session that included the interpretation of expected observations prior to the exploration phase of the lesson.

School P. This instructional phase was observed after the exploration phase in half of the practical lessons. In the rest of the lessons, the expected results and the interpretation were made available to learners at the beginning of the lesson either orally or through the worksheet.

Considering both schools, we see that the explanation phase of the 5E model was used at least half of the time. Also, in both schools, the learners were asked to interpret their observations at least one third of the time. The same proportion was true of the interpretation of observations made available before the exploration phase.

Elaboration phase

In School O, this phase was present in one of the three lessons observed. In the lesson, the elaboration phase was implemented through the use a numerical problem. However, the elaboration phase was not used in any of the practical work observed in School P.

Evaluation phase

School O. This phase was used in all three lessons observed, for example, through teacher interaction with learner groups and also through post-exploration questions on worksheets. The learners were to provide their answers to these questions through a written report.

School P. The practical lessons observed in this school all involved this phase based on formative interactions between the teacher and learners, especially during group work, in addition to written reports to be submitted by learners after the practical lesson (summative evaluation). However, in two lessons observed, there were no post-exploration questions for learners neither on the worksheet nor otherwise. Thus, in both schools, this instructional phase was used in all the practical lessons through formative teacher-learner interactions, as well as through the submission of written reports. The reports included answers to post-exploration questions except in two cases in School P where such questions were not provided.

In line with SRP2, the above results may be summarised as shown in Table 5.3.

Table 5.3 Consistency in design and implementation of practical work (PW) in relation to inquiry-based (IB) science education (Source: Researcher)

Aspect of PW		Consistent with IBPW	Inconsistent with IBPW
Designing	Initiation (problem/ question, strategy)	- Most practical activities observed in both schools included a goal. - One practical activity observed in School O involved structured inquiry.	- A central question or problem is hardly included in PW - At least half of the practical lessons observed in each school followed Theory Lesson involving concept development. - Two in three practical lessons observed in each school were confirmatory in design. - Some teachers in both schools ignored strategy, reduced the level of inquiry in practical activities or favoured a confirmatory strategy
	Planning (safety,	- Consideration of learner safety and provision of	- No safety precautions on worksheets or safety rules/practices

Aspect of PW		Consistent with IBPW	Inconsistent with IBPW
	group formation, preparing materials)	safety equipment respectively reported and observed in one instance in School P. - Formation of learner groups prior to practical lessons in both schools. - 50% of teachers select and/or produce improvised resources for practical work in both schools.	displayed in the classroom/laboratory in both schools. - Formation of large learner groups (e.g. 10 to 11 learners per group or more) in School P. - Interactive computer simulations not integrated into practical work in both schools.
Implementation	Phases of a lesson	- At least half the participants of each school reported observing certain so-called phases in the conducting of practical work (e.g. checking prior learning, grouping learners, formulation of hypotheses by learners and moving through the groups).	- One teacher in each school did not report any specific phases used in practical work. - A teacher in School P reported demonstrating tasks in the beginning of practical work. - The demonstrator in School P noted that the teachers did not use any logical sequence of phases in practical work.
	Engagement	- A teacher of School P reported checking prior learning and the provision of the aim of the practical lesson in the beginning of practical work.	- Engagement phase not observed in practical lessons in both schools.
	Exploration	- Routine use of group work and only brief teacher-learner interaction 50% of the time in both	- Teachers in both schools sometimes insisted on strict adherence to provided procedure. - Teacher spent a relatively long

Aspect of PW		Consistent with IBPW	Inconsistent with IBPW
		schools. - Monitoring progress, providing support (e.g. providing additional directives) and guidance (e.g. indirect answers and guiding questions) during group work reported in both schools. - Ensuring learner safety during group work reported in School P.	time in individual groups, in some cases observed in both schools. - Teachers in School P sometimes stopped the entire class during group work in order to provide information, as observed and also reported.
	Explanation	- Present in most lessons, observed in both schools (e.g. through the interpretation of their observations).	- Occurs before 'exploration' phase in 50% of observed lessons in both schools (e.g. through information provided orally or on worksheet or learners asked to interpret observations given beforehand).
	Elaboration	- Phase used in one instance in School O through a numerical problem.	- Use of phase not reported in both schools and not observed in School P.
	Evaluation	- Practised in all practical lessons in both schools through formative interactions and submission of written reports.	- No post-exploration questions provided in the two lessons observed in School P.

The third column of Table 5.3 contains 13 practices of these teachers that are consistent with inquiry-based practical work (IBPW). However, the core practices (such as asking questions and engaging in evidence-based arguments) advocated by the National Research Council (2012) in relation to science education were hardly applied. Also, column four of the table contains 17 teaching practices that are inconsistent with IBPW. Generally, the teaching practices of Physical Science teachers in both schools in relation to the design and implementation of practical work are more inconsistent with inquiry-based science teaching and learning than they are consistent. At the same time, some of the practices thought to be consistent with inquiry-based pedagogy were at a low level of implementation in practical work.

5.3.1.3 Revisiting design principles

Two design principles from the previous research cycle may be reconsidered in relation to designing a PDF useful in improving the above reality of practical work in the Physical Science classrooms in the resource-constrained schools studied. These are the design principles linked to the professional development goal (#1.2b) and the instructional design perspective (#8.2).

Design Principle #1.2b partly requires that a PDF to support teachers in the design and implementation of IBPW be aimed at enhancing their practice. In relation to the present participants, the enhancement focused on inquiry-based teaching practices such as those advocated by the National Research Council (2012). However, the design principle also requires that the PDF be aimed at enhancing the competences and professional identify of the participating teachers. Thus, the design principle may not be revised until the intrinsic challenges faced by participating teachers have been clarified. Although the results in Table 5.3 verify design principle #1.2b only partly, they fully verify #8.2, which provides a framework in which inquiry-based practices linked to the designing and implementing of IBPW may be incorporated. Design principle #8.2 is thus verified as follows:

> *Design Principle #8.3:* Combine the SLID[a] model and the 5E[b] instructional model in order for the PDF to reflect practical work that is consistent, systematic, adequately sequenced and organised, more relevant and effective, and more consistent with inquiry-based teaching and learning.
>
> (Balta, 2015; Bybee, 1997; Dick et al., 2001; Dogru-Atay & Tekkaya, 2008; Kallio, 2008; National Research Council, 2000; Peterson, 2003; Reiser & Dempsey, 2007).
>
> [a] SLID = Science Laboratory Instructional Design.
>
> [b] 5E = Engagement, Exploration, Explanation, Extension and Evaluation.

The results in the next section lead to the consideration of another component of the PDF and its corresponding design principle, which addresses the contextual factors component.

5.3.2 Results on extrinsic challenges

The results in this section respond to RP2a. During the six weeks of observation preceding the interviews with the participants, as revealed by the field notes, the teachers across the two schools cancelled and/or rescheduled ten practical lessons. The reasons provided for the cancellations and/or rescheduling included routine demands of school life such as staff meetings. However, the teachers also cited such reasons as unfinished planning work and inadequate SEEMs. The latter reasons suggest extrinsic challenges linked to the designing of practical work. In reality, the teachers faced many extrinsic challenges linked to IBPW. In relation to framing these challenges, Figure 4.3 provides further data. There is juxtaposition of the individual challenges in each category and the actors who may have had a role to play in the reduction of these challenges. In presenting the results, the exact words of some participants and excerpts of interviews are provided in some cases. In this regard, it is worth bearing in mind that the word 'practical' is used by some participants as a colloquialism for practical work.

5.3.2.1 System-level challenges

Restrictive curriculum. Teachers P2 and P4 (where P represents School P), noted that the Physical Science curriculum contains prescribed experiments that teachers must conduct with their learners. In addition, as noted by Teacher O1 (O representing School O), "[w]e've got this practical guide that tells you that with this topic these are the practicals that you must do – some are informal, some are formal." Thus, the practical work component of the Physical Science curriculum does not encourage teachers to design their own practical activities or practical activities to response to their learners' questions (open-inquiry). This is in the sense that "[o]nce you give … the methodology (in a task)… it is closing everything," as noted by Teacher P1. That said, Teacher P3 found prescribed informal experiments challenging to carry out in the classroom. Thus, this teacher reported that sometimes he took his learners to the ICT lab to show them similar experiments in the form of

YouTube videos. However, the curriculum is restrictive not only by way of providing mandatory practical work. In response to a question soliciting her opinion on allowing learners to design experiments to test their own ideas, Teacher O1 stated that the Physical Science curriculum "says that they [Grade 10 learners] cannot design their own experiments. They need to be helped…" Thus, the curriculum does not encourage teachers nor learners to design their own practical work. We see that curriculum developers may consider curricular changes that better support the design and implementation of IBPW.

Mandatory work plan. Regarding allowing learners to design experiments to test their own ideas, Teacher P4 noted that the mandatory work plan from the department of education was unfavourable in this regard. The teacher explained that the work plan was heavily focused on theory lessons, leaving limited time for practical work. As the teacher further stated, the work plan allocated about only two hours for learners to conduct and report on their practical work. This is a teacher challenge that educational planners may consider alleviating through a work plan that better accommodates IBPW.

Lack of district support towards use of simulations in practical work. Teacher P2 stated during the interview that district authorities discouraged the use of simulations in practical work as ". . . they [learners] just collect … the results [from the Internet] … without understanding." The same point was mentioned by Teacher O2 based on the field notes. The teacher mentioned this point during an interview where the recording failed, but refrained from raising the same point when the interview was later successfully recorded. However, the National Research Council (2005a) notes that practical work includes activities that allow learners to interact with data about the physical world that is not necessarily collected by the learners. It is considered here that the role of the teacher is to design this interaction so that it is instructive. Thus, district authorities concerned about the usage of simulations in practical work may rather assist teachers in the effective utilisation of this resource.

5.3.2.2 Institutional-level challenges

School P

The challenges were material-related and non-material-related challenges. Below, in addition to presenting the challenges in each of these secondary categories, actor(s) who may have played a role in the reduction of each challenge have been identified.

Material-related challenges

Lack of facilities. The demonstrator noted that in School P, classroom space was limited. Thus, as observed by the researcher, learner groups tended to be large with about 10 to 11 learners per group. The demonstrator and three other teachers noted that the school also lacked a science laboratory. In this regard, Teacher P4 stated that "we've got a dysfunctional lab," while Teacher P3 noted that "we never had a functional lab." In the context of resource-constrained schools, it may be difficult to resolve this challenge. However, alternative ways of gaining access to facilities include using facilities that lie outside individual schools. These include mobile laboratories, local museums and science centres (e.g., Musar, 1993; Singh & Singh, 2012). At the same time, Abrahams and Reis (2012) hold that what matters is how practical work is done, and not where it takes place. It is posited that it is the role of the teacher in collaboration with school managers to consider alternative facilities for practical work in the face of a lack of facilities in school.

Lack of science education equipment. This constraint was noted by the demonstrator and by Teacher P4. In the words of this teacher, "some sets [of science education equipment and materials] are not complete, some are just broken, some … are not functional anymore." Also, the demonstrator stated that the micro-kits provided by the department of education were limited in number, especially in terms of the chemicals they contain. Regarding the effect on practical work, Teacher P4 noted that "because we had limited resources, not everyone could partake in the practical. Some had to watch …" Ultimately, this teacher showed learners a YouTube video of a similar practical activity. Teacher P3 also observed that data loggers were unavailable at school, making him and his colleagues dependent in this regard on the partner institution from where the demonstrator came. As revealed by the field notes, the demonstrator in one occasion had to bring the data loggers, laptops and SEEMs requested as needed by the participants. Teachers P1 and P4 reported sometimes using improvised SEEMs when lacking conventional ones. This includes the collection of hydrogen gas using balloons, in addition to certain activities in mechanics and physics where chemicals are not involved.

Lack of chemicals and lack of procurement. This is a difficulty that was raised by all of the participating teachers of School P. They noted that their stock of most chemicals had either been exhausted or had expired. In this regard, Teacher P1 noted that "we don't necessarily have a replenishment method… When we don't have a certain chemical, even if you try to requisite it… it was never procured." The procurement of physical resources such as chemicals could assist science teachers in the implementation of IBPW. Thus, there is a need for school managers to give increased attention to the procurement of not only chemicals, but SEEMs in general considering that, as noted by Lin et al. (2013), IBPW relies heavily on the availability of SEEMs. In the meantime, three of the four participating teachers at this school indicated that they had to depend on external sources for chemicals. One of these sources was neighbouring schools with larger stock of usable chemicals from which these teachers borrowed. The teachers also obtained chemicals from the partner institution. These options for accessing SEEMs may not be sustainable, thus the importance of on-going procurement in school should be emphasised. However, Teacher P4 reported sometimes using improvised chemicals (e.g. hydrochloric acid meant for treating his swimming pool).

Non-material-related challenges

Inaccessibility of simulations. This was noted by all the teachers, as well as the demonstrator at School O. However, some simulations are freely available over the Internet, including the Virtual Chemistry Laboratory simulations from the Chemcollective at the Chemistry Department at Carnegie-Mellon University, Pittsburgh and the Physics Education Technology (PhET) project simulations, which are freely available to download or run over the internet (Donnelly et al., 2013; Perkins et al., 2006). Thus, the inaccessibility of simulations may be alleviated through assisting Physical Science teachers to access these. In this regard, Information Technology (IT) staff may be helpful.

Time constraints. In terms of allowing learners to design experiments to test their own ideas (open inquiry), Teacher P4 considered time as an impediment. The teacher blamed the lack of time on the tight nature of his work schedule. The demonstrator confirmed that the teachers often noted that they were pressed for time, but blamed this partly on the allocation of too much time to examinations, which caused teachers to sacrifice practical work sometimes. He added that a 55 minute period was normally inadequate and the results limited teacher-learner interaction during practical work. It may thus be useful for school managers to consider ways of reducing the pressure on time-starved Physical Science teachers.

Learner-related factors. Teacher P4 stated that due to poor planning on the part of learners, they often exhausted the chemicals that they were provided with before the goal of the practical work had been attained. However, it is the role of the teacher to see to it that learners have a better understanding of the practical work they are about to engage in before beginning. Thus, the poor utilisation of resources by learners is not actually an extrinsic challenge regarding IBPW. Contrarily, the demonstrator noted that during practical work, the learners tended to be busy with their tablets as monitoring was not very effective. However, the use of tablets during practical work for unrelated activities may be linked to the lack of use of these tablets in practical work, as revealed by the field notes. This is, however, not surprising considering the inaccessibility of simulations for use in practical work. This makes the support of IT staff all the more useful regarding the utilisation of simulations in practical work.

School O

It is worth noting first of all that the extrinsic challenges faced by the teachers at this school were different in number, but similar to the challenges faced in School P. Thus, the same role players identified above were involved. Thus, this aspect has not been discussed below regarding this school.

Material-related challenges

Lack of SEEMs and procurement. As reported by both teachers of this school, conventional equipment was inadequate in some cases. In this regard, Teacher O2 notes that "…sometimes you find that the chemicals that you are supposed to be using have expired." In a particular case in which this teacher tried to use a household alternative to ammonium nitrate, she found that "the results are not that good." In two cases in a space of six weeks, as revealed by the field notes, Teacher O2 cancelled a practical class, providing the expired nature of chemicals and an inadequate number of light bulbs as the respective reasons for the cancellation. Teacher O1 also explained that, "it is a long process buying those materials that are not here, so we normally use whatever that we have – we compromise…" This compromise consists of carrying out a teacher demonstration, showing a YouTube video, or using improvised SEEMs to enable learners to have a hands-on experience.

Non-material-related challenges

Lack of access to interactive computer simulations. Although Teacher O1 could access PhET simulations on her laptop, this was not the case in the classroom using the Smart Interactive Board. Here, the teacher was also unable to provide her learners access to PhET simulations on their tablets. The teacher explained that these simulations required Java, the installation of which had been blocked on the tablets. It may, however, be noted that not all simulations require Java.

Time constraints. Teacher O1 noted that there were time constraints in relation to persuading Grade 10 learners to design experiments in the laboratory. However, when asked about asking learners to do so in advance, the teacher admitted that this was allowed. Thus, a time constraint was not the only challenge the teacher faced in relation to persuading learners to design experiments.

The results presented above show that while the teachers at School O faced the same extrinsic challenges faced in School P, the teachers in the latter school faced additional challenges. However, in order to provide an overall picture, the results from both cases are summarised in Table 5.4. In each category, the challenges have been arranged in decreasing order of recurrence among the participants.

Table 5.4 Intrinsic challenges being face by participants and actors useful in reducing challenges (Source: Researcher)

Category		Specific extrinsic challenge	Recurrence (on a scale of 1-7)	Role player(s)
System level		- Restrictive curriculum	5	- Curriculum developers
		- Mandatory work plan	2	- Developers of teacher work plans.
		- Lack of district support towards use of simulations	1	- District authorities
Institutional level	Material-related	- Lack of SEEMs[a] and lack of procurement.	7	- School managers (administrators).
		- Lack of facilities.	3	- Science teachers/school managers.
	Non-material-related	- Lack of access to simulations.	5	- IT[b] staff.
		- Time constraints.	3	- School managers.
		- Learner use of tablets for non-practical work[c]-related activities.	2	- IT staff.

[a] SEEMs = Science Education Equipment and Materials (Chemicals, equipment and simulations).

[b] IT= Information Technology.

[c] PW= Practical Work

5.3.2.1 Revisiting relevant design principles

The results in Table 5.4 verify design principle #9.2 while providing specific extrinsic challenges and actors useful in reducing the challenges in the different categories. On this basis, the design principle may be revised as follows:

Design Principle #9.3: Incorporate the reduction of identified system-level challenges[a] in addition to institutional-level challenges that are material-related[b] and non-material-related[c] into the PDF in order to create circumstances that are more favourable towards teacher learning and practice in school.

(Abrahams & Reis, 2012; Chin, 2004; Goldman, 2005; Higgins, 2009; Kapanadze & Eilks, 2014; Lederman & Lederman, 2012; Lin et al., 2013; Poppe et al., 2011; Toplis & Allen, 2012; Wheater, Langan & Dunleavy, 2005)

[a]Consisting of a restrictive curriculum, mandatory work plan and lack of district support towards use of simulations.

[b] Consisting of inadequacy in science education equipment and materials, their procurement and facilities.

[c]Consisting of inadequate access to simulations, time constraints and learner use of tablets for non-practical work-related activities.

As seen below, the participating teachers also faced intrinsic challenges linked to the design and implementation of IBPW. This calls for professional development aimed at reducing these challenges in conjunction with the reduction of extrinsic challenges. In this regard, design principle #10.2 is maintained as follows:

Design Principle #10.3: Locate efforts towards reducing intrinsic challenges within efforts aimed at reducing extrinsic challenges in order to align the PDF with the Ecological Theory of Development and the multi-faceted approach needed in curriculum implementation and improvement.

(Bronfenbrenner, 1979; Fullan, 1992).

Efforts towards reducing the intrinsic challenges being faced by the participants are informed by the results in the next section.

5.3.3 Results on intrinsic challenges

The discussion in this section responds to SRP3b. In this regard, the participating Physical Science teachers faced various intrinsic challenges linked to IBPW. Figure 4.3 was used to frame the challenges, which have also been clarified based on the conceptual framework used to clarify intrinsic challenges linked to IBPW (Section 4.2.3.3). In addition, direct evidence of gaps in the competences of the participants is also provided. In presenting and interpreting the results, the exact words of the participants have been used in some cases. In this regard, and as before, it is useful to bear in mind that the word ‘practical’ is used as a colloquialism by some participants to refer to practical work.

5.3.3.1 Intrinsic challenges and their clarification

Initiation-phase challenges

Misconception relating to the role of practical work. All four teachers of School P held the opinion that practical work is normally meant for confirming theory. Thus, Teacher P1 stated that “… to me… you have to go through the theory (lesson) before you come to the practical.” A similar result has been obtained in School O as Teachers O1 and O2 considered practical work to have a confirmatory role in relation to theory lessons and textbook content. The fact that these teachers were in favour of the confirmation strategy in practical work is indicative of a shortfall in their CK considering that this knowledge includes that on scientific and classroom-based inquiry. Also, these teachers lacked adequate PCK considering that this includes knowledge of the prescribed goals and objectives of science teaching. The South African Physical Science curriculum (Department of Basic Education, 2011b) partly aims to equip learners with investigative skills that include hypothesising and the designing of investigations.

Planning-phase challenges

Issues linked to learner safety. The data from the interviews show that Teacher P4 was against allowing learners to design experiments to test their own ideas on safety grounds. A second issue linked to safety contained in the field notes is the absence of information on laboratory safety practices and procedures in the science laboratory in School O, and in the classrooms in School P. Also, the document analysis shows that the worksheets lacked safety precautions for the learners. The above results are indicative of a shortfall in the knowledge of these teachers about safety equipment and procedures and/or a gap in their management skills regarding laboratory safety.

Difficulties linked to improvised SEEMs. Classroom observation shows that only Teacher O1 used improvised SEEMs. In the place of carbon rods, the teacher used panel nails in three of five groups when investigating electrical conductivity in aqueous solutions. Teacher P1 found the improvisation of SEEMs quite demanding regarding the effort and the skills required. In School O, one teacher had a perception issue, more specifically, Teacher O1 wondered whether the same results could be achieved with improvised equipment as with conventional equipment. However, she admitted to not having used such equipment in the classroom. This would be a gap in the TPK of the teacher linked to hands-on classroom technology. Alternatively, the teacher may have lacked PCK about curricular materials. The South African Physical Science curriculum (Department of Basic Education, 2011b) incorporates improvised SEEMs (e.g. acid-base indicators derived from red cabbage and magnets taken from old loudspeakers).

Implementation-phase challenges

Unfamiliarity with instructional models (IMs). In relation to implementing practical work, none of the participating teachers in either of the schools used the 5E or another IM that I could recognise. Specifically, the observation data indicated that none of the lessons involved an engagement phase. Also, only one lesson each involved an explanation and an elaboration phase. What would have been considered to be the explanation phase was often done through giving expected outcomes using the worksheet or orally prior to what would have been the exploration phase. An example in this regard is provided by the excerpt below from the observation schedule from a practical lesson taught by Teacher O2 on Faraday's law.

a) Engagement: “Missing”.

b) Exploration: Teacher presents Faraday's law prior to its exploration. She writes $\varepsilon = - N \Delta\varphi/\Delta t$ [on the chalkboard] and asks learners to define Faraday's law in words from the equation. This leads to a lengthy question and answer session between the teacher and a few learners. When finally carried out, this phase [exploration] is a verification of the law.

c) Explanation: This phase is compromised by the commencement of the lesson with a presentation of Faraday’s law.

Evidence of the lack of familiarity with the use of an instructional model useful in sequencing and organising the implementation of practical work was also found in the interview data. Teachers P1 and P2, for example, considered the phases of a practical lesson to include providing the aims, checking prior knowledge and grouping learners. While these so-called phases of a practical lesson may be linked to the first two phases of the 5E IM, Teachers P3 and P4 did not provide any 'phases' that could be linked to those of this IM, for example, Teacher P4 rather provided steps to be followed by learners in writing their laboratory report: aims, apparatus, method . . . conclusion. While Teacher O1 observed the phases in her practical lessons, these phases were different to those of the 5E IM and included "collect the apparatus", "write your hypothesis," and "follow these instructions." However, considering the document analysis, these *phases* of a practical lesson were not considered in the above order in a lesson on Electrical conductivity of aqueous solutions. The worksheet only provided room for the hypotheses of the learners at the end where the questions were listed.

Misconception about notion of prior knowledge. The learners were provided with information linked to the relevant prior learning in two lessons observed. The information was provided through the use of the worksheet and orally, respectively. However, when asked whether the prior knowledge of the learners was adequate when they engaged in practical work, all of the teachers at School P disagreed. Their opinions are reflected in the words of Teacher P3 as follows, "[W]hen we start with the practical, obviously I have to give them more information about what we are going to do, what we are expecting… the theory, the methods…" This opinion is in line with the first type of inquiry in Table 4.1 and is thus unfavourable for IBPW as understood in this paper. Similarly, both Physical Science teachers of School O considered the prior knowledge of their learners as inadequate in relation to engaging them in practical work. In this light, and with particular reference to the misconceptions that some learners possessed, Teacher O1 noted that "it is better to check in which topic they have certain misconceptions then address them before they could even come here". The word "here" in the last sentence refers to the science laboratory where the teacher was being interviewed.

The above misconception about prior knowledge and the unfamiliarity of participants with the 5E IM or another IM that could be recognised are attributable to gaps in the same domains of teacher knowledge. This consists of PK in relation to instructional implementation, as well as PCK associated with instructional approaches in science education.

Teaching practices incompatible with group learning. Classroom observation shows that in one instance each, Teacher O2 and P1 stopped the whole class during group learning in order to provide information in full. While not observed in his classroom, Teacher P3, when interviewed, noted in a similar vein that "[i]f I discover that most of them [learners] are doing something wrong or I want them to find out something, obviously what I will do is I will stop all the groups and try to emphasise the point …". On a separate note, Teacher P3 and O1 were observed in the classroom to interact relatively too long with individual groups. In addition, Teacher O2 noted when interviewed that "with Grade 8 and 9, I just go from group to group checking … but with Grade 11 and 12, I just let them do everything." This teacher thus provided inadequate teacher-learner interaction during group learning In relation to the latter grades. The interview data also shows that the same was true of Teacher P2, who taught Grade 12 only. The above teaching practices indicate a gap in certain domains of teacher knowledge such as PCK on instructional approaches in science education and PK in relation to the implementation of group learning in practical work.

In summation, the above challenges are linked to a shortfall in the CK, various domains of PKC, TPK and various skills of the participants. I also found direct evidence of gaps in the knowledge of the participants, which although not linked to specific challenges, may have had a bearing on their teaching considering the link between the knowledge of teachers and their classroom practices (Section4.2.3.3).

5.3.3.2 Direct evidence of inadequate competences

School O

Inadequate CK. During an informal conversation, Teacher O2 explained to me that she was unsure about which rule to use to determine the direction of the induced current in a wire coil. This gap in CK is recorded in the field notes.

Inadequate TK. When asked about the accessibility of interactive computer simulations in her experience, Teacher O2 responded by saying "I don't know where to get them. The one that I am using right now, someone from ____ (name of a university) came with … I can't get something new…" Also, Teacher O1 noted that she was not able to access PhET simulations through her Smart Board due to her inability to load the simulations on the device.

Lack of adequate TPK. On the one hand, Teacher O2 considered hands-on SEEMs as necessarily superior to interactive computer simulations. On the other hand, when asked about how she used interactive computer simulations, Teacher O2 stated, "I just teach first the topic, then after that, I show them what I was teaching." Teacher O1 also demonstrated inadequate TPK, as evidenced by the field notes in that the teacher stated to the researcher that she was unfamiliar with ticker tape experiments and requested help with the teaching of a practical lesson involving this device.

School P

Inadequate TK. Teacher P3 referred to a temperature probe (data logger) as a computer simulation when asked about interactive computer simulations. The teacher also referred to the temperature probe as a pH probe. In his words: "We just needed to have computer simulations, just to check the temperatures. Otherwise, with the pH probes that we have, the manual pH probes, we cannot." When asked to assess the competence of the Physical Science teachers at School P in relation to selecting appropriate interactive computer simulations for use in practical work, the demonstrator said the following, "Educators seem not to be too friendly to the use of computers and as such you see that simulations which might help … are not done." Responding to a question about the use of tablets in practical work, the demonstrator stated,

> I don't think they seem to have realised that for their simulations, they can still use those tablets instead of trying to find a laptop from somewhere for simulations. They seem not to get that fact. And for such a reason they (the tablets) have been of limited use when it comes to practical work.

Lack of adequate PK and PCK. Teacher P4 had an incorrect concept of prior knowledge, as evidenced in the following statement: "What I actually do before a practical… I teach them… the theory… Now, they got the prior knowledge." Also, Teacher P2 was of the opinion that learners need support during practical work only if the teacher poorly prepared them.

Inadequate PCK linked to interactive computer simulations. Teacher P1 explained regarding the selection of interactive computer simulations that the selected simulation has to be "so simple and understandable" and "it has to validate a theory." Furthermore, all four teachers at this school found interactive computer simulations useful only in one of the following respective situations: when hands-on equipment was unavailable, when faced with an invisible phenomenon, when conventional equipment was hazardous, and when involved in concept development, unlike developing hands-on skills.

Inadequate professional values. In this regard, the demonstrator explicated,

> "You would find that teachers become so relaxed if they know there is someone who is going to do practicals... [T]he hands-on competence, it seems to be lacking in most teachers and if not lacking, they seem to be reluctant to carry out those hands-on experiments".

This remark is in line with the field notes as all of the five practical lessons finally observed at this school fell on days in which the demonstrator was at school. On one such a day, Teacher P1 suddenly invited the researcher to attend a practical lesson although this teacher earlier indicated that there were no plans for practical work that week. All the equipment finally used in this lesson was from the school, raising questions as to why Teacher P1 did not have plans for this practical lesson until the demonstrator was at school. The practical lesson thus appeared to be opportunistic. Also, when asked about the quality of the practical activities selected or designed by the Physical Science teachers of School P, the demonstrator found that: "You would find that the teachers can only do the practical work if it's a school-based assessment task from the department of education… for the whole year they can just do three because it's part of the assessment plan." These comments gathered during the interview are consistent with the field notes. In the case of School P, the researcher seldom witnessed the participants taking SEEMs to class or returning them to the cupboards after class. These teachers thus revealed a limitation in their dedication to practice and the desire for excellence.

Against the above background, the quantity and quality of practical work offered by these teachers is questionable. In the case of School P and with reference to quality, the demonstrator revealed that, "From my own assessment, there is a problem regarding their [Physical Science teachers] actual capacity to deal with practical work… Practical is just done so that it gets out of the way." The view of this participant is not only a synopsis of the results in this section, but is also a reflection of Table 5.5, which summarises the discussion in Section 5.3.3.1.

Table 5.5 Categories and clarification of intrinsic challenges linked to IBPW (Source: Researcher)

Category	Intrinsic challenge	Clarification
Initiation-phase	Misconception linked to the role of practical work. [a]	• Gap in: - CK link to inquiry. - PCK associated with the curriculum.
Planning-phase	• Issues linked to learner safety: - Perception that open inquiry is unsafe. - Safety procedures and practices not displayed. - Worksheets lack information on learner safety.	• Shortfall in: - Pedagogical knowledge linked to instructional planning in relation to learner safety.
	• Difficulties linked to improvised SEEMs[b]: - Effort and skills needed to produce them. - Perceived ineffectiveness.	• Inadequate: - Practical skills. -TPK linked to hands-on classroom technology/PCK related to curricula materials.
Implementation-phase	• Unfamiliarity with IMs. [c] • Misconception about	• Gap in: - PK linked to instructional

	prior knowledge notion.	implementation.
	• Teaching practices incompatible with group learning.	-PCK associated to instructional approaches. - PK linked to instructional implementation. - PCK on instructional approaches.

[a] PW = practical work; [b] SEEMs; [c] IMs = Instructional Models.

5.3.3.1 Revisiting relevant design principles

Considering Table 5.5 and the discussion in Section 5.3.3.2, the design principle linked to the goal of the PDF may be revised as follows:

Design Principle #1.3: Aim the PDF at enhancing the related competences* in addition to the professional identity and practice of teachers as these are important in effective teacher learning in general, and in relation to the intrinsic challenges♦ linked to IBPW in particular.

(Clarke & Hollingsworth, 2002; Elster, 2009; Fishman, Marx, Best & Tal, 2003; Hoban, 2007; Loucks-Horsley, Love, Hewson, Stiles & Mundry, 2003; Magnusson et al., 1999; Mishra & Koehler, 2006; Rozenszajn & Yarden, 2014; Sweeney & Paradis, 2004).

* Consisting of knowledge[a], skills[b], values[c] and practices[d]

[a] such as CK, PK, TK, TPK and PCK,

[b] consisting of practical skills and skills linked to laboratory safety,

[c] including care and concern for learners, commitment and dedication to their practice in addition to the desire for continuous learning, innovation and excellence,

[d] in relation to inquiry-based learning (e.g. asking questions, constructing explanations and engaging in evidence-based arguments).

♦ including issues linked to learner safety; misconceptions on the notion of prior knowledge; misconceptions relating to the role of practical work, difficulties linked to improvised SEEMs, and unfamiliarity with instructional models.

5.3.4 Final design principles and context-specific PDF

Three design principles were either verified or revised based on the above context and needs analysis. The design principles concern three components of a PDF: an instructional design perspective, a professional development goal, and attending to contextual factors. The remaining seven design principles from the previous research cycle stand unchanged. These seven principles concern learning phases, learning perspective, strategies, instructional functions, and teacher motivation. These design principles have not been (and could not have been) affected by the context and needs analysis carried out. The revised, verified and unchanged design principles were useful in synthesising a context-specific PDF to support IBPW in South African Physical Science classrooms in resource-constrained schools. To synthesise the PDF, the design principles are as follows:

Design Principle #1.3: Aim the PDF at enhancing the related competences* in addition to the professional identity and practice of teachers as these are important in effective teacher learning in general, and in relation to the intrinsic challenges♦ linked to IBPW in particular.

(Clarke & Hollingsworth, 2002; Elster, 2009; Fishman, Marx, Best & Tal, 2003; Hoban, 2007; Loucks-Horsley, Love, Hewson, Stiles & Mundry, 2003; Magnusson et al., 1999; Mishra & Koehler, 2006; Rozenszajn & Yarden, 2014; Sweeney & Paradis, 2004).

* Consisting of knowledge[a], skills[b], values[c] and practices[d]

[a] such as CK, PK, TK, TPK and PCK,

[b] consisting of practical skills and skills linked to laboratory safety,

[c] including care and concern for learners, commitment and dedication to their practice in addition to the desire for continuous learning, innovation and excellence,

[d] in relation to inquiry-based learning (e.g. asking questions, constructing explanations and engaging in evidence-based arguments).

♦ including issues linked to learner safety; misconceptions on the notion of prior knowledge; misconceptions relating to the role of practical work, difficulties linked to improvised SEEMs, and unfamiliarity with instructional models.

Design Principle #2.3: Use the Social Cognitive Theory as the learning perspective in the PDF in order to allow for collective participation in a professional learning community in which the competences and practice of each teacher are enhanced through observation, enactment and reflection.

(Bandura, 2001; El-Deghaidy, Mansour, & Alshamrani, 2015; Marx & Harris, 2006; National Science Teachers Association, 2006; Ostermeier et al., 2010; Schunk, 2012; (Teacher Professional Growth Consortium, 1994)

Design Principle #3.3: Incorporate a pre-participation phase, an exploration/planning phase, an implementation phase and a post-implementation phase into the PDF with reference to studies on effective teacher learning.

(Chikasanda et al., 2013; Mansour, EL-Deghaidy, Alshamrani & Aldahmash, 2014; Rozenszajn & Yarden, 2014; Yerushalmi & Eylon, 2013).

Design Principle #4.3: Adopt lesson study as the professional development strategy in the PDF given, for example, that lesson study is usable across different socio-economic contexts, involves active learning in a professional learning community, and is aligned to core features of effective teacher learning.

(Desimone, Porter, Garet, Yoon & Birman, 2002; Gaible & Burns, 2005; Lewiset al., 2006; Perry & Lewis, 2009).

Design Principle #5.3: Incorporate lesson study phases into the PDF under related major phases of professional development (pre-participation, exploration/planning, implementation and post-implementation), in order to provide a sequence for planning activities within these major professional development phases.

(McKenney et al., 2006; Reigeluth, 1999)

Design Principle #6.3: Include instructional functions (e.g. reviewing relevant prior learning, providing overviews and learning goals, providing guidance and feedback, and reviewing learning periodically) in the PDF in order for professional development to be more effective and also to serve as a transition between its phases.

(Mettes, Pilot & Roossink, 1981; Rosenshine &Stevens, 1986; Stolk et al., 2012; Terlouw, 2001).

Design Principle #7.3: Incorporate intrinsic and extrinsic teacher motivation into the PDF given that teachers need to be motivated in order to change their practice. Although goal-setting and improved performance is effective as an intrinsic incentive, motivation is difficult to sustain without extrinsic incentives (such as access to additional resources and observing the success of peers).

(Boyd, Banilower, Pasley & Weiss, 2003; Gaible & Burns, 2005; Pintrick & Schunk, 1996; Stolk et al., 2009b; Schunk, 1995, 2012).

Design Principle #8.3: Combine the SLID[a] model and the 5E[b] instructional model in order for the PDF to reflect practical work that is consistent, systematic, adequately sequenced and organised, more relevant and effective, and more consistent with inquiry-based teaching and learning.

(Balta, 2015; Bybee, 1997; Dick et al., 2001; Dogru-Atay & Tekkaya, 2008; Kallio, 2008; National Research Council, 2000; Peterson, 2003; Reiser & Dempsey, 2007)

[a] SLID = Science Laboratory Instructional Design.
[b] 5E = Engagement, Exploration, Explanation, Extension and Evaluation.

Design Principle #9.3: Incorporate the reduction of identified system-level challenges[a] in addition to institutional-level challenges that are material-related[b] and non-material-related[c] into the PDF in order to create circumstances that are more favourable towards teacher learning and practice in school.

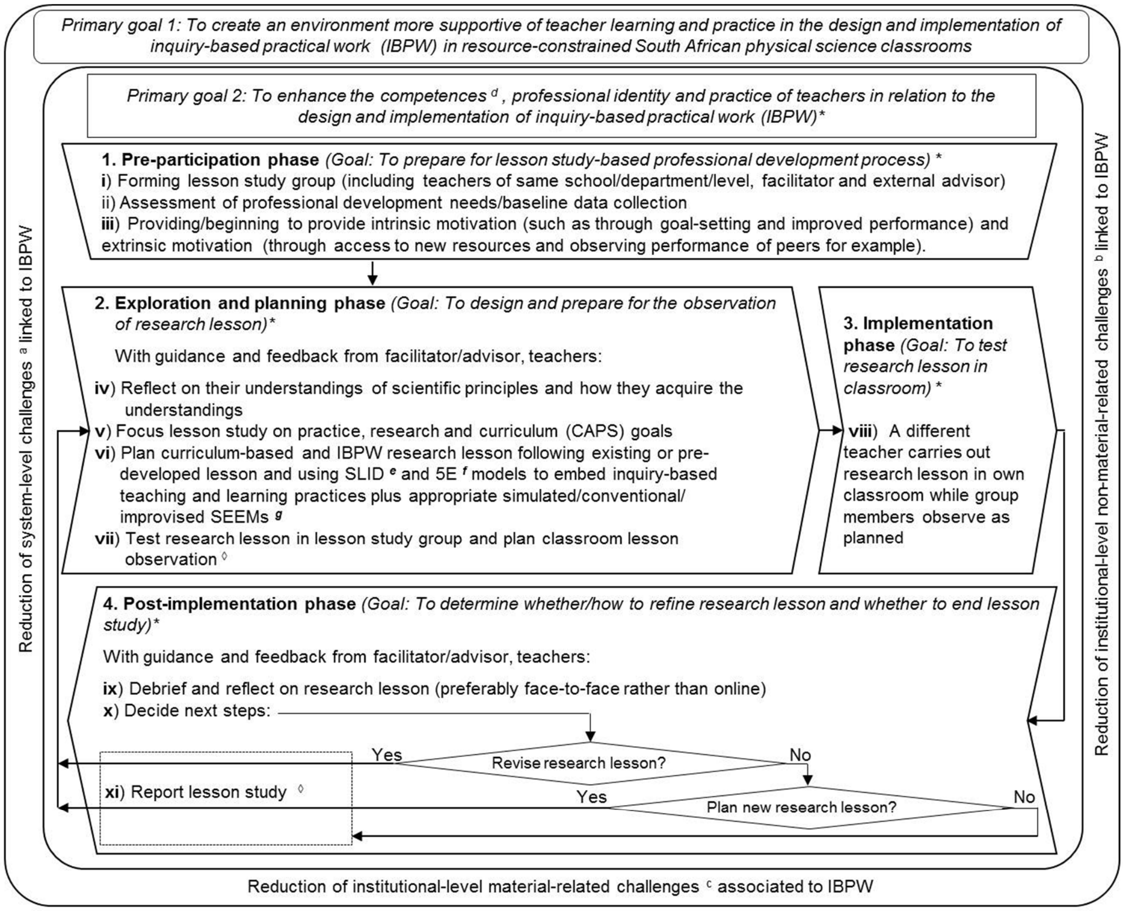
(Abrahams & Reis, 2012; Chin, 2004; Goldman, 2005; Higgins, 2009; Kapanadze & Eilks, 2014; Lederman & Lederman, 2012; Lin et al., 2013; Poppe et al., 2011; Toplis & Allen, 2012; Wheater, Langan & Dunleavy, 2005).

[a] Consisting of a restrictive curriculum, mandatory work plan and lack of district support towards use of simulations.
[b] Consisting of inadequacy in science education equipment and materials, their procurement, and facilities.
[c]Consisting of inadequate access to simulations, time constraints, and learner use of tablets for non-practical work-related activities.

Design Principle #10.3: Locate efforts in reducing intrinsic challenges within efforts aimed at reducing extrinsic challenges in order to align the PDF with the Ecological Theory of Development and the multi-faceted approach needed in curriculum implementation and improvement.

(Bronfenbrenner, 1979; Fullan, 1992).

Based on the ten design principles above, the completed context-specific version of the PDF in Figure 5.2 has been produced.



Legend:
[a] consisting of a restrictive curriculum, mandatory work plan and lack of district support towards use of simulations
[b] consisting of inadequate access to simulations, time constraints, and learner use of tablets for non-practical work related activities
[c] consisting of inadequacy in science education equipment and materials, their procurement and also facilities

[d] consisting of knowledge [h], skills [i], values [j] and practices [k]
  [h] consisting of CK, PK, TK, TPK and PCK
  [i] consisting of practical skills and skills linked to laboratory safety
  [j] including desire for continuous learning, innovation and excellence
  [k] in relation to inquiry-based learning (e.g., asking questions, constructing explanations and engaging in evidence-based arguments)

[e] SLID = Science Laboratory Instructional Design model (Phases: Initiation, Planning, Implementation (based on 5E [g] instructional model in this case), Evaluation and Feedback)
[f] 5E instructional model (Phases: Engagement, Exploration, Explanation, Extension and Evaluation)
[g] SEEMs = Science Education Equipment and Materials

* Providing learning goals on a continuous basis (Primary goal 2 lies in enhancing teacher competences and professional identity in order to reduce intrinsic challenges [l] linked to designing and implementing IBPW)

◊ Reviewing learning periodically
  [l] including misconception about notion of prior knowledge, misconception relating to role of practical work, difficulties linked to improvised SEEMs and unfamiliarity with instructional models

Figure 5.2 Context-specific PDF to support IBPW (Source: Researcher)

Due to design principles #1.3 and #9.3, the context-specific PDF in Figure 5.2 is different from the revised conceptual content-specific PDF in Figure 4.11. This is because particular extrinsic and extrinsic challenges that need to be reduced in the context of resource constrained South African Physical Science classrooms have been specified. Both categories of challenges have been specified in a systemic manner. In relation to the identified intrinsic challenges, the specific domains of competence that need to be enhanced have also been detailed.

5.4 EVALUATION PHASE 3

5.4.1 Introduction

In line with Figure 5.1, the quality criteria for the evaluation of the context-specific version of the PDF in Figure 5.2 were expected practicality and effectiveness. Thus, these criteria will now be discussed.

Expected practicality. Expected practicality refers to the feasibility (argued predictions about the functioning) of an intervention (in this case PDF) in the context for which the intervention has been designed and developed (Prins & Pilot, 2013). The evaluation of the feasibility of an intervention often focuses on its acceptability (Moore, Audrey, Barker, Bond, Bonell, Hardeman et al.,, 2015). Moreover, an intervention is practical when representatives of the target group of users (in this case professional development providers) consider the intervention easy to use in a manner that is largely compatible with the intentions of developers (Plomp, 2013). It is also the extent to which experts and users consider the intervention as clear, usable, appealing and cost-effective under 'normal' conditions (Van den Akker, 1999, 2007).

Expected effectiveness. Expected effectiveness involves the extent to which the experiences offered by the intervention are consistent with the intended goal of the intervention (Van den Akker, 2007). It also deals with the question of the extent to which the intended goals can be achieved based on the experiences provided. The expected effectiveness focuses on the expected teacher learning outcomes. In this case, given that these outcomes are specified in the PDF, the focus lies on whether the PDF allows for the attainment of the specified goals.

It is worth considering that formative evaluation of an artefact under development is aimed at identifying not only weaknesses, but also how the artefact may be improved (Venable et al., 2012). Thus, it is necessary to determine weaknesses in the context-specific version of the PDF in relation to expected practicality and expected effectiveness, in addition to how these aspects of the PDF may be improved.

5.4.2 Data collection and analysis

Like the previous phase of this research cycle, this phase involved the collection and analysis of empirical data. In this regard, the discussion of techniques of empirical data collection and analysis in Section 2.7 was useful in providing guidance. Thus, the sampling of participants, techniques of data collection, data analysis, as well as ethical issues are considered below.

5.4.2.1 Sampling

In order to collect data on the expected practicality and expected effectiveness of the context-specific version of the PDF in Figure 5.2, two experts were identified and herein referred to as Expert 3 (E3) and Expert 4 (E4) respectively. They were chosen as practitioners and/or researchers in inquiry-based science education and in teacher professional development in South Africa. These experts are considered as examples of the potential users of the completed PDF.

5.4.2.2 Data collection techniques

Contained in this section is the method of data collection, a description of the data collection instrument, as well as the data collection procedure.

Method of data collection. To evaluate the PDF as described above, the walkthrough (one-to-one) method of formative evaluation was useful. It is on this basis that the two experts (E3 and E4) were used.

Data collection instrument. Against the above background, and also considering the work of Ouma (2013), an evaluation instrument was designed (Appendix P). The instrument includes three primary sections: a general introduction, the introduction of a professional development framework, and formative evaluation. The first section provides the background and purpose of this study. Also included in this section are the ethical principles followed in the data collection, analysis and dissemination. In the second section of the instrument, the context-specific version of the PDF is introduced on a component-by-component basis. The last section contains nine open-ended evaluation questions: five on aspects of expected practicality and three on aspects of expected effectiveness. The ninth question allows the experts to provide data on any other aspect of practicality or effectiveness. Regarding expected practicality, the aspects evaluated in relation to the PDF were appeal, clarity of terminology, ease of understanding the PDF, and acceptability. In relation to expected effectiveness, the focus was on the extent to which the goals of the PDF could be achieved based on the experiences provided for in the PDF. The likelihood of the professional development process in the PDF being adequate for achieving the professional development goal in the PDF was further included.

Data collection procedure. Unlike E4, E3 had two opportunities to become acquainted with this research before answering the nine evaluation questions. First, E3 listened to a 15 minute presentation on the research during a post-graduate student research conference. One week later, the researcher had a session lasting more than two hours with E3 in her office. The researcher also had a session with E4 in her office. The session lasted one hour and forty-five minutes. Each of these sessions focused on the presentation and formative evaluation of the context-specific version of the PDF. In this regard, the researcher and each expert went over the PDF initially component-by-component. This was to obtain a thorough description of each component present in the PDF, and where and how each component was implemented in the PDF. During this time, the researcher paused to allow the expert time to take notes. In addition to taking notes, the experts asked questions in order to enhance their understanding. It was only after this that the discussion focused on the evaluation questions. The researcher asked follow-up questions and took notes of the responses of the experts to each question.

After the data analysis (described below), the respective results were sent by email to each expert for verification. In light of this, E3 enhanced a point in the results as follows, “I think ‘more emphasis’ should be clarified: the link between boxes should be more prominent to emphasize the flow. So the arrows and boxes should be equally prominent in the diagram.” However, E3 noted that “[n]o correction [is] needed.”

5.4.2.3 Data analysis

The data thus collected could be analysed based on the deductive-inductive approach involved in this study. As such, the data was analysed in relation to expected effectiveness and expected practicality as the primarily categories. Each of these categories had *a priori* secondary categories, for example, the effected practicality of the PDF was considered in relation to the aspects of clarity of terminology, appeal of the PDF diagram, and the acceptability of the PDF. Under these categories, the data-driven inductive approach to thematic analysis (Boyatzis, 1998) could then be used based on the method of constant comparison (Strauss & Corbin, 1990).

5.4.2.4 Ethical considerations

As seen above, the real names of the experts have not been disclosed. This is in line with the promise of anonymity offered by the researcher prior to the data collection. Other principles employed in the data collection consisted of safety in participation, voluntary participation, informed consent, privacy and trust (Section 2.8). These principles were implemented in introduction emails, in the data collection instrument and in the conducting of the data collection. The introduction email, for instance, included the background, research problem and purpose of the research, as well as the role of the formative evaluation in the study. Only after this was the expert asked about the possibility of their participation in the evaluation on a voluntary basis. Moreover, during the conducting of the evaluation, the researcher promised the expert confidentiality and anonymity. In addition, it was up to each expert whether to complete the one-to-one evaluation in one session or in more than one session.

5.4.3 Outcomes and reflection

It is necessary to first present a profile of the two experts who participated in the above manner in the formative evaluation of the context-specific version of the PDF. This profile can be seen in Table 5.6.

Table 5.6 Profile of experts involved in the evaluation of context-specific PDF (Source: Researcher)

Aspect	Expert 3	Expert 4
Highest qualification	PhD	PhD
Position	Professor	Lecturer
University where you work currently	"Research intensive university"	"Research intensive university"
Years of experience in teacher professional development research	5	4
Years of experience in delivering teacher professional development	5	6
Years of involvement in inquiry-based science education research	5	6
Years of involvement in inquiry-based teaching	5	4

As seen in Table 5.6, the two experts involved in the evaluation of the PDF were qualified professionals with considerable experience in research and practice in both teacher professional development and in inquiry-based science education in South Africa. The results of the analysis of the data from these experts are presented below under three headings: expected practicality, expected effectiveness and other aspects.

5.4.3.1 Expected practicality of PDF

Appeal of PDF diagram. Both experts were unsatisfied with the appeal of the PDF diagram. In this light, E3 noted that the diagram of the PDF had excessive text, while E4 similarly stated that the diagram of the PDF was overwhelming as it was too compact. Thus, E4 advised that the amount of text in the diagram be reduced by wording the diagram more succinctly. E4 also noted the usefulness of highlighting the most important information, such as through the use of bolder typing, for example. E3 noted that the arrows linking the boxes should be more prominent and that these arrows and the boxed should also be prominent in the diagram. E3 also recommended the use of colour in order to make the PDF diagram more appealing. When asked whether an abridged version of the framework would be useful, E3 agreed. Therefore, E3 suggested starting with the abridged version, including the phases of professional development and then breaking down these phases subsequently.

Clarity of terminology. Both experts found the terminology used in the PDF adequate in relation to professional development researchers and professional development providers, such as lesson study advisors.

Ease of understanding the PDF. E4 noted that the incorporation of goals in the PDF helped in making the PDF understandable to its users. However, E4 noted that a brief introduction was needed when presenting the PDF. This introduction should indicate what the PDF is all about. Also, E3 noted that enhancing the appeal of the diagram of the PDF, as she explained above, would also enable users to better understand the PDF.

Acceptability of the PDF. In this regard, E3 noted that in relation to professional development researchers and providers (such as lesson study advisors), the PDF should be acceptable. This is in the sense that the PDF is useful in providing professional development experiences, which is something that these users are normally eager to do. However, regarding the participating teachers, E3 noted that the PDF may not be acceptable due to such systematic issues linked to teacher professional development in South Africa as the allocation of time and the availability of extrinsic incentives. E4 commented on the acceptability of the PDF in relation to not only professional development providers, but also policy makers. Regarding the latter, E4 referred to the point-based system for monitoring teacher professional development run by the South African Council of Teachers (SACE) (Department of Basic Education, 2011a). The system is aimed at encouraging teachers to participate in professional development. The points gained by an individual teacher over several years are linked to job retention. In this regard, E4 noted that the PDF offers policy makers a blueprint of a professional development process to consider towards enabling teachers to gain professional development points. Given that the PDF can thus assist in policy implementation, it may be acceptable to policy makers. Concerning professional development providers and researchers, E4 stated that the PDF may be acceptable to them considering that it was theory based and blended a number of theories.

Cost effectiveness (cost-benefit ratio) of implementing PDF. Both experts considered the PDF cost-effective to implement in the context of South African Physical Science education. E4 explained this as follows. Firstly, a useful policy framework within which to implement the PDF is already in place, for example, there are mechanisms for the replenishment of science education equipment and materials, which may be used not only in classroom teaching, but also in teacher professional development. This point was, however, contradicted by the reality in School P and O where the teachers found that the procurement of SEEMs was lacking (Section 5.3.2.2). However, the PDF is also likely to be cost-effective to implement considering that it reflects a school-based profession development process. This removes the cost of transporting and accommodating teachers at professional development venues that are away from individual schools. However, E3 pointed out that the implementation of the PDF must be accompanied by rewards in order to encourage teachers to get involved in professional development. When asked about the intrinsic and extrinsic teacher motivation, as incorporated into the PDF, E3 noted that monetary incentives are needed. The expert added that support in relation to making teacher professional development attractive is needed at a systemic level.

5.4.3.2 Expected effectiveness of PDF

Expected effectiveness of PDF in achieving primary goal 1. Both experts expected the PDF to be effective in achieving this goal. As E4 noted, this is because the PDF considers both the system- and institutional-level challenges being faced by teachers in relation to the design and implementation of inquiry-based practical work. E3 added that based on her experience in the professional development of science teachers, the PDF should be effective in creating an environment that better supports the design and implementation of inquiry-based practical work in resource constrained South African Physical Science classrooms. However, as the expert denoted, this is possible only if opportunities are created for teacher professional development and if extrinsic teacher motivation is given attention. In this regard, E3 earlier highlighted the need for a monetary incentive. In relation to teacher enhancement, E3 noted that the PDF allows for professional development experiences that are consistent and adequate in relation to the teacher learning goal (primary goal 2) in the PDF. However, E3 noted that primary goal 1, which deals with the creation of a supportive environment, must first be achieved.

Consistency of professional development experiences and primary goal 2. E4 found the professional development experiences reflected in the PDF as being consistent with the goal of the PDF. In this regard, the expert added that the experiences were explicit and could occur in a step-wise manner. E3 also found the experiences consistent with the goal.

Adequacy of professional development experiences in relation to primary goal 2. Both experts considered the professional development experiences adequate in relation to the goal. E4 added that the PDF provides for a safe learning environment. However, E3 insisted that primary goal 1 must be achieved first.

5.4.3.3 Other aspects of the PDF

Both experts provided other ways of improving the expected practicality and effectiveness of the PDF. E3 noted the need to address the issue of attracting teachers to professional development whether during working or private hours. This aspect, as noted by E3, needs to be addressed at a systemic level. In particular, more extrinsic motivation is needed. This motivation may take the form of a salary increase, for example. E4 suggested the use of after-class hours before 3 p.m. for implementing the PDF in schools. Also, laboratory assistants/technicians could be helpful in the implementation of the PDF. In addition, this expert noted the need to prepare participants in the pre-participation phase in order for them to feel reassured and have a sense of ownership of the professional development process. This is in relation to the fact that the focus should not be on individual styles of delivering a practical lesson, but rather on the design of the lesson. In other words, it needs to be clear in the pre-participation phase that reflections in the post-implementation phase of professional development are not judgmental. In this regard, the lesson study advisor nevertheless needs to be prepared to handle any conflicts.

The above results indicate that the PDF can be expected to be effective and practical in certain ways, but not in other ways. In the former regard, the

- Terminology used in the diagram of the PDF is adequate.
- The PDF should be acceptable to professional development providers.
- The PDF is cost-effective as it uses a school-based professional development strategy and fits into an existing policy framework.
- The cost of implementing the PDF is worth it.
- The PDF is expected to be effective in achieving its goals as long as the primary goal is achieved first.
- PDF provides policy makers options to consider in enabling teachers to gain professional development points.
- PDF blends a number of theories and is thus theory-based.

While the PDF is expected to be practical or effective in the above ways, the expected practicality and effectiveness of the PDF may be improved in a number of ways, which are as follows:

- Prior attention to systemic issues linked to teacher professional development (such as time allocation and extrinsic motivation).
- Introducing the especially non-judgmental nature of lesson study in the pre-participation phase of professional development.
- Making both the arrows and boxes in the PDF diagram more prominent and to the same degree.
- Highlighting the most important information in the diagram of the PDF through the use of bold type and colour.
- Incorporating professional development points and financial incentives into the PDF as extrinsic motivation.
- Providing a brief introduction (synopsis) prior to presenting the PDF diagram.
- Creating and presenting an abridged version of the PDF before the more succinctly worded, full version.

In addition to the above, and in order to further reduce the text in the diagram of the PDF, the footnotes on instructional functions were fully incorporated directly into the diagram where this was not already the case.

5.4.4 Revised outcomes of research cycle

The above formative evaluation results call for the revision of three of the ten design principles in Section 5.3.4. The design principles are #7.3 and #9.3 and #10.3. These design principles were revised as follows:

Design Principle #7.3b: Incorporate intrinsic and extrinsic teacher motivation into the PDF given that teachers need to be motivated in order to change their practice. Although goal-setting and improved performance is effective as an intrinsic incentive, motivation is difficult to sustain without extrinsic incentives (that include access to additional resources, observing the success of peers and financial rewards).

(Boyd, Banilower, Pasley & Weiss, 2003; Gaible & Burns, 2005; Pintrick & Schunk, 1996; Stolk et al., 2009b; Schunk, 1995, 2012).

Design Principle #9.3b: Incorporate the reduction of identified system-level challenges[a] in addition to institutional-level challenges that are material-related[b] and non-material-related[c] into the PDF in order to create circumstances that are more favourable towards teacher learning and practice in school.

(Abrahams & Reis, 2012; Chin, 2004; Goldman, 2005; Higgins, 2009; Kapanadze & Eilks, 2014; Lederman & Lederman, 2012; Lin et al., 2013; Poppe et al., 2011; Toplis & Allen, 2012; Wheater, Langan & Dunleavy, 2005).

[a]Consisting of time allocation, extrinsic motivation, a restrictive curriculum, mandatory work plan and lack of district support towards use of simulations.

[b] Consisting of inadequacy in science education equipment and materials, their procurement and also facilities.

[c]Consisting of inadequate access to simulations, time constraints and learner use of tablets for non-practical work-related activities.

Design Principle #10.3b: Combine a) Efforts aimed at reducing extrinsic challenges, and b) Efforts towards reducing intrinsic challenges in order to align the PDF with the Ecological Theory of Development and the multi-faceted approach needed in curriculum implementation and improvement, starting with point a).

(Bronfenbrenner, 1979; Fullan, 1992).

The revision of design principle 10.3 has made the design principle in its latest version (10.3b) better reflect the existing version of the context-specific version of the PDF. However, as a result, design principle #10.3b has no effect on the PDF. It may, however, be useful to indicate when presenting the PDF that its implementation must begin in the enclosing shell with efforts aimed at reducing extrinsic challenges to teacher learning and practice in the design and implementation of inquiry-based practical work. Having said that, the PDF can be enhanced based on the revised design principles #9.3b and #7.3b in addition to the other ways identified above for improving the practicality and effectiveness of the PDF. The abridged version of the PDF is shown in Figure 5.3.

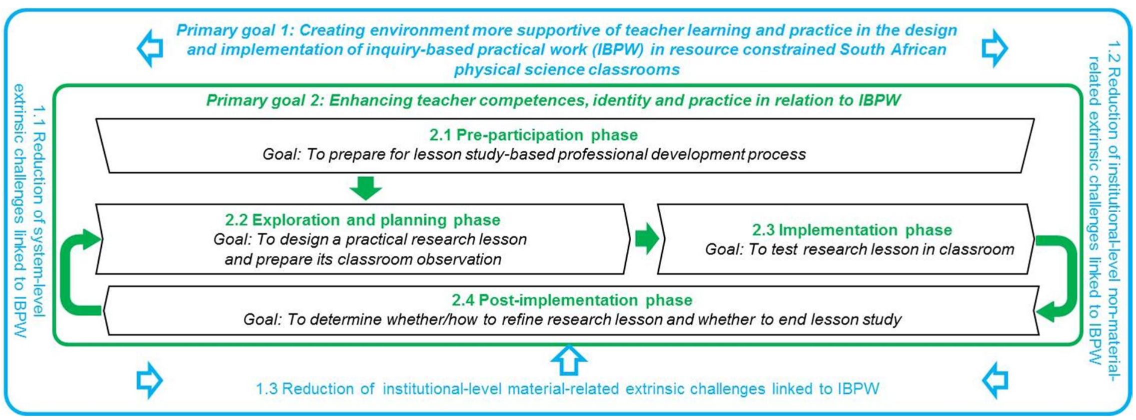
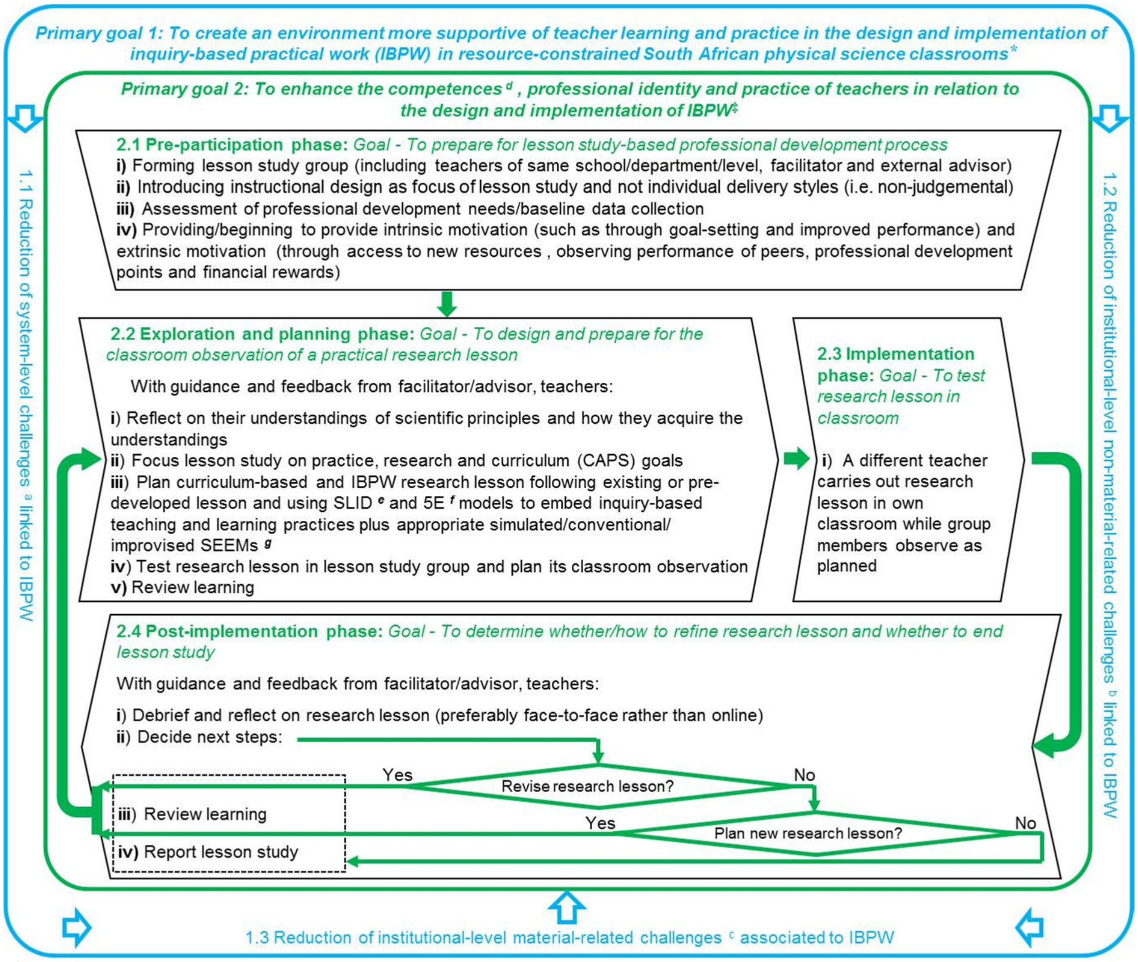


Figure 5.3 Abridged version of revised context-specific PDF to support IBPW (Source: Researcher)

As may be seen in Figure 5.3, the PDF reflects a professional development process driven by two primary goals to be achieved sequentially. The first goal is to create an environment that better supports teacher learning and practice in the design and implementation of inquiry-based practical work in South African Physical Science classrooms in resource-constrained schools. This is through the reduction of the related systemic, as well as institutional-level challenges, seen in shell of the PDF (shown here in light blue). The actual enhancement of teachers can be successful only after the above goal has been achieved, as indicated by the bottom middle blue arrow. The achievement of the first goal allows the second goal of the professional development process to take over. This goal is to enhance the competences, identity and practice of teachers in relation to the design and implementation of inquiry-based practical work. This is a cyclical school-based professional development process based on lesson study as the professional development strategy. In addition to lesson study, the PDF in Figure 5.3 has three other components, which comprise attending to contextual factors (in the shell), professional development goals (as specified), and professional development phases (numbered 2.1 to 2.4).

Against the above background the full version of the PDF may be presented. This version contains details of some of the above components, as well as four other primary components. The four additional components consist of a learning perspective, instructional design perspective, instructional functions, and teacher motivation. The full version of the PDF is shown in Figure 5.4.



Legend:

[*] This goal is towards the reduction of extrinsic teaching challenges linked to teacher learning and practice in inquiry-based practical work

[a] consisting of time allocation, extrinsic motivation, a restrictive curriculum, mandatory work plan and lack of district support towards use of simulations
[b] consisting of inadequate access to simulations, time constraints, and learner use of tablets for non-practical work related activities
[c] consisting of inadequacy in science education equipment and materials, their procurement and also facilities

[‡] This goal is towards reduction of intrinsic challenges linked to the design and implementation of inquiry-based practical work including misconception about notion of prior knowledge, misconception relating to role of practical work, difficulties linked to improvised SEEMs and unfamiliarity with instructional models

[d] consisting of knowledge [h], skills [i], values [j] and practices [k]
  [h] consisting of CK, PK, TK, TPK and PCK
  [i] consisting of practical skills and skills linked to laboratory safety
  [j] including desire for continuous learning, innovation and excellence
  [k] in relation to inquiry-based learning (e.g., asking questions, constructing explanations and engaging in evidence-based arguments)

[e] SLID = Science Laboratory Instructional Design model (Phases: Initiation, Planning, Implementation (based on 5E [g] instructional model in this case), Evaluation and Feedback)
[f] 5E instructional model (Phases: Engagement, Exploration, Explanation, Extension and Evaluation)
[g] SEEMs = Science Education Equipment and Materials

Figure 5.4 Full version of revised context-specific PDF to support IBPW (Source: Researcher)

The full version of the PDF in Figure 5.4 further describes how the primary goals (1 and 2) may be achieved. Thus, this version of the PDF provides a breakdown of the four professional development phases (2.1 to 2.4) contained in Figure 5.3. The learning perspective, instructional design perspective, instructional functions and teacher motivation are evident in the full version of the PDF. The learning perspective is Social Cognitive Theory, which underlies the achievement of primary goal 2. The instructional design perspective combines an instructional design model (SLID) and an instructional model (5E) in secondary phase 2.2(iii). The instructional functions incorporated into the PDF consist of the continuous provision of learning goals and the periodic review of learning. The latter aspect occurs in each lesson study cycle in secondary phases 2.2 vii and 2.4 iii. Teacher motivation (intrinsic and extrinsic) begins in secondary phase 2.1 iv) and should last until the end of the professional development process due to the combination of ways of attracting and sustaining the teacher motivation involved. At the end of the professional development process, the competences, professional identity and practice of teachers in relation to the design and implementation of inquiry-based practical work should have developed. This is within an environment that is supportive at the institutional and systemic levels.

5.5 CHAPTER SUMMARY AND CONCLUSION

This chapter builds on the previous cycle and contains the third and last cycle in this design research. The research cycle fulfils the third major step in the process (Figure 1.1) considered for developing a Professional Development Framework (PDF). The purpose of the step is to synthesis a context-specific version of a PDF to support South African Physical Science teachers in resource-constrained schools, in the design and implementation of inquiry-based practical work. In order to achieve this purpose, a multi-method, multi-case study was useful. The case study enabled a context and needs analysis to be conducted and used as a basis for revising the ten design principles from the previous research cycle. The revised design principles allowed the PDF in to be synthesised. This has enabled the following secondary research purposes (SRPs) to be achieved:

SRP2: To determine how inquiry-based, or not, is the way in which practical work is being designed and implemented in resource-constrained South African Physical Science classrooms

SRP3a: To determine the extrinsic challenges being faced by teachers in these classrooms in relation to the design and implementation of inquiry-based practical work.

SRP3b: To determine the intrinsic challenges being faced by teachers in these classrooms in relation to the design and implementation of inquiry-based practical work.

SRP4: To generate the final design principles considering SRP2, SRP3a and SRP3b, and then design a context-specific version of the Professional Development Framework.

The PDF has undergone formative evaluation using the walkthrough (one-to-one evaluation) method, with the quality criteria being expected practicality and expected effectiveness. The aspects of practicality evaluated consisted of the appeal of the PDF diagram, clarity of terminology, ease of understanding the PDF, the acceptability of the PDF, as well as the cost effectiveness of implementing the framework. Concerning expected effectiveness, the PDF has been evaluated in relation to the creation of an environment more supportive of the design and implementation of inquiry-based practical work (IBPW). The PDF has also been evaluated regarding the consistency and adequacy of reflected professional development experiences in relation to the enhancement of the competences and practice of the participants in relation to IBPW. On this basis, the expected practicality and expected effectiveness of the PDF and the associated design principles have been improved. As part of the improvement, the completed PDF is available in two versions: an abridged (Figure 5.3) and a full version (Figure 5.4).

This research cycle has contributed towards the achievement of the primary research purpose (PRP) of this study, which is:

> **PRP:** To generate design principles and use them over a number of research cycles to develop a professional development framework. This framework is to support teachers in resource-constrained South African Physical Science classrooms in the design and implementation of inquiry-based practical work.

Against the above background, it remains, among other aspects, to discuss the outcomes of this study and consider the practice- and research-based implications of the PDF. The discussion in this regard is contained in the next and last chapter of this design research.

CHAPTER 6 : SUMMARY AND CONCLUSION

6.1 OVERVIEW OF CHAPTER

This last chapter begins with an overview of this design research study. The rest of the chapter presents and discusses the primary outcomes of the study. These outcomes include the development process coupled with the resulting design principles and the associated intervention. The intervention is the completed Professional Development Framework (PDF) to support South African Physical Science teachers in resource-constrained schools. This support is in relation to the design and implementation of inquiry-based practical work. Also discussed in this chapter are the limitations and the implications of this study.

In the above regard, the outline of this chapter is as follows:

- Overview of the study;
- Primary outcomes of the study;
- Reflecting on the final outcomes;
- Limitations of the study
- Implications: Practice- and research-related.

6.2 OVERVIEW OF THE STUDY

This section presents the practice- and research-based problem involved in this study. Also included are the associated primary and secondary research questions and purposes. In addition, the research strategy is outlined. This section, however, begins with the context in which this study was located.

6.2.1 Background information

Around the world, the interest of young people in science is declining (Institute of Physics, 2010), coupled with the dwindling uptake of science and science-related subjects and careers (Helliar & Harrison, 2011; Organisation for Economic Co-operation and Development, 2008). In this regard, South Africa is not an exception. Against the background of these undesirable effects linked to science education in South Africa and internationally, it is useful to reconsider practical work in science classrooms in schools.

Some researchers have found that the effectiveness of practical work in enhancing the conceptual understanding of learners is unclear (e.g. Hofstein & Mamlok-Naaman, 2007; Tobin, 1990). However, practical work is still considered by many people as a critical component of science education (Abrahams &Millar, 2008; Lee et al., 2008). In reality, the rationale for practical work in science classrooms provided by many authors goes beyond conceptual learning (e.g. Lynch, 1986; Tamir, 1991). In the light of this, and among other aspects, practical work promotes the development of practical, problem-solving, and analytical skills; assists in nurturing scientific values and attitudes; in addition to enhancing the motivation and interest of learners in science. This rationale for practical work is better fulfilled using the inquiry-based teaching and learning approach in science education than using the traditional (transmission-orientated) approach.

Internationally and in South Africa, inquiry-based teaching and learning has been infused in science curricula (Department of Basic Education, 2011b; Gott & Duggan, 2007) despite certain drawbacks associated with inquiry-based science education. In this regard, some teachers are concerned about time, learner safety and grading (Anderson, 2007; Deters, 2004). However, the level of engagement involved in inquiry-based teaching and learning (in this case during practical work) can have a positive effect on the attitudes of learners towards science (Osborne & Dillon, 2008; Rocard, 2007). Also, inquiry-based teaching positively affects learning in terms of enabling learners to better understand scientific concepts and procedures than through rote (transmission-orientated) learning (e.g., Lee & Krapfl, 2002; Minner et al., 2010). In addition, inquiry-based learning assists in gaining an understanding of the nature of science (Gaigher et al., 2014a). Furthermore, inquiry-based teaching enhances the interest, motivation and engagement of learners in science (e.g., Mistier-Jackson & Songer, 2000; O'Neill & Polman, 2004; Osborne, 2010).

Against the above background, this study focuses on teacher professional development in relation to inquiry-based practical work. Here, the following definition is considered:

Inquiry-based practical work involves learners in collaboratively manipulating a combination of hands-on and computer-based science education equipment and materials, or existing data sets in order to gain an understanding of the *natural world as they experience inquiry-based learning practices through structured, directed or open inquiry.*

From the perspective of such practical work, this study makes a contribution to the reduction of the above undesirable effects linked to science education. The contribution is in relation to teacher professional development associated with inquiry-based practical work.

6.2.2 Practice- and research-based problem involved

Practical work is inadequately designed and implemented in many school science classrooms around the world (Childs et al., 2012; Hodson, 1991; Singh & Singh, 2012). In South Africa, this inadequacy is more serious in resource-constrained schools (Singh & Singh, 2012) where Physical Science teachers are strongly orientated towards expository science instruction followed by confirmatory practical work (Ramnarain & Schuster, 2014). This was the practice-based problem in this study.

While inquiry-based teaching and learning is the widely-accepted direction in science education reform internationally, the implementation of this strategy in science classrooms is a challenge (Alhendal et al., 2015; Higgins, 2009; Ruhrig & Höttecke, 2015). However, teacher professional development is an effective mechanism for realising standards-based reforms in school classrooms (McHenry & Borger, 2013). In order to achieve reform-based (practical) teaching and learning, a professional development strategy that is more collegial and collaborative, and that values local teacher knowledge, although still using appropriate external expertise, is needed (Yager, 2005). As a generally low-cost professional development strategy (Gaible & Burns, 2005), this study considered the case of lesson study. Based on this strategy, teachers come together to discuss (inquiry-based practical) lessons that they have jointly planned (designed) and observed (implemented) in actual classrooms (Lewis, Perry, & Murata, 2006; Perry & Lewis, 2009). Lesson study is thus a useful strategy to support South African Physical Science teachers in resource-constrained schools, in the design and implementation of inquiry-based practical work.

It is worth noting that although common in Japan, China, and increasingly in the United States, Canada, Australia and Europe (Gaible & Burns, 2005), lesson study is an emerging innovation (Perry & Lewis, 2009). Thus, guidance is needed in relation to the implementation of lesson study to support South African Physical Science teachers in resource-constrained schools, in the design and implementation of inquiry-based practical work. For this purpose, a professional development framework (PDF) was used. In this study,

> *A PDF is an abstract artefact serving as a blueprint of the associated professional development process and consisting of concepts, assumptions, principles, values and practices linked to the processes, means and ways through which the desired professional development outcomes can be achieved.*

From the literature (e.g., Stolk et al., 2009b), data useful in designing a PDF in terms of its components can be identified. These components consist of goals, learning perspective, teacher motivation, instructional functions, strategy, and professional development phases. However, a PDF for supporting teachers in the design and implementation of inquiry-based practical work and the associated design principles and processes for developing a PDF were unavailable at the time of this study. This is evidenced by a systematic literature review (Chapter 3), which searched ten databases and included 23 peer reviewed articles from eleven journals in the Web of Science database (2016). With reference to South African Physical Science classrooms in resource-constrained schools, this gap in the literature is considered to be the research-based problem in this study.

Against the above background, the study involves a research- and practice-based problem. These problems are contained in Table 6.1, which is similar to Table 1.1 in Chapter 1.

Table 6.1 Recal of practice- and research-based problems addressed in this study (Source: Researcher)

Problem type	Statement
Practice-based	Confirmatory rather than inquiry-based practical work is prevalent in many South African Physical Science classrooms, especially in resource-constrained schools.
Research-based	The scarcity of data regarding a development process, the design principles and a PDF* to support the design and implementation of inquiry-based practical work in South African Physical Science classrooms in resource-constrained schools.

* PDF = Professional Development Framework

6.2.3 Research questions and purposes

Linked to the research-based problem in Table 6.1 is the following primary research question addressed in this study:

How can one develop a Professional Development Framework to support teachers in resource-constrained South African Physical Science classrooms in the design and implementation of inquiry-based practical work?

A breakdown of the above primary research question is contained in Table 6.2. The table also indicates where in this study each secondary research question has been addressed.

Table 6.2 Secondary research questions and where each has been addressed in this study

Secondary research question (as in section 1.3.2)	Where question is addressed
SRQ1a: What are the characteristics of a conceptual content-generic Professional Development Framework to support science teachers?	Chapter 3 (Research Cycle 1)
SRQ1b: What are the characteristics of a conceptual content-specific Professional Development Framework to support inquiry-based practical work in secondary school science classrooms?	Chapter 4 (Research Cycle 2)

SRQ2: How inquiry-based is the way in which practical work is being designed and implemented in resource-constrained South African Physical Science classrooms?	Chapter 5 (Research Cycle 3)
SRQ3a: What specific extrinsic challenges are being faced by teachers in these classrooms in relation to the design and implementation of inquiry-based practical work?	Chapter 5 (Research Cycle 3)
SRQ3b: What specific intrinsic challenges are being faced by the teachers in relation to the design and implementation of inquiry-based practical work?	Chapter 5 (Research Cycle 3)
SRQ4: What are the characteristics of a context-specific Professional Development Framework to support these teachers in the design and implementation of inquiry-based practical work?	Chapter 5 (Research Cycle 3)

As seen in Table 6.2, the six secondary research questions involved in this study have been addressed in the three research cycles contained in the study. As an example, the answer to SRQ1a is the seven tentative design principles listed in Section 3.3.2.1 in Chapter 3. Similarly, the ten final design principles in Section 5.3.4 with three of the principles revised after formative evaluation in Section 5.4.4, respond to SRQ4.

The above secondary and primary research questions are reflected in the secondary and primary research purposes of this process-orientated study. The primary research purpose achieved is:

To generate design principles and use them over a number of research cycles to develop a professional development framework. This framework is to support teachers in resource-constrained South African Physical Science classrooms in the design and implementation of inquiry-based practical work.

The above primary research purpose has been broken down into the following secondary research purposes (SRPs):

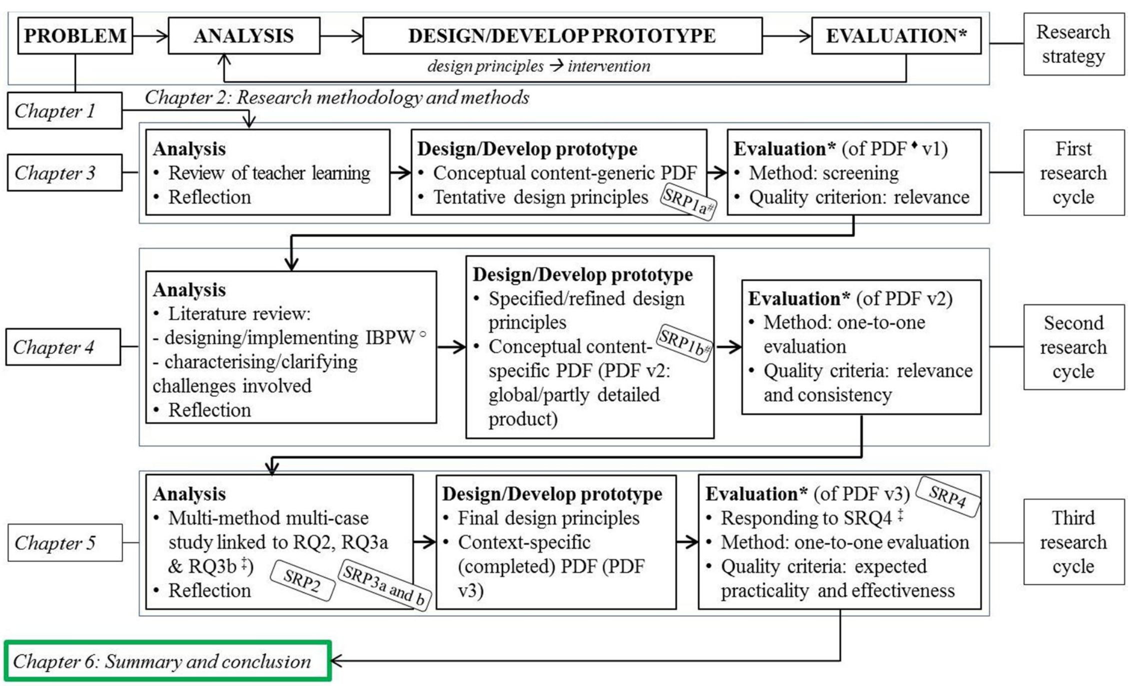
- To generate tentative design principles in relation to effective teacher professional development. This would form the basis for a conceptual content-generic PDF to support science teachers, which was then designed (SRP1a).
- To generate refined/specified design principles in relation to the design and implementation of inquiry-based practical work and the related challenges, and then design the associated conceptual content-specific PDF to support science teachers (SRP1b)
- To determine how inquiry-based, or not, is the way in which practical work is being designed and implemented in resource-constrained South African Physical Science classrooms (SRP2).
- To determine the extrinsic challenges being faced by teachers in these classrooms in relation to the design and implementation of inquiry-based practical work (SRP3a).
- To determine the intrinsic challenges being faced by teachers in these classrooms in relation to the design and implementation of inquiry-based practical work (SRP3b).
- To generate the final design principles considering SRP2, SRP3a and SRP3b, and then design a context-specific version of the Professional Development Framework (SRP4)

The chapters or research cycles in which each of the above secondary research purposes were achieved are the same as those of the corresponding secondary research questions (Table 6.2).

6.2.4 Research strategy

Design research, an emerging strategy in educational research, has been useful as the overarching research strategy in this study. This is because the study involved a practice-based problem (Table 6.1). Also, considering its purpose, the study needed an overarching research strategy with a design and develop function. In this regard, design research and action research may be used. However, action research places emphasis on outcomes and not the research process (Järvinen, 2007) in addition to not involving the generation of design principles (Denscombe, 2007). Thus, action research departs from design research, making the latter more useful in this study.

The specific form of design research used in this study was a development study. The purpose of development studies is to design and develop an intervention towards solving a complex educational problem while advancing knowledge about the characteristics of the intervention and the processes of designing and developing these (Plomp, 2013). The implementation of this research strategy in this study is illustrated in Figure 6.1. The basis of the research process represented in the figure is described in Chapter 2 (Section 2.4.3). At the top of the figure (first row) is the primary design research implementation model (Plomp, 2013) used. The rest of the figure shows how this model was implemented with the help of other more specific design research implementation models (Nieveen & Folmer, 2013; Nieveen et al., 2006) spanning the three research cycles contained in this study.



Legend:
* Consisting of data collection and analysis, in addition to results and reflection
♦PDF = Professional Development Framework; ◦ IBPW = Inquiry-Based Practical Work; # SRPi = Secondary Research Purpose i (section 1.3.3)

‡SRQ1a = What are the characteristics of a conceptual content-generic PDF to support science teachers?
‡SRQ1b = What are the characteristics of a conceptual content-specific PDF to support IBPW in secondary school science classrooms?
‡SRQ2 = How inquiry-based is the way in which practical work is being designed and implemented in resource-constrained South African Physical Science classrooms?
‡SRQ3a = What specific extrinsic challenges are being faced by teachers in these classrooms in relation to the design and implementation of IBPW?
‡SRQ3b = What specific intrinsic challenges are being faced by the teachers in relation to the design and implementation of IBPW?
‡SRQ4 = What are the characteristics of a context-specific PDF to support these teachers in the design and implementation of IBPW?

Figure 6.1 Research process used in this study (Source: Researcher)

Figure 6.1 is derived from Figure 1.2. Based on the research process in Figure 6.1, the design principles and the associated PDF have been generated and developed over three research cycles (Chapters 3 to 5 respectively). For this purpose, the evolutionary prototyping process was used in line with the iterative nature of design research. As seen in the figure, each cycle in the research process consisted of an analysis, a design/develop, and an evaluation phase. The analysis phase of the first two research cycles involved a systematic review of international literature. The literature reviews focused on effective (science) teacher professional development (Chapter 3) and the design and implementation of inquiry-based practical work (Chapter 4) respectively. The second systematic literature review focused on the extrinsic and intrinsic challenges faced by the teachers. The literature reviews gave this design research its theory-orientated nature.

As a design research study, this study also had a grounded nature. Design research recognises the complexities of classroom instruction and informs both researchers and practitioners through the development of theoretical ideas grounded in practice (Mishra & Koehler, 2006). In this light, and unlike in the two preceding research cycles, the analysis phase of the last research cycle (Chapter 5) involved a multi-method, multi-case study. The data collection methods used in the case study consisted of interviews, classroom observation, artefacts and field notes. The case study allowed for the conduct of a needs and context analysis in Physical Science classrooms in two South African resource-constrained schools (School O and School P). In relation to the case study and in the formative evaluations (contained in Chapter 3 and 4), the researcher abided by the principles of good ethical conduct in research (Section 2.8).

On the above basis, design principles were generated and/or revised in the second phase of each research cycle. The design principles evolved from the tentative version (Chapter 3), through the specified/refined version (Chapter 4) to the final version (Chapter 5). The evolution of the design principles is illustrated in Table 6.3 in the case of the first design principle.

Table 6.3 Example illustrating evolution of design principles (Source: Researcher)

Research phase	Design principle
Design/ develop prototype phase 1	*Design Principle #1.1:* Aim the PDF at enhancing the related knowledge, attitudes, beliefs and practices of teachers as this is a goal in effective teacher learning.
Design/ develop prototype phase 2	*Design Principle #1.2:* Aim the PDF at enhancing the related knowledge[a], skills[b], attitudes, beliefs[c], values[d] and practices[e] of teachers as effective teacher learning in general, and in relation to practical work in particular, focuses on these areas of competence, which are linked to various specific intrinsic teaching challenges. [a] Consisting of CK, PK, TK and PCK [b]Consisting of pedagogical skills, creativity and practical skills [c] Including about the science curriculum and the understandings of science learners [d] Which include care and concern for learners, commitment and dedication to their practice, collaboration and team spirit, in addition to the desire for continuous learning, innovation and excellence [e] In relation to the IB learning practices in Table 4.2.
Evaluation phase 2	*Design Principle #1.2b:* Aim the PDF at enhancing the related competences* in addition to the professional identity and practice of teachers as these are important in effective teacher learning in relation to the intrinsic challenges linked to IBPW. * Consisting of knowledge[a], skills[b], attitudes, beliefs[c], values[d] and practices,[e] [a]such as CK, PK, TK and PCK, [b] consisting of pedagogical skills, creativity and practical skills, [c]including about the science curriculum and the understandings of science learners, [d]which include care and concern for learners, commitment and dedication to their practice, collaboration and team spirit, in addition to the desire for continuous learning, innovation and excellence [e]in relation to the IB learning practices in Table 4.2.

Research phase	Design principle
Design/ develop phase 3	*Design Principle #1.3:* Aim the PDF at enhancing the related competences* in addition to the professional identity and practice of teachers as these are important in effective teacher learning in general and in relation to the intrinsic challenges♦ linked to IBPW in particular. * Consisting of knowledge[a], skills[b], values[c] and practices,[d] [a] such as CK, PK, TK, TPK and PCK, [b] consisting of practical skills and skills linked to laboratory safety, [c] including care and concern for learners, commitment and dedication to their practice in addition to the desire for continuous learning, innovation and excellence [d] in relation to inquiry-based learning (e.g., asking questions, constructing explanations and engaging in evidence-based arguments). ♦Including issues linked to learner safety; misconception about notion of prior knowledge; misconception relating to role of practical work, difficulties linked to improvised SEEMs, and unfamiliarity with instructional models.

Table 6.3 illustrates the evolution of design principles in response to the data collected through the two systematic literature reviews (Chapter 3 and 4), the multi-method, multi-case study (Chapter 5) and also due to formative evaluation involving experts (Chapter 4 and 5). As illustrated by the example contained in Table 6.3, the design principles evolved from a set of tentative principles to the final set of design principles.

By implementing each set of design principles, the PDF evolved from a content-generic version (Chapter 3) to a content-specific version (Chapter 4), to a context-specific version (Chapter 5). The evolution of both the design principles and the PDF was informed by the formative evaluation of each version of the PDF. In addition to self-evaluation (Chapter 3), the evaluation involved input from experts (in Chapter 3 and 4). The involvement of experts gave this study its collaborative dimension as a design research study. In the formative evaluation, the method and the quality criteria evolved in line with the adaptive nature of design research. Specifically, self-evaluation (screening) based on relevance (content validity) as a quality criterion was used in the first research cycle (Chapter 3) while one-to-one evaluation (walkthrough) was used in the last two cycles (Chapters 4 and 5 respectively). However, in these last two cycles, the quality criteria in the formative evaluation were respectively relevance and consistency (construct validity); and expected practicality and effectiveness. The implementation of the last quality criteria enabled the final outcome of this study to be utility-orientated.

6.3 PRIMARY OUTCOMES OF THE STUDY

In line with development studies approach in design research, this study has a three-fold outcome. The outcomes consist of a development process, design principles, and an intervention, which in this case was a PDF. Prominent amongst these outcomes are the final design principles, in addition to the associated completed version of the PDF to support South African Physical Science teachers in resource-constrained schools in the design and implementation of inquiry-based practical work. However, the previous versions of this PDF and the corresponding design principles are also useful intermediate outcomes. These outcomes are presented below.

6.3.1 Content-generic PDF and associated design principles

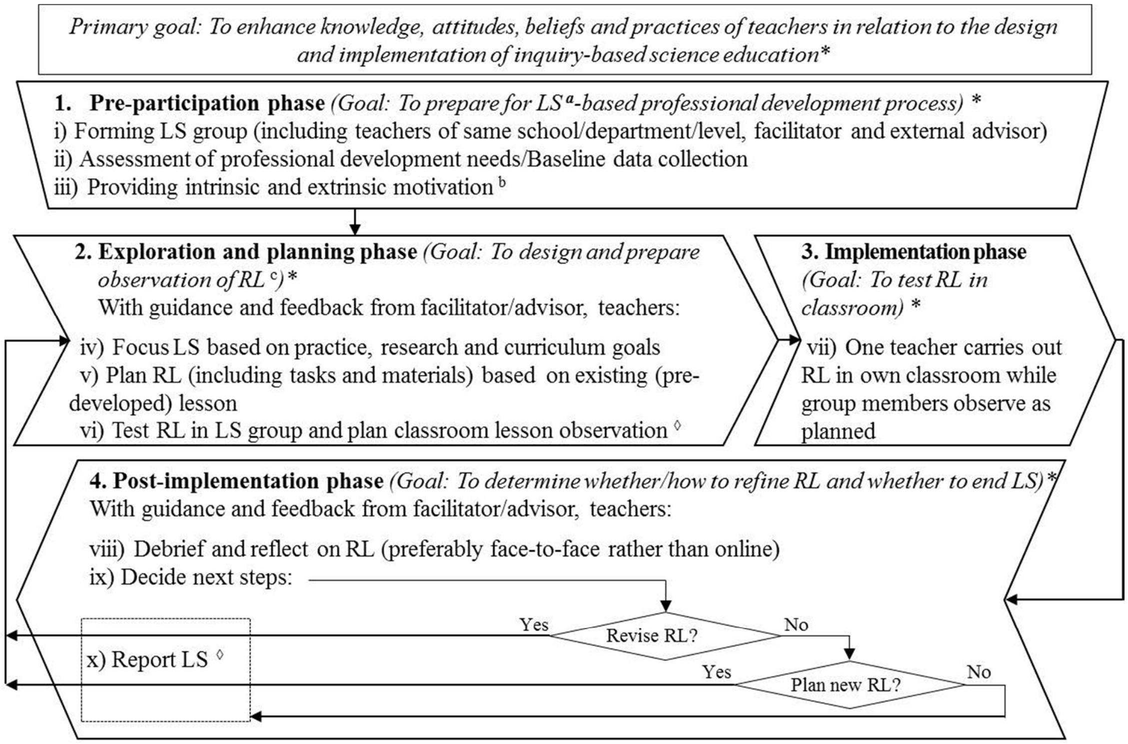
These outcomes are the result of the first step of the process considered here for developing a PDF. The process was outlined in Figure 1.1 with details provided in Figure 6.1. The first step of this process is contained in the first research cycle (Chapter 3). It involved a thesis literature review and a systematic literature review (Section 2.4.4.2) of the international literature on teacher professional development. The thesis literature review yielded the core features of effective teacher professional development programmes (Table 3.1) and the principles of designing such programmes (Table 3.2). The systematic literature review covered the literature on the professional development of mostly science teachers that has accumulated internationally for almost a decade (2007-2015). Only data gathered using more than one data collection method were included. Based on the systematic literature review, a PDF for supporting science teachers in any educational setting in the design and implementation of inquiry-based science education may consist of the following six components:

- Professional development goal;
- Learning phases;
- Learning theory;
- Professional development strategy;
- Instructional functions; and
- Teacher motivation.

In addition to identifying the above components of a conceptual content-generic PDF, the systematic literature review allowed the components to be tentatively specified. On this basis, seven tentative design principles could be generated. The design principles are applicable to the development of a PDF for teacher enhancement in the design and implementation of inquiry-based science education in any educational context. These principles, listed in Section 3.3.2.1, enabled the content-generic version of the PDF to be synthesised. The fifth design principle which gives the PDF a lesson study-based nature, is as follows:

> *Principle #5.1:* Incorporate lesson study phases into the PDF under related major phases of professional development (pre-participation, exploration and planning, implementation and post-implementation) in order to provide a sequence for planning activities within the major professional development phases.
>
> (McKenney et al., 2006; Reigeluth, 1999).

The content-generic version of the PDF is shown in Figure 6.2, which is the same as Figure 3.8.



Legend:

[a] LS = Lesson Study
[b] such as potential improvement in performance and provision of additional educational resources
[c] RL = Research Lesson

* Provide learning goals on a continuous basis
◊ Review learning periodically

Figure 6.2 Content-generic version of PDF from first research cycle (Source: Researcher)

The version of the PDF in Figure 6.2 is content-generic in the sense that it is open for use in supporting teachers in designing and implementing any science lesson. Thus, this version of the PDF does not focus on inquiry-based practical work, unlike the next version. However, before considering this next version, it may be worth noting that based on screening against the features of effective teacher Professional Development Programmes and core features of such programmes, the above version of the PDF has been found to be relevant (content valid).

In addition to the associated design principles (Section 3.3.2.1), the content-generic version of the PDF (Figure 6.2) fulfils the first secondary research purpose (SRP1a) restated above in Section 6.1. The second secondary research purpose (SRP1b) was fulfilled by the version of the design principles and PDF considered next.

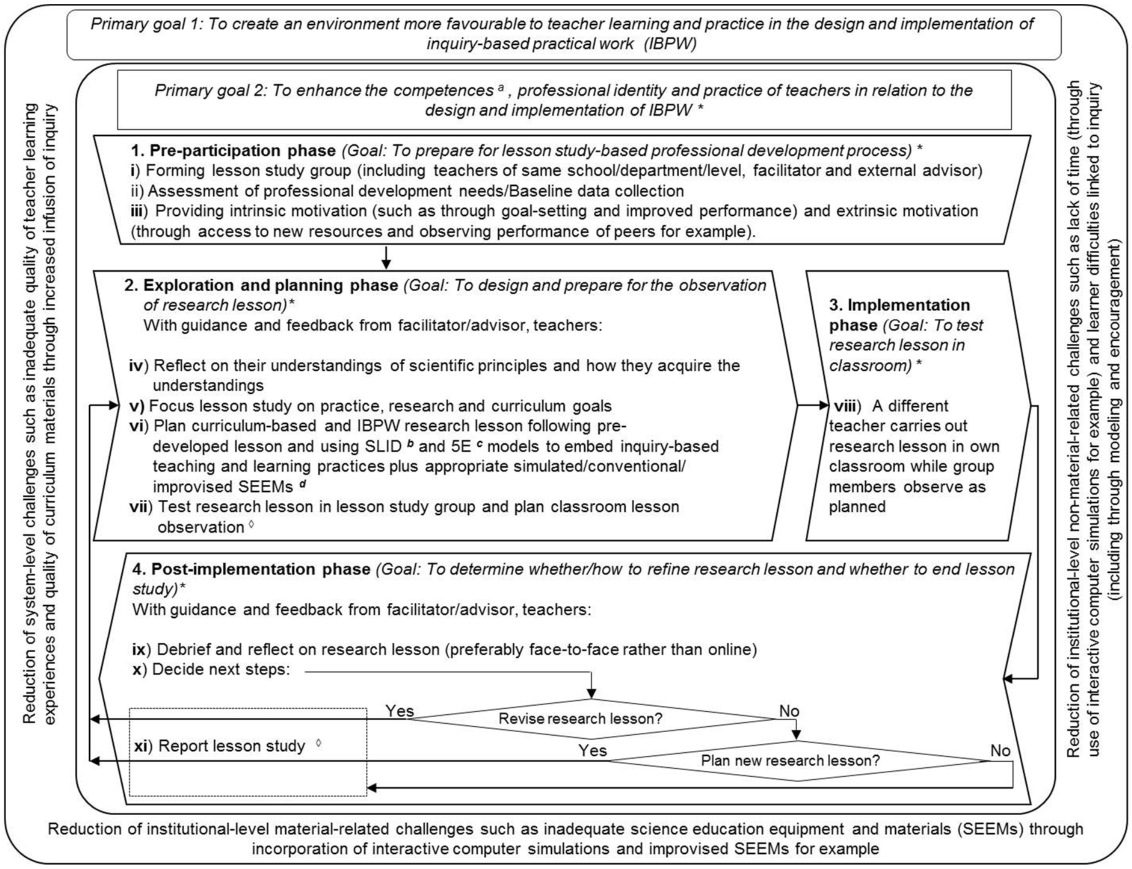
6.3.2 Content-specific PDF and associated design principles

These enhanced intermediate outcomes are the result of the second major step of the process considered for developing a PDF (Figure 1.1). Involved in this step is a systematic review of the international literature on practical work in school science conducted in the second research cycle (Chapter 4). The purpose of the literature review was to characterise and clarify the teaching challenges linked to the design and implementation of inquiry-based practical work in addition to considering ways through which the challenges could be reduced. The literature review included research articles from various Thomson Reuters Web of Science Core Collection (2016) database of journals involving multiple data collection methods. The articles also came from studies conducted on five continents in the last decade or so.

The above literature review allowed two components of a PDF not found in the literature to be uncovered. The components comprised the following:

- Instructional design perspective; and
- Attending to contextual factors.

The identification of the above two components raised the number of components of a PDF to eight (considering the six listed above in Section 6.3.1). The systematic literature review also allowed for three new design principles to be generated in relation to the above two new components of a PDF. Additionally, the literature review enabled the seven existing design principles to be revised accordingly. The result was a set of ten specified/refined design principles for synthesising a PDF to support teachers in the design and implementation of inquiry-based practical work in any educational setting. These principles are listed in Section 4.3.4.1 with three of these revised based on formative evaluation data, as seen in Section 4.4.4.1. It is on the basis of these design principles that the content-specific version of the PDF was created (Figure 6.3). This figure is the same as Figure 4.11.



Legend:
[a] *competences = knowledge [e], skills [f], attitudes, beliefs [g], values [h] and practices [i]*
[e] consisting of content knowledge, pedagogical knowledge, technological knowledge and pedagogical content knowledge
[f] consisting of pedagogical skills, creativity and practical skills
[g] including about the science curriculum and the understandings of science learners
[h] including care and concern for learners, commitment and dedication to practice, collaboration and team spirit, in addition to desire for continuous learning, innovation and excellence
[i] linked to inquiry-based learning (e.g., asking questions, planning and conducting investigations, analysing and interpreting data, constructing explanations and engaging in evidence-based arguments)

[b] SLID = Science Laboratory Instructional Design model (Phases: Initiation, Planning, Implementation (based on 5E [c] instructional model in this case), Evaluation and Feedback)
[c] 5E instructional model (Phases: Engagement, Exploration, Explanation, Extension and Evaluation)
[d] SEEMs = Science Education Equipment and Materials

* Providing learning goals on a continuous basis (Primary goal 2 lies in enhancing teacher competences and professional identity in order to reduce intrinsic challenges regarding the design and implementation of IBPW. For example, teachers not giving learners opportunity to link new learning to prior learning (intrinsic challenge) is reduced by enhancing pedagogical content knowledge linked to the understanding learners through the use of the SLID and 5E instructional models (way of reducing intrinsic challenge)

◊ Reviewing learning periodically

Figure 6.3 Content-specific version of PDF from second research cycle (Source: Researcher)

This version of the PDF is content-specific as it focuses on inquiry-based practical work. Unlike its predecessor, this version of the PDF has two primary goals: creating a supportive environment and enhancing teachers in the design and implementation of inquiry-based practical work. As shown in Figure 6.3, the relevance (content validity), and consistency (construct validity) of the PDF has been improved based on formative evaluation. However, the PDF is not aimed specifically to support the design and implementation of inquiry-based practical work in South African Physical Science classrooms in resource-constrained schools.

6.3.3 Context-specific PDF and associated design principles

These are the context-bound and primary outcomes of this study. The outcomes are the products of the third major step in the process used here for developing a PDF (Figure 1.1). This step of the process is contained in the third and last research cycle (Chapter 5) of this study. In this last major step of the process, the completed context-specific PDF to support South African Physical Science teachers in resource-constrained schools could be synthesised thanks to the multi-method, multi-case study. The case study involved two schools, six Physical Science teachers, one demonstrator, which allowed for a needs and context analysis. In this regard, data was collected using individual interviews, lesson observation, document analysis and field notes. The data was analysed by combining the data-driven inductive and *a priori* template of codes approaches.

On the above basis, and also based on the formative evaluation of the data, certain existing design principles could be revised while others were simply verified.

6.3.3.1 Final design principles

There were ten design principles, which provided the key characteristics of a PDF to support South African Physical Science teachers in resource-constrained schools in the design and implementation of inquiry-based practical work. The design principles are as follows:

1. Aim the PDF at enhancing the related competences* in addition to the professional identity and practice of teachers as these are important in effective teacher learning in general, and in relation to the intrinsic challenges♦ linked to IBPW in particular.

(Clarke & Hollingsworth, 2002; Elster, 2009; Fishman, Marx, Best & Tal, 2003; Hoban, 2007; Loucks-Horsley, Love, Hewson, Stiles & Mundry, 2003; Magnusson et al., 1999; Mishra &Koehler, 2006; Rozenszajn & Yarden, 2014; Sweeney & Paradis, 2004).

* Consisting of knowledge[a], skills[b], values[c] and practices[d]

[a] such as CK, PK, TK, TPK and PCK,

[b] consisting of practical skills and skills linked to laboratory safety,

[c] including care and concern for learners, commitment and dedication to their practice in addition to the desire for continuous learning, innovation and excellence

[d] in relation to inquiry-based learning (e.g. asking questions, constructing explanations and engaging in evidence-based arguments).

♦Including issues linked to learner safety; misconceptions about the notion of prior knowledge; misconceptions relating to the role of practical work; difficulties linked to improvised SEEMs; and unfamiliarity with instructional models.

2. Use the Social Cognitive Theory as the learning perspective in the PDF in order to allow for collective participation in a professional learning community in which the competences and practice of each teacher are enhanced through observation, enactment and reflection.

(Bandura, 2001; El-Deghaidy, Mansour & Alshamrani, 2015; Marx & Harris, 2006; National Science Teachers Association, 2006; Ostermeier et al., 2010; Schunk, 2012; (Teacher Professional Growth Consortium, 1994).

3. Incorporate a pre-participation phase, an exploration/planning phase, an implementation phase and a post-implementation phase into the PDF with reference to studies on effective teacher learning.

(Chikasanda et al., 2013; Mansour, EL-Deghaidy, Alshamrani & Aldahmash, 2014; Rozenszajn & Yarden, 2014; Yerushalmi & Eylon, 2013).

4. Adopt lesson study as the professional development strategy in the PDF given, for example, that lesson study is usable across different socio-economic contexts, involves active learning in a professional learning community, and is aligned with the core features of effective teacher learning.

(Desimone, Porter, Garet, Yoon & Birman, 2002; Gaible & Burns, 2005; Lewis et al., 2006; Perry & Lewis, 2009).

5. Incorporate lesson study phases into the PDF under related major phases of professional development (pre-participation, exploration/planning, implementation and post-implementation) in order to provide a sequence for planning activities within these major professional development phases.

(McKenney et al., 2006; Reigeluth, 1999).

6. Include instructional functions (e.g. reviewing relevant prior learning, providing overviews and learning goals, providing guidance and feedback, and reviewing learning periodically) in the PDF in order for professional development to be more effective and also to serve as a transition between its phases.

(Mettes, Pilot & Roossink, 1981; Rosenshine &Stevens, 1986; Stolk et al., 2012; Terlouw, 2001).

7. Incorporate intrinsic and extrinsic teacher motivation into the PDF given that teachers need to be motivated in order to change their practice. Although goal-setting and improved performance is effective as an intrinsic incentive, motivation is difficult to sustain without extrinsic incentives (that include access to additional resources, observing the success of peers and financial rewards).

(Boyd, Banilower, Pasley & Weiss, 2003; Gaible & Burns, 2005; Pintrick & Schunk, 1996; Stolk et al., 2009b; Schunk, 1995, 2012).

8. Combine the SLID[a] model and the 5E[b] instructional model in order for the PDF to reflect practical work that is consistent, systematic, adequately sequenced and organised, more relevant and effective, and more consistent with inquiry-based teaching and learning.

(Balta, 2015; Bybee, 1997; Dick et al., 2001; Dogru-Atay & Tekkaya, 2008; Kallio, 2008; National Research Council, 2000; Peterson, 2003; Reiser & Dempsey, 2007).

[a] SLID = Science Laboratory Instructional Design.

[b] 5E = Engagement, Exploration, Explanation, Extension and Evaluation.

9. Incorporate the reduction of identified system-level challenges[a], in addition to institutional-level challenges that are material-related [b] and non-material-related [c] into the PDF in order to create circumstances that are more favourable towards teacher learning and practice in school.

(Abrahams & Reis, 2012; Chin, 2004; Goldman, 2005; Higgins, 2009; Kapanadze & Eilks, 2014; Lederman & Lederman, 2012; Lin et al., 2013; Poppe et al., 2011; Toplis & Allen, 2012; Wheater, Langan & Dunleavy, 2005).

[a]Consisting of time allocation, extrinsic motivation, a restrictive curriculum, mandatory work plan and lack of district support towards the use of simulations.

[b] Consisting of inadequacy in science education equipment and materials, their procurement, and facilities.

[c]Consisting of inadequate access to simulations, time constraints, and learner use of tablets for non-practical work-related activities.

10. Combine a) Efforts aimed at reducing extrinsic challenges, and b) Efforts towards reducing intrinsic challenges in order to align the PDF with the Ecological Theory of Development and the multi-faceted approach needed in curriculum implementation and improvement, starting with point a).

(Bronfenbrenner, 1979; Fullan, 1992).

The above outcomes illustrate the pragmatic nature this study as a design research study in the sense that design research is concerned with developing usable solutions to practice-based problems while generating usable knowledge. This knowledge includes the above ten design principles. The solution to the practice-based problem is the completed context-specific version of the PDF.

6.3.3.2 Completed context-specific version of PDF

This version of the PDF is based on the above ten final design principles. The design principles and relevant details contained in the PDF were derived from the literature reviews (Chapter 3 and 4); the multi-method, multi-case study (Chapter 5); as well as the comments and suggestions of four expert reviewers (Chapter 4 and 5). The reviewers all had considerable experience in teacher professional development research and practice, and in inquiry-based science education research and practice.

The PDF proposes a professional development process driven by two primary goals that are to be achieved sequentially. The first primary goal is to create an environment that is more supportive of teacher learning and practice in the design and implementation of inquiry-based practical work (IBPW) in South African Physical Science classrooms in resource-constrained schools. This is to be done through the reduction of identified system-level, as well as institutional-level extrinsic challenges. The efforts in this regard form the shell of the Professional Development Framework and are shown in light blue in Figure 6.4. The actual enhancement of teachers may be initiated only after the above primary goal has been achieved. This is indicated by the bottom middle blue arrow in Figure 6.4. Thus, the achievement of the first primary goal (primary goal 1) allows the second primary goal (primary goal 2) to take over the professional development process.

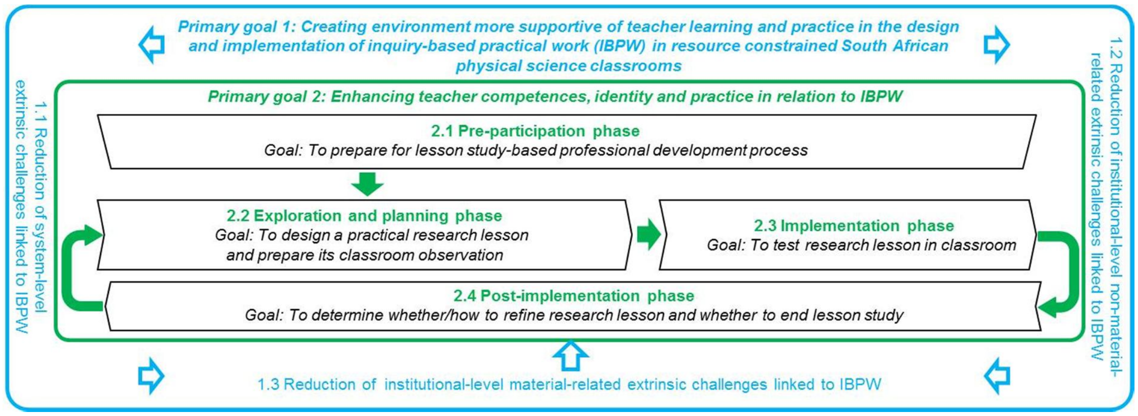


Figure 6.4 Abridged version of completed PDF (Source: Researcher)

The second primary goal (primary goal 2) of the PDF is to enhance the competences, identity, and practice of teachers in relation to the design and implementation of IBPW. This is through a cyclical, school-based professional development process with lesson study as the professional development strategy. In addition to goals, the abridged version of the PDF contains two other primary components, one of which is attending to contextual factors (the shell and professional development phases numbered 2.1 to 2.4).

The version of the PDF in Figure 6.4 is useful in outlining what the PDF concerns. However, this version provides limited guidance in supporting teachers in the design and implementation of inquiry-based practical work. More useful in this regard is the full version of the PDF. This version consists of eight primary components: attending to contextual factors, professional development goals, professional development phases, professional development strategy, teacher motivation, instructional design perspective, instructional functions and learning perspective. These components of the professional development framework are described in Table 6.4 and simultaneously linked to the full version of the PDF (Figure 6.5).

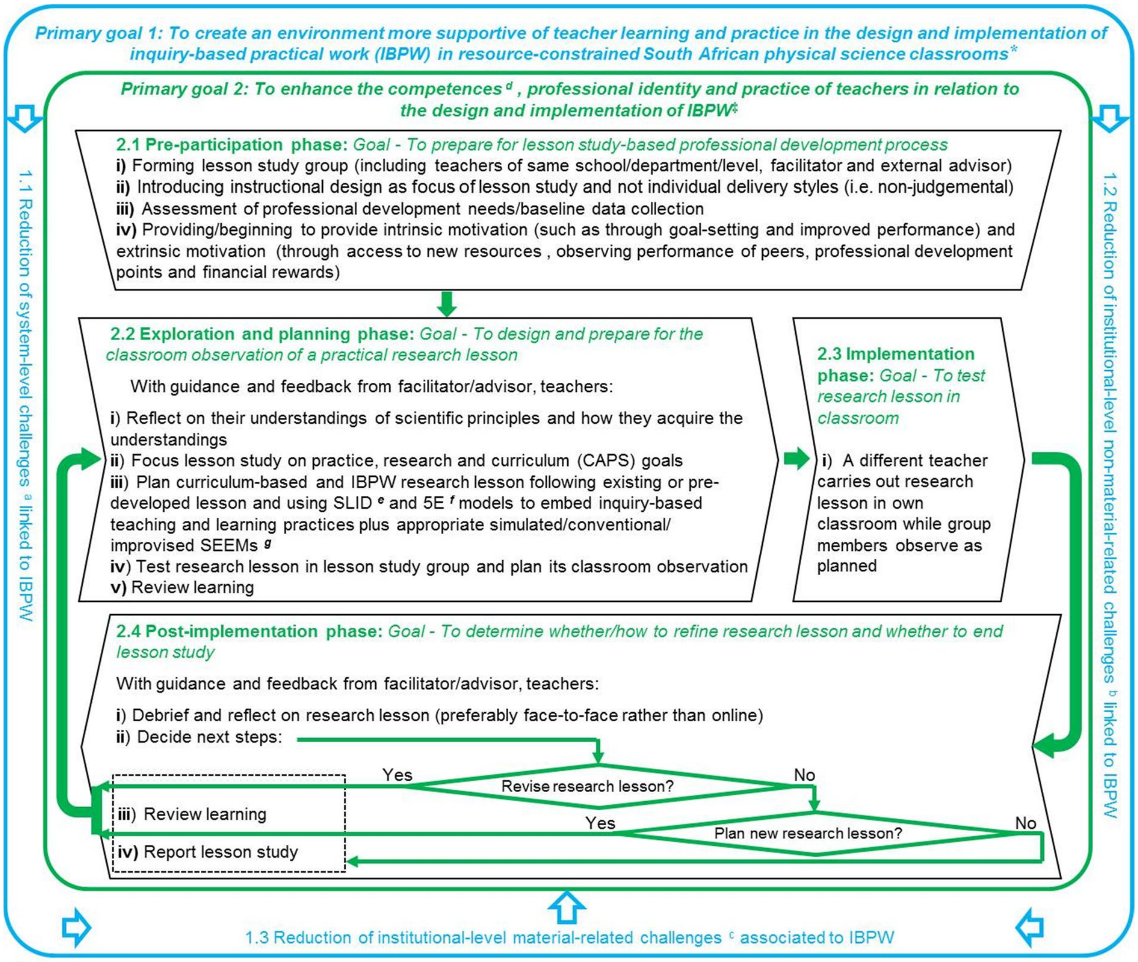
Table 6.4 Description and expression of components of completed PDF (Source: Researcher)

Component of PDF	Description of component	How and where the component is expressed in the PDF
Attending to contextual factors	Dealing with extrinsic challenges linked to the design and implementation of IBPW*.	This involves reducing system-level and institutional-level extrinsic challenges. Details in this regard are found in the shell of the PDF and in the legend of Figure 6.5
Professional development goals	The intended outcomes of the professional development process in terms of teacher learning and practice, as well as the creation of a supportive environment.	The outcomes (goals) are *italicised* and identified as a goal in Figure 6.5: • *Primary goal 1* deals with the creation of a supportive environment. • *Primary goal 2* deals with teacher learning and practice and is broken down into *secondary goals* for the different phases of professional development.
Professional development phases	The stages in a professional development process consisting of primary and secondary phases.	• Primary phases are numbered 2.1 to 2.4 in Figure 6.5. • Secondary phases are numbered in roman numerals in Figure 6.5.
Professional development strategy	The sequence in which activities in a Professional Development Programme are planned or implemented. In this case, lesson study is the professional development strategy. On this basis, teachers collaboratively learn to improve instruction.	Consists here of a sequence of seven phases included among the secondary professional development phases. The secondary phases, due to lesson study, consist of 2.1 i) and ii); 2.2 ii) to vi); 2.3 i); 2.4 i) and ii).
Teacher motivation	Attracting teachers and sustaining their involvement in the professional development process. Motivation has an intrinsic and an extrinsic component.	Intrinsic and extrinsic teacher motivation begins in secondary phase iv) in Figure 6.5.

Component of PDF	Description of component	How and where the component is expressed in the PDF
Instructional design perspective	This is how IBPW may be designed and implemented.	In this regard, the PDF combines the SLID and 5E models described in the legend of Figure 6.5 under [e] and [h].
Instructional functions	Measures needed to bridge and complete phases of a learning programme.	These consist here of: - Reviewing learning periodically as seen in 2.2 v) and 2.4 iii) in Figure 6.5. - Providing learning goals on a continuous basis, as seen throughout the inner part of Figure 6.5.
Learning perspective	This is the theory on which learning is based. The theory is a description of how learning occurs.	The Social Cognitive Theory is used here, which holds that people acquire knowledge, skills, beliefs, attitudes, strategies and attitudes by observing other people (vicarious learning), as well as through actual performance (enactive learning). Teachers may also be enhanced by engaging in reflection. These ways of learning are involved in the exploration/planning, implementation and post-implementation phases in Figure 6.5.

* IBPW = Inquiry-Based Practical Work

The full version of the PDF described in Table 6.4, is shown below in Figure 6.5.



Legend:

* This goal is towards the reduction of extrinsic teaching challenges linked to teacher learning and practice in inquiry-based practical work

[a] consisting of time allocation, extrinsic motivation, a restrictive curriculum, mandatory work plan and lack of district support towards use of simulations

[b] consisting of inadequate access to simulations, time constraints, and learner use of tablets for non-practical work related activities

[c] consisting of inadequacy in science education equipment and materials, their procurement and also facilities

‡ This goal is towards reduction of intrinsic challenges linked to the design and implementation of inquiry-based practical work including misconception about notion of prior knowledge, misconception relating to role of practical work, difficulties linked to improvised SEEMs and unfamiliarity with instructional models

[d] consisting of knowledge [h], skills [i], values [j] and practices [k]

- [h] consisting of CK, PK, TK, TPK and PCK
- [i] consisting of practical skills and skills linked to laboratory safety
- [j] including desire for continuous learning, innovation and excellence
- [k] in relation to inquiry-based learning (e.g., asking questions, constructing explanations and engaging in evidence-based arguments)

[e] SLID = Science Laboratory Instructional Design model (Phases: Initiation, Planning, Implementation (based on 5E [g] instructional model in this case), Evaluation and Feedback)

[f] 5E instructional model (Phases: Engagement, Exploration, Explanation, Extension and Evaluation)

[g] SEEMs = Science Education Equipment and Materials

Figure 6.5 Full version of completed PDF (Source: Researcher)

6.3.4 Process used to develop the PDF

In relation to the outcomes of development studies, the intervention and its characteristics have been outlined above in the case of this study. The process through which these outcomes were reached is remaining and is provided in Figure 6.6, which is similar to Figure 1.1.

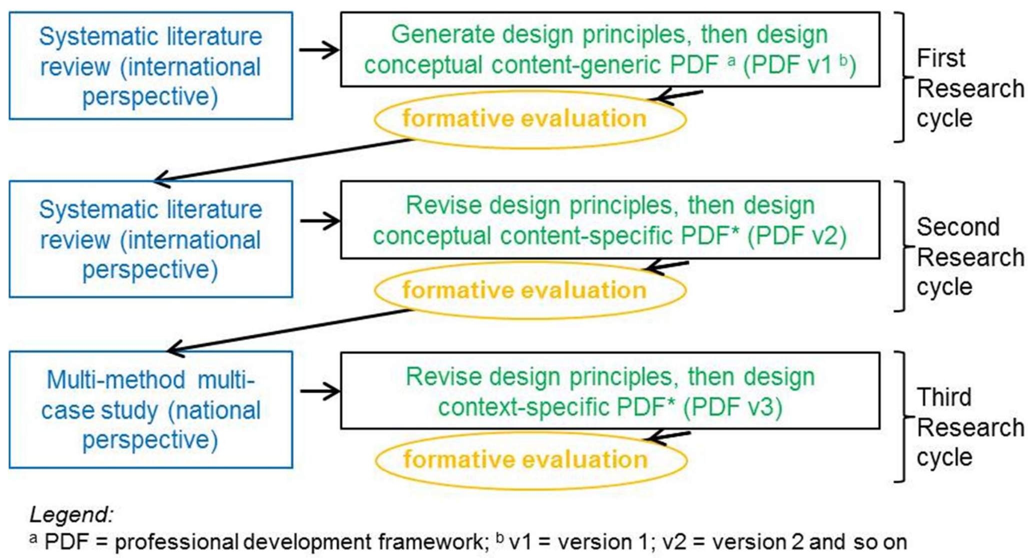


Figure 6.6 Process used to develop PDF to support IBPW (Source: Researcher)

The process contained in Figure 6.6 is reflected in the detailed research process used in developing the intervention (Figure 6.1). The intervention is the completed context-specific version of the PDF (Figure 6.5). The process for developing this intervention (Figure 6.6) reflects the conceptual framework of this study (Section 2.4.3). The conceptual framework is reflected in Figure 6.1.

The process for developing the PDF consisted of three design research cycles. Through this process, the design principles and intervention evolved towards the final version. Two systematic reviews of the international literature on effective (science) teacher learning and inquiry-based practical work (cycles one and two), as well as a multi-case study in favour of a needs and context analysis were necessary to achieve the research purposes and answer the research questions, which resulted in the creation of the PDF.

6.4 REFLECTING ON THE FINAL OUTCOMES

Although some of the outcomes of this study were context-bound (as expected), this was not the case with all the outcomes. The outcomes may thus be categorised regarding generalisability and be considered against the outcomes of other development studies. It is also necessary to consider the significance of the outcomes.

The outcomes of development studies are: design principles, the associated intervention, and the process for developing the intervention (Plomp, 2007; Plomp, 2013). Design principles assist educational designers and practitioners in the designing of interventions (Prins & Pilot, 2013). However, some studies (e.g., Mafumiko et al., 2013; Stolk et al., 2012) focus on the intervention only. This study involved design principles and an intervention (in this case a PDF), as reflected in Section 6.3.3, for example. Attention has also been given to the development process (Figure 6.6), which was elaborated on in the conceptual framework of the study (Section 2.4.3). The framework is reflected in Figure 6.1.

Against the above background, this study yielded two categories of outcomes regarding generalisability. The generalisable outcomes included the process for developing a PDF (Figure 6.6). Also included in this category are the content-generic and the content-specific versions of the PDF, and their related design principles (Section 6.3.1 and 6.3.2 respectively). These intermediate outcomes are generalisable in the sense that they result from a systematic review of the international literature on effective teacher learning and inquiry-based practical work respectively. The second category of outcomes comprises the primary outcomes, which are context-bound. These outcomes are the completed PDF, and the final design principles (Section 6.3.3).

The completed (final) PDF from this study is similar and also different from other PDFs. The PDF builds on the content-generic version resulting from a review of the international literature on PDFs. In this way, the context-specific PDF in Figure 6.5 contains components that are similar to those contained in some other PDFs (e.g., Stolk, 2013; Stolk et al., 2012). These components consist of a professional development goal, learning phases, learning theory, professional strategies, instructional functions, and teacher motivation. However, professional development goals tend to be limited to enhancing the competences and practice of teachers (e.g., Higgins & Parsons, 2011; Ostermeier et al., 2010). The context-specific PDF synthesised here goes further by involving the prior creation of an environment that supports teacher enhancement. This is reflected in primary goal 1 and in the shell of the PDF in Figure 6.5. This difference between the completed PDF synthesised here and other PDFs (e.g., Stolk, 2013; Stolk et al., 2012) is linked to the fact that this PDF contains more components than the others. Additional components in this PDF consist of an instructional design perspective (combining SLID and 5E models) and attending to contextual factors (primary goal 1). This last component contributes to aiming the PDF specifically to assist South African Physical Science teachers in resource-constrained schools.

Having said the above, the need to enhance the knowledge and skills of teachers in relation to inquiry-based teaching has been noted by researchers (Dudu & Vhurumuku, 2012; Korthagen, 2010) and teachers themselves (Kriek & Basson, 2008b). In this regard, this study proposes the design principles and a blueprint of the professional development process. This is in relation to the design and implementation of practical work in South African Physical Science classrooms in resource-constrained schools.

6.5 STUDY CONTRIBUTION

This study makes a contribution towards teacher professional development research and practice. The contribution has three dimensions: theoretical, methodological, and practical.

6.5.1 Theoretical dimension of contribution

These are made up from several contributions. Firstly, two new components of a PDF have been identified and consist of the instructional design perspective and attending to contextual factors. In relation to this second new component, a new goal in teacher professional development has been formulated. The goal applicable internationally and in South Africa is primary goal 1 in Figure 6.3, Figure 6.4 and Figure 6.5. The goal is as follows:

> *To create an environment more favourable to teacher learning and practice in the design and implementation of inquiry-based practical work.*

The theoretical contribution of this study also includes the three sets of design principles generated and the first two versions of the PDF produced. Also included is the process for developing a PDF (Figure 6.6). As part of this process and based on the systematic literature review in Chapter 3, seven tentative design principles were generated and the associated content-generic version of the PDF synthesised (Figure 6.2). The systematic literature review in Chapter 4 allowed the design principles to be specified/refined with three more added as a basis for the content-specific version of the PDF (Figure 6.3). The multi-method, multi-case context and needs analysis in Chapter 5 enabled ten final design principles to be generated. Also, the study provided a process for developing design principles and an intervention towards supporting the design and implementation of inquiry-based practical work in resource constrained Physical Science classrooms (Figure 6.6).

In the above way, this study contributes to filling a gap in the teacher development research literature. This is important as inadequate attention has been given to the process of teacher professional development (Stolk et al., 2009b). As a result of this inadequacy, some professional development programmes have been unsatisfactory in their outcomes (Stolk et al., 2011). In relation to improving the outcomes of these programmes, the above theoretical contributions of this study may be useful.

6.5.2 Practical dimension of contribution

The practical contribution of the study lies in the completed context-specific version of the PDF (Figure 6.4 and Figure 6.5). This contribution responds to the educational (practice-based) problem in Section 1.3.1 and in Table 6.1. This refers to the completed PDF to support teachers in the design and implementation of inquiry-based practical work in the context of South African Physical Science classrooms in resource-constrained schools. This contribution is a reflection of the research strategy implemented in this study as design research narrows the divide between theory and application, as well as between practice and research (Mishra & Koehler, 2006).

6.5.3 Methodological dimension of contribution

Along this dimension, this study makes two contributions. Firstly, the study used development studies as the overarching research strategy. Such studies are a specific approach in design research, which as a whole, is an emerging strategy in educational research. Thus, the use of developmental studies in this study is a methodological contribution to design research. This contribution responds to calls for the use of design research in a variety of contexts (Plomp, 2007), given its emerging status (Plomp, 2013). The context in this case was that of practical work in Physical Science classrooms in South African resource-constrained schools. In this context, the study makes its second methodological contribution, which lies in the implementation of lesson study as the professional development strategy in the Professional Development Framework. Lesson study is an emerging innovation (Perry & Lewis, 2009) commonly used in only Japan, China, and increasingly in the United States, Canada, Australia and Europe (Gaible & Burns, 2005).

Despite making a contribution along the above three dimensions, this study is not without its limitations.

6.6 LIMITATIONS OF THE STUDY

This study has limitations despite the attention that has been given to the challenges inherent in design research. The challenges to design research discussed in Section 2.4.2.3 include the tension linked to the researcher being a designer and often also an evaluator and implementer. Also included is the adaptability of the research design, in addition to the fact that real-world contexts bring about real-world complications. In this regard, various ways of addressing these challenges have been used. These include opening research to the scrutiny of people outside the research effort (in this case the experts involved in the formative evaluation). Furthermore, the fact that the researcher was a ‘cultural stranger’ (Thijs, 1999) in the research setting in this study allowed for a degree of objectivity and honesty. However, the six weeks spent by the researcher in the research setting allowed for the development of trust from participants and an understanding of the research context. Moreover, each research cycle in this study used the same research design implementation model, as seen in Figure 6.1. Specifically, the same phases of design research were used in each research cycle: analysis, develop/design, and evaluation. Thus, the research design did not change from one cycle to the other. The same is true of the research activities carried out in the same phase of each of the three research cycles. In this way, a strong research design was used across the study. This avoids the use of an ever-changing research design, which can weaken a design research study.

Despite attending to the above challenges linked to design research, this study had certain limitations. One of the limitations was that, as in any development study, the final outcomes of this study were context-bound as the context-specific version of the PDF is strictly applicable to South African Physical Science classrooms in resource-constrained schools only. However, by being context-bound in this way, the results are more useful to professional development providers and policy makers, for example. At the same time, this study yielded intermediate outcomes that are generalisable. The outcomes consist of the content-generic version of the PDF (Figure 3.8), the content-specific version of the PDF (Figure 4.11), and the related design principles. These outcomes are generalisable in the sense that they result from a (systematic) review of the international literature on teacher education and inquiry-based practical work, respectively.

The second limitation is related to the span of this study in relation to the possible span of developmental design research. Based on Model 2 in Figure 2.4, design research involves not only preliminary research and prototyping (development), but also summative evaluation. This final phase of many design research studies aims to gather evidence of the effectiveness of an intervention or evidence to support the decision to continue or discontinue the project (Nieveen & Folmer, 2013). However, these types of evaluations are time consuming, costly and need to meet criteria that are difficult to meet in an educational context. As a result, this development study was limited to the formative evaluation involving the expected effectiveness of the intervention (PDF) in addition to its expected practicality.

6.7 IMPLICATIONS: PRACTICE- AND RESEARCH-RELATED

The second limitation above and the outcomes of this study have a number of implications linked to educational research, policy and practice. One research-based implication is that the process for developing a PDF (Figure 6.6), content-generic version of the PDF (Figure 6.2), like the content-specific version (Figure 6.3) and their associated design principles, may be useful to professional development researchers in different education settings. This is, for example, in the designing of interventions to support teachers in any aspect of inquiry-based science education

(Figure 6.2) and inquiry-based practical work (Figure 6.3), independent of the educational setting.

Another research-based implication of this study is that the context-specific version of the PDF (Figure 6.5) needed summative evaluation. This study provided evidence in support of this need. The evidence lies in the fact that the PDF meets the criteria of relevance and consistency (Chapter 3 and 4) and is expected to be effective and practical (Chapter 5). The PDF may thus undergo summative evaluation with the aim of assessing its actual practicality and actual effectiveness. This calls for the implementation of the PDF. However, in this regard, it is a challenge for the researcher (designer) to also serve as the implementer and evaluator of an intervention (Section 2.4.2.3). For instance, the researcher may become less objective due to his/her attachment to the research, while the respondents may become biased due to their awareness of the amount of effort deployed by the researcher in designing the intervention. Thus, educational researchers in collaboration with practitioners such as professional development providers are encouraged to implement and undertake a summative evaluation of the context-based PDF. University professors and subject specialists are helpful in this regard. These people may also serve as lesson study advisors considering that the PDF is lesson study-based. The naturalistic settings in which the summative evaluation needs to take place makes the use of a (quasi) experimental approach difficult to use. Thus, a large-scale survey combined with a number of in-depth case studies may be used instead. While this combination cannot detect a cause-effect relationship, it can provide data on the effectiveness of the PDF (intervention) in a cost-effective way.

Coupled with the above research-based implications are a number of practice-based implications. The PDF may be implemented not only for the purpose of its summative evaluation, but also for the purpose for which it has been created. This purpose is that of supporting South African Physical Science teachers in resource-constrained schools in the design and implementation of inquiry-based practical work. The formation evaluation of the expected effectiveness and expected practicality of the PDF (Section 5.4.3) supported the use of the PDF for this purpose. However, the efforts of policy makers, as well as district and school managers are needed. This is in terms of the prior creation of a supportive environment in line with the first primary goal (primary goal 1) of the context-specific PDF. What these role players need to do is included in the shell of the PDF in relation to the various categories and specific extrinsic challenges that need to be reduced. The PDF is, however, silent about how these challenges may be reduced. Useful ideas to resolve this can be found in Section 4.3.2, which includes how specific system- and institutional-level extrinsic challenges faced by teachers internationally in relation to inquiry-based practical work may be reduced. In order to support time-starved science teachers, for example, some schools use laboratory technicians, science technicians or teacher aids (often special needs teachers) in the classroom (e.g., Higgins, 2009; Royal Society (The) & Association For Science Education, 2001). This is supported by Expert 4 (E4, third research cycle), who also suggested the use of after-class hours before 3 p.m. for implementing the PDF in schools. This may be facilitated by school managers, who have a role to play in determining whether science teachers receive the professional development experiences they need in order to develop their knowledge and skills (National Research Council, 2005a). In this case, school managers need to facilitate the enhancement of teachers' competences, professional identity and practice in relation to the design and implementation of inquiry-based practical work (primary goal 2 in Figure 6.4 and Figure 6.5). The role of school managers in this regard is important because it is difficult for teachers to reach the standards of inquiry-based (practical) instruction that reformers expect of them in the absence of strong institutional support (Lin et al., 2013). Further support for participants is needed from other educators and parents (Huziak-Clark et al., 2007). However, the PDF indicates that this support may focus not only on an institutional, but also at a system level. Thus, there are also role players (such as district authorities and policy makers) at this level regarding the translation of the completed context-specific version of the PDF into practice.

Another system-level practice-based implication of this study was noted by E4, which was that the PDF offers policy-makers a blueprint of a professional development process to consider in enabling teachers to gain professional development points. These points are linked to job retention. The associated final design principles are also useful in several ways, considering that design principles (Section 2.4.3.1):

- Contain rich data that educational designers can use in designing similar interventions in comparable settings;
- Provide future users both information needed in selecting and applying interventions, and insight into the required implementation conditions; and
- Assist policy makers in making research-based decisions towards addressing complex educational problems.

The complex educational problem involved in this study was that of the design and implementation of inquiry-based practical work in South African Physical Science classrooms, especially in resource-constrained schools. In this regard, for example, the multi-method, multi-case study in Chapter 5 indicates that teachers in these classrooms face many intrinsic and extrinsic (institutional and system-level) teaching challenges. However, the systematic literature review in Chapter 4 reveals that the challenges associated with inquiry-based practical work are not limited to Physical Science classrooms, nor are they limited to South Africa. Thus, the design principles generated here may be useful in designing interventions in physical and other science classrooms in comparable settings internationally. As noted above, the design principles could also assist in determining the implementation conditions for the intervention.

6.8 CLOSURE

As the practice-based problem, this study focused on the fact that confirmatory rather than inquiry-based practical work is prevalent in many South African Physical Science classrooms, especially in resource-constrained schools. The research problem was that of scarcity of data regarding a development process, the design principles and a PDF to support the design and implementation of inquiry-based practical work in South African Physical Science classrooms in resource-constrained schools. The research question thus concerned how one can develop a Professional Development Framework (PDF) to support teachers in this context. Thus, the primary purpose of the study involved the generation of design principles and the use of these principles over a number of research cycles to develop a Professional Development Framework (PDF) to support South African Physical Science teachers in resource-constrained schools in the design and implementation of inquiry-based practical work. This development study, which allowed for the combination of a theory-based approach (through two systematic literature reviews) and grounded approach (based on a multi-method multi-case study) was thus necessary. In the process, two new components of a PDF were identified in addition to a new teacher professional development goal linked to contextual factors. Additionally, three sets of design principles corresponding to the content-generic, content-specific and context-specific versions of the PDF were generated. The different versions of the PDF were formatively evaluated for relevance (content validity); relevance and consistency; as well as expected practicality and expected effectiveness respectively. The completed PDF is associated with ten final design principles.

The results above may be useful to professional development researchers and providers; policy-makers and educational designers, as discussed above. Through the joint efforts of these role players, the outcomes of this study could be implemented. Alongside its implementation, the completed context-specific PDF may undergo summative evaluation. These activities should give Physical Science learners in resource-constrained schools more opportunities to engage in inquiry-based science education in the context of practical work. This should contribute towards increased learner interest and performance in Physical Science.

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APPENDICES

Appendix A: Introduction email about evaluation of content-specific PDF

Professional development framework for supporting inquiry-based practical work

Dear Prof/Dr …..[Actual title and name of expert]:

I hope that this email finds you well. Internationally, and in South Africa, many science teachers face challenges linked to the design and implementation of inquiry-based practical work. Thus, my study focuses on the development of a professional development framework (PDF) as essentially the blueprint of a professional development process aiming to support these teachers. As part of the process of developing the PDF, I would like to benefit from your comments and advice. This is in relation to the current version of the proposed PDF. Your assist in this way (if possible), will greatly assist me towards reaching the completed PDF.

Please let me know about the possibility of your assistance in the above regard and also your availability if such assistance is possible.

Kind regards,
Fru V. Akuma
(Researcher)

Supervisors:
Dr Ronel Callaghan [a], Dr Jeanine Mwambakana [a], Prof Marlien Herselman [a, b]

[a] University of Pretoria, South Africa
[b] Council of Scientific and Industrial Research, South Africa

Appendix B: One-to-one evaluation of content-specific PDF

Time of interview ____________________ Duration _______________
Interview date ____________________ Place _________________
Interviewer ____________________
Interviewee (Expert) pseudonym___________________
Interviewee (Expert) details:

Position:	
Highest level of education (Bachelor, Masters, Doctorate):	
University/Institution where you work currently:	
Country of origin:	
Total years of experience in teacher profession development *research*	
Total years of experience in *delivering* teacher profession development*:*	
Total years of experience in inquiry-based *teaching and learning:*	
Total years of *research* involving inquiry-based science education*:*	
Highest level of education (Bachelor, Masters, Doctorate):	

Section A: General introduction

- (My name is …... and I am a student of ……)
- Thank you for accepting to take part in this discussion which will focus on a professional development framework (PDF) for supporting science teachers in the design and implementation of inquiry-based practical work. Here, a PDF is understood as essentially the blueprint of a professional development process. A PDF thus contains the processes, ways and means through which profession development outcomes may be attained. The PDF we will discuss here is a tentative outcome of my study which I am interested in improving. First, I propose to present the PDF to you. For this purpose, I will give you a document titled *Introduction of professional development framework*. We will go over the document together. Thereafter, we will use five questions linked to the presented PDF as the basis of our discussion.
- In the discussion, there is no right or wrong answer. Everything you say will be considered confidential and used only for the purpose of the research. Your views will remain anonymous and will not be used against you in any way. You are thus requested to feel free to say what you really think and how you really feel. You may decline to participate in the discussion at any time.
- The discussion will take about one hour or less. The discussion will be audio recorded so that I may be able to listen to it at a later stage to ensure that I capture your views correctly. The information on the tape will not be reproduced or used anywhere else.
- Do you have any questions or comments before we proceed?

Section B: Introduction of professional development framework

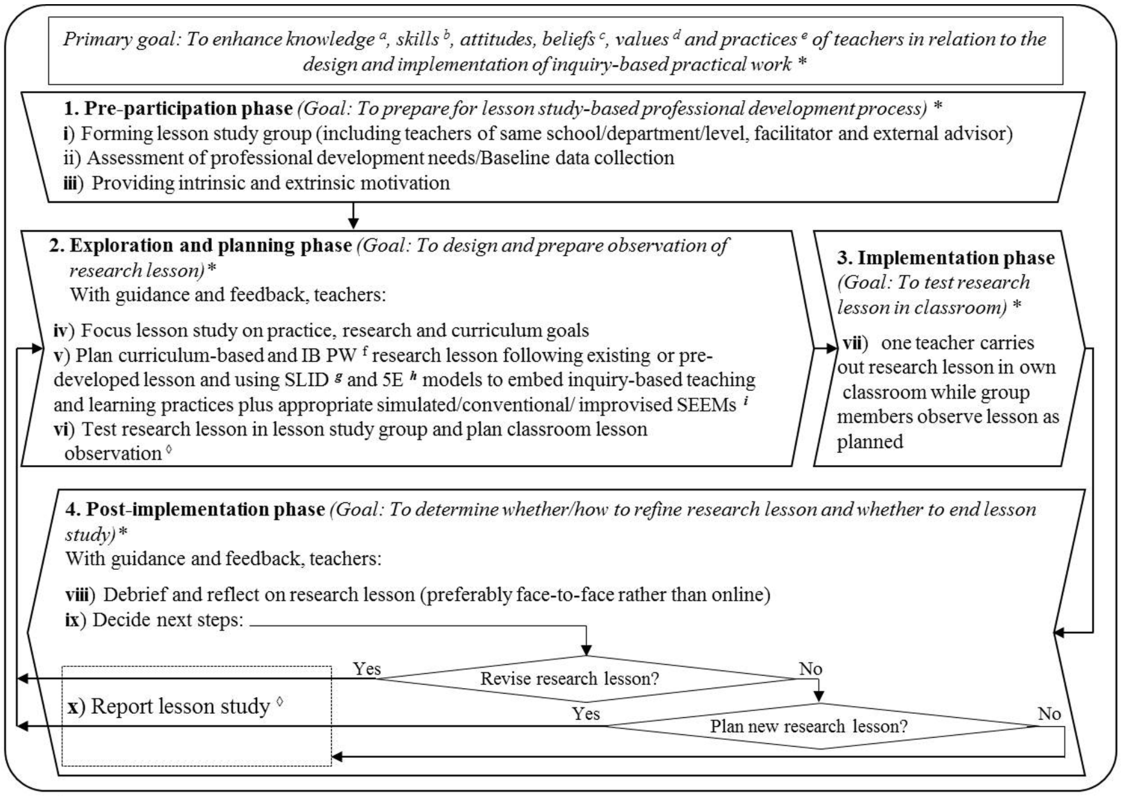
The professional development framework (PDF) is shown in Figure 1. The framework consists of seven primary components. These components are attending to extrinsic challenges, learning perspective (learning theory), teacher motivation, instructional functions, learning goals, professional development strategy and professional development phases. These components of the professional development framework are briefly described in Table 1.

Table 1

Components of professional development framework (PDF)

Component of PDF	Details
Professional development phases (stages in a professional development process)	• primary phases are numbered 1 to 4 in Figure 1 • secondary phases are numbered i) to xi) in Figure 1
Professional development strategy (sequence in which activities in a professional development programme are planned or implemented)	Lesson study - strategy in which teachers collaboratively learn to improve instruction - consists here of six phases numbered i) to xi) in Figure 1
Learning goals (desired teacher learning outcomes)	These are italicized and identified as a goal in Figure 1
Instructional functions (measures needed to bridge and complete phases of a learning programme)	These consist of: - reviewing learning periodically (marked with a lozenge (◊) in Figure 1) - providing learning goals on a continuous basis (marked with an asterisk (*) in Figure 1)
Teacher motivation (attracting teachers and sustaining their involvement)	Involves two aspects: - intrinsic motivation (e.g., improved performance) and - extrinsic motivation (e.g., access to new or additional resources) (secondary phase iii) in Figure 1)
Learning perspective (a description of how learning occurs)	• sociocultural (learning occurs through social interactions), or • situated cognition (learning occurs through participation and apprenticeship) (This component is implemented through the choices made for the other components such as the professional development strategy which is lesson study)
Attending to contextual factors (extrinsic challenges)	Reducing system-level challenges (e.g., quality of curriculum materials) and institutional-level challenges (e.g., lack of time) that constrain teachers (external box in Figure 1 explained in the legend of the figure)

The professional development framework (PDF) in Figure 1 contains other details not described in Table 1. The PDF and the formative evaluation questions now follow.



Legend:
[a] consisting of content knowledge, pedagogical knowledge, technological knowledge and pedagogical content knowledge
[b] consisting of pedagogical skills, creativity and practical skills
[c] including about the science curriculum and the understandings of science learners
[d] including care and concern for learners, commitment and dedication to practice, collaboration and team spirit, in addition to desire for continuous learning, innovation and excellence
[e] linked to inquiry-based learning (e.g., asking questions, planning and conducting investigations, analysing and interpreting data, constructing explanations and engaging in evidence-based arguments)
[f] IB PW = Inquiry-Based Practical Work
[g] SLID = Science Laboratory Instructional Design model (Phases: Initiation, Planning, Implementation (based on 5E [h] instructional model in this case), Evaluation and Feedback)
[h] 5E instructional model (Phases: Engagement, Exploration, Explanation, Extension and Evaluation)
[i] SEEMs = Science Education Equipment and Materials

* Providing learning goals on a continuous basis (Primary goal lies in enhancing teacher competences in order to reduce intrinsic challenges regarding the design and implementation of IB PW. For example, teachers not giving learners opportunity to link new learning to prior learning (intrinsic challenge) is reduced by enhancing pedagogical content knowledge linked to the understanding learners through the use of the SLID and 5E instructional models (way of reducing intrinsic challenge)

◊ Reviewing learning periodically

= Learning and practice environment where various specific system-level and institutional-level extrinsic challenges are reduced (For example, in relation to inadequate quality of teacher learning experiences (extrinsic challenge), professional development providers (role players) provide more practical learning experiences involving either structured, guided or open inquiry (way of reducing extrinsic challenge)

Figure 1 Proposed PDF to support teachers in designing and implementing inquiry-based practical work

Section C: Formative evaluation of professional development framework

1. How relevant are the components of the professional development framework (PDF)? In other words, to what extent are the components in line with state-of-the-art knowledge on the designing of effective teacher learning experiences?

2. Please provide suggestions, if any, on the relevance of the professional development framework.

3. How well integrated (logically arranged) are the different components of the professional development framework?

4. Please provide suggestions (if any) for improving the integration of the components of the framework (i.e., improving the consistency of the PDF).

5. Please comment (positively and/or negatively) on any other aspect than relevance and consistency in relation to the professional development framework. Add related suggestions, if any.

Appendix C: Observation schedule

Observation date ___________________ Place ________________________
Time of observation __________________ Duration __________
Teacher observed___________________ Pseudonym____________________
Observation number ________of 3 Grade _________

Type of practical work:
◌ Demonstration ◌ verification-based ◌ Investigation (Inquiry-based)

0. Topic of practical work ____
Lesson taught before practical work____
Lesson scheduled after practical work______________________________________

[Institutional-level:]
1a. Venue at which practical work is holding. *[Availability of laboratory facilities]*
____

b. Which types of equipment (simulated, improvised or conventional) are available in class?
____

[Teacher-level:]
c. What is the nature of the simulation (if involved)? (e.g., interactive/a passive demonstration, how does it reflect the real world?)
____

2. What is the intended learning outcome as specified to learners (orally or in written form)? *[Provision of intended learning goal]*
____

3. How are the following phases of learning achieved (by teacher, learners or on worksheet?)*[Use of 5E instructional model]*

a.	Engage: Accessing prior learning/identification of learner misconceptions: -Teacher asks a "What do you know/think?" question - Learners respond communicating prior conceptions and understandings in the process Promoting curiosity/capturing attention: - Encouraging learners to think about subject matter, raising questions in their minds, stimulating their thinking, through e.g., creating a surprise or doubt based on e.g., a demonstration followed by a discussion) - Teacher may simply provide rules/procedures for learner formulation of clear questions about the natural world that can be investigated - No need for closure ("right answer") at this stage
b.	Explore: (e.g., exercise verification or inquiry-based?, authentic goal/task/problem provided? goal/task/problem linked to prior learning/learner experiences?; only essential procedures provided? **learners** develop hypotheses, participate in designing/planning practical exercise …?)
c.	Explain:

	(e.g., teacher encourages learners to derive concepts from reflecting on their observations, develop concepts by guiding learners towards generalizations/new terminology; **learners apply** new learning/vocabulary to explain exploration)
d.	Elaborate: (e.g., application of learning in new context (e.g., in relation to concept, topic, grade level, extracurricular activity) further exploration, solving numerical problems based on teacher provided questions)
e.	Evaluate: (e.g., learner reflection on new understandings, formative* and summative evaluation of learning by teacher)

* Applicable to all phases of instructional model
(Based on Bybee (1997), , Bybee (2009); Bybee et al. (2006) and Eisenkraft (2003), Ramnarain (2011a)

4. Use of other desirable practices:

a.	When demonstrating (if any), how does teacher involve learners?(e.g., in predicting outcomes)
b.*	How does teacher guide learners (e.g., during a demonstration if involved)?(e.g., use of direct answers/indirect answers/hints/suggestions):
c.*	How does teacher interact with learners when they are carrying out practical work? (e.g., stops entire class to provide additional information, contacts groups individually, contact time with individual groups long or short?)
d.	Forms of learner-learner interaction (e.g., pairs, small groups, whole class discussions)
e.	i) Which real world (e.g., every day, scientific and technological) context(s) are integrated in the practical work?
	ii)** How is/are the contexts integrated in the practical work? (i.e. from concepts to context(s) OR from context(s) to concepts)

(* Based on McComas (2005), McComas (1991) and Urban-Woldron (2009); **Based on Ng and Nguyen (2006)

Appendix D: Interview schedule (physical science teachers)

Time of interview ____________________ Duration _______________
Interview date ____________________ Place _________________
Interviewer ____________________
Interviewee (Teacher) ________________ Pseudonym___________________

Introduction:

- Thank you for accepting to take part in this discussion which will focus on practical work in physics. My name is …... and I am a student of ………………….. I am currently researching issues related to the planning and carrying out of practical work in FET physics classrooms in resource-constrained schools.
- In this discussion, there is no right or wrong answer. Everything you say will be considered confidential and used only for the purpose of the research. Your views will remain anonymous and will not be used against you in any way. You are thus requested to feel free to say what you really think and how you really feel. You may decline to participate in the discussion at any time without any consequences for you.
- The discussion will take about 30 minutes. The discussion will be audio recorded so that I may be able to listen to it at a later stage to ensure that I capture your views correctly. The information on the tape will not be reproduced or used anywhere else.
- Do you have any questions or comments before we proceed?

Questions:
[Institutional-level:]
1. Based on your experience, how available in your school is each of the following types of equipment for practical work in physical science
a) interactive computer simulations (simulated equipment)?
b) conventional hands-on equipment
c) improvised hands-on equipment

[Teacher-level:]
Planning-phase
2. Tell me what you consider when designing or selecting practical work exercises so that learners can learn best.
3. What is your opinion, if any, on the following regarding interactive computer simulations?
    a) which ones are the best for practical work in physics?
    b) when to use and when not to use them in practical work in physics
4. What are your experiences, if any, with the selection and/or the production of improvised equipment that is useful in practical work?

Instruction-phase
5. What phases (steps), if any, do you follow when carrying out practical work? What usually happens during each phase (step)? *[Use 5E instructional model]*

[Knowledge on other aspects of constructivist practical work:]

6. What is your experience on the use of real-life contexts in practical work? In what way (s), if any, do you use real-life contexts?.
7. Some people believe that learners' prior knowledge and experiences are enough at the beginning of practical work? What is your opinion?
8. What do you think about allowing learners to design experiments to test their own ideas?
9. In what way (s) do you respond to the questions learners ask during practical work?
10. How do you normally interact with learners when they are working in small groups?

[Regarding simulated, ready-made and improvised equipment:]
11. How do you normally use interactive computer simulations (simulated equipment) during practical work? What is your reason, if any, for using simulations in this way?
12. What are your experiences in relation to the use of improvised equipment in practical work?

Thank you very much for your time and contribution.

Appendix E: Interview schedule (demonstrator)

Time of interview ____________________ Duration _______________
Interview date ____________________ Place _________________
Interviewer ____________________
Interviewee (Teacher) ________________ Pseudonym___________________

Introduction:

- Thank you for accepting to take part in this discussion which will focus on practical work in physics. My name is …... and I am a student of ………………….. I am currently researching issues related to the planning and carrying out practical work in FET physics classrooms in resource-constrained schools.
- In this discussion, there is no right or wrong answer. Everything you say will be considered confidential and used only for the purpose of the research. Your views will remain anonymous and will not be used against you in any way. You are thus requested to feel free to say what you really think and how you really feel. You may decline to participate in the discussion at any time without any consequences for you.
- The discussion will take about 30 minutes. The discussion will be audio recorded so that I may be able to listen to it at a later stage to ensure that I capture your views correctly. The information on the tape will not be reproduced or used anywhere else.
- The discussion is based on what you have experienced as you collaboratively plan and carry out practical work with the different physical science teachers of this school.
- Do you have any questions or comments before we proceed?

Questions:
[Institutional-level:]
1. Based on your experience, how available in this school is each to following types of equipment for practical work in physical science
a) interactive computer simulations (simulated equipment)?
b) conventional hands-on equipment
c) improvised hands-on equipment

[Teacher-level:]
Planning-phase
2. Tell me whether the practical work exercises the physical science teachers of this school generally select or design is such as to give learners the best chance of understanding physical science or not. Please elaborate on your answer.

3. What is your opinion on the state of knowledge and skills of these teachers in the following areas regarding interactive computer simulations useful in practical work?
a) selecting the ones that are best for learners
b) determining when to use and when not to use simulations

4. What are your experiences in relation to these teachers regarding their selection and/or production of improvised equipment that is useful in practical work?

Instruction-phase
5. What are the phases (steps), if any, that teachers of this school follow when carrying out practical work? What usually happens during each phase (step)? *[Use 5E instructional model]*

[Knowledge on other aspects of constructivist practical work:]
6. What is your experience on the use by these teachers of real-life contexts in practical work? In what way (s), if any, do they use real-life contexts?.
7. In what way (s) do the teachers respond to the questions learners ask during practical work?
8. How do they normally interact with learners when the learners are working in small groups?

[Regarding simulated, ready-made and improvised equipment:]
9. Tell me how these teachers usually use interactive computer simulations (simulated equipment) during practical work?
10. What are your experiences in relation to the use by these teachers of improvised equipment in practical work?

Thank you very much for your time and contribution.

Appendix F: Excerpt of field notes and reflections

03/09

- I am invited to attend PW unexpectedly by Mr [redacted] who earlier indicated he ~~will not~~ has no plans for PW for the week. Coincidentally a Laboratory Manager from [redacted] a partner institution is in school ~~of~~ today. ~~He~~ During the lab work he is the one who does most of the work with the learners. In the final analysis all the equipment used is from the school as additional eqt from [redacted] could not be used due to incompatibility b/w plugs and local sockets. So why did Mr [redacted] not have plans of doing this practical work until the arrival of his partner from [redacted]?

PW = Practical Work; b/w = between

Tuesday 08/09

Observed 2 experiments in Mrs [redacted] lab with Grade 12. However, second exp could not be completed by learners as no resistor could be found. Apparently the educator did not prepare for this lab in advance.

Appendix G: Sample worksheet from observed lessons

CHEMICAL CHANGE PART 2 (TERM 3)

Experiment Endothermic reactions

Apparatus and Chemicals

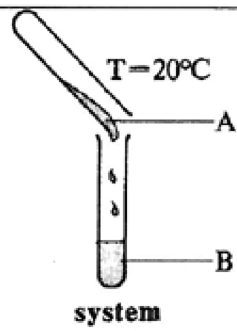
Test tubes Thermometer Measuring cylinder	Beakers Spatula Mass meter	Magnesium chloride Sodium carbonate Water

Method

1. Prepare the following solutions:

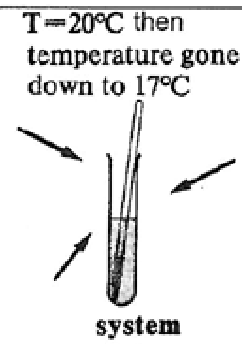
A:	Magnesium chloride	Prepare these solutions by adding 10 g of each to 50 ml water.
B:	Sodium carbonate	

2. Follow the instructions as shown in the drawing.



(a)

The system & surroundings are at the same temperature.



(b)

The system is now colder than the surroundings.

The reaction has made the temperature of the system go down. The energy exchange is from surroundings to system – the reaction is endothermic.

Appendix H: Institutional ethics committee approval

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Faculty of Education

RESEARCH ETHICS COMMITTEE

CLEARANCE CERTIFICATE	**CLEARANCE NUMBER: SM 15/03/01**
DEGREE AND PROJECT	**PhD**
	A professional development framework for supporting inquiry-based practical work in resource constrained classrooms
INVESTIGATORS	**Fru Vitalis Akuma**
DEPARTMENT	**Science, Mathematics and Technology Education**
APPROVAL TO COMMENCE STUDY	**08 June 2015**
DATE OF CLEARANCE CERTIFICATE	**22 November 2016**

Please note:

For Master's application, Ethics Clearance is valid for 2 years
For PhD application, Ethics Clearance is valid for 3 years

CHAIRPERSON OF ETHICS COMMITTEE: **Prof Liesel Ebersöhn**

CC **Bronwynne Swarts**
Ronel Callaghan

This Ethics Clearance Certificate if issued subject to the following conditions:

1. **A signed personal declaration of responsibility**
2. **If the research question changes significantly so as to alter the nature of the study, a new application of ethical clearance must be submitted**
3. **It remains the student's responsibility to ensure that all the necessary forms for informed consent are kept for future queries**

Please quote the clearance number in all enquiries

Appendix I: Governmental research approval (initial)

GAUTENG PROVINCE
Department: Education
REPUBLIC OF SOUTH AFRICA

For administrative use:
Reference no. D2015318 GA

GDE AMENDED GROUP RESEARCH APPROVAL LETTER

Date:	19 March 2015
Validity of Research Approval:	19 March 2015 to 02 October 2015
Previous GDE Research Approval Letter Reference Number	D2015/141G dated 18 June 2014
Name of Supervisor	Dr P Callaghan
Name of Researcher:	Botha M;Bruwer M,Coetzee C;De Lager LJ;Hannaway GM;Joubert JC;Magojane NV;Simalenga FD;Stols G;Van Putten LS;Loost E and Fru Vitalis A
Address of Researcher:	P.O Box 38040
	Faerie Glen
	0043
Telephone Number:	012 420 5521 or 083 445 4918
Fax Number:	012 420 5621
Email address:	Ronel.callaghan@up.ac.za
Research Topic:	Mobile technologies in teaching and learning
Number and type of schools:	Thirty Schools
District/s/HO	All Districts

Re: Approval in Respect of Request to Conduct Research

This letter serves to indicate that approval is hereby granted to the above-mentioned researcher to proceed with research in respect of the study indicated above. The onus rests with the researcher to negotiate appropriate and relevant time schedules with the school/s and/or offices involved to conduct the research. A separate copy of this letter must be presented to both the School (both Principal and SGB) and the District/Head Office Senior Manager confirming that permission has been granted for the research to be conducted.

1

Making education a societal priority

Office of the Director: Knowledge Management and Research
9th Floor, 111 Commissioner Street, Johannesburg, 2001
P.O. Box 7710, Johannesburg, 2000 Tel: (011) 355 0506
Email: David.Makhado@gauteng.gov.za
Website: www.education.gpg.gov.za

Appendix J: Governmental research approval (renewal)

For administrative use:
Reference no. D2016 / 346 GA
Enquiries: 011 843 6503
Diane Buntting

GAUTENG PROVINCE
EDUCATION
REPUBLIC OF SOUTH AFRICA

GDE AMENDED GROUP RESEARCH APPROVAL LETTER

Date:	3 December 2015
Validity of Research Approval:	8 February 2016 to 30 September 2016
Previous GDE Research Approval letter reference number	D2016 / 257 GA dated 1 September 2015; D2016 / 168 GA dated 1 July 2015; D2015 / 318 GA dated 10 October 2014 and D2015/141 G dated 18 June 2014
Name of Supervisor/s:	Dr P. Callaghan
Name of Researchers:	Botha M.; Bruwer M.; Coetzee C.; De Jager L.J.; Hannaway D.M.; Joubert J.C.; Magojane N.V.; Simalenga F.D.; Stols G., Van Putten L.S., Loots E., De Bruin I.; Moodley K.; Van der Merwe S.J.; Kruger M.; Smith T.; Schoeman H., Neethling S.; Pienaar O.; Pretorius N.; Akuna F. and Van Zyl L.
Address of Supervisor:	P.O. Box 38040; Faerie Glen; 0043
Telephone / Fax Number/s:	012 420 5521; 083 445 4918; 012 420 5621
Email address:	ronel.callaghan@up.ac.za
Research Topic:	Mobile technologies in teaching and learning
Number and type of schools:	THIRTY Schools
District/s/HO	ALL Districts

Re: Approval in Respect of Request to Conduct Research

This letter serves to indicate that approval is hereby granted to the above-mentioned researcher to proceed with research in respect of the study indicated above. The onus rests with the researcher to negotiate appropriate and relevant time schedules with the school/s and/or offices involved. A separate copy of this letter must be presented to the Principal, 1

Making education a societal priority

Office of the Director: Knowledge Management and Research
9th Floor, 111 Commissioner Street, Johannesburg, 2001
P.O. Box 7710, Johannesburg, 2000 Tel: (011) 355 0506
Email: David.Makhado@gauteng.gov.za
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Appendix K: Permission from principals

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Private Bag X20 Hatfield 0028 Republic of South Africa
Tel 012 420 3111 Fax 012 420 4555
http://www.up.ac.za

Date ……………………………
The Principal
…………………………………
…………………………………..

Dear Madame/Sir,

RE: **<u>LESSON STUDY FOR SUPPORTING CONSTRUCTIVIST PRACTICAL WORK IN RESOURCE CONSTRAINED FURTHER EDUCATION AND TRAINING PHYSICS CLASSROOMS</u>**

I am Fru Vitalis Akuma, a registered student of the University of Pretoria. With reference to the above mentioned topic, and in accordance with permission granted by the Gauteng Department of Education to conduct research in some schools in the Tshwane South School District, your school has been selected to participate in the research. In this regard, this letter aims at introducing the research project and requesting the participation of your school.

The performance of South African school learners in science remains poor, despite efforts from the government and the private sector to improve the situation. Amongst the worst affected subjects is physical science where the national average matric pass rate during the period 2010 to 2013 was only 58.6 %. One of the factors to blame for the low performance of learners in physical science is poor practical work. However, many teachers face challenges about the fact that as recommended by National Curriculum and Assessment Policy Statement (CAPS), all physical science learners need to carry out practical work and construct knowledge by themselves. This approach to practical work which may be referred to as constructivist, allows learners to gain a better understanding of physical science. The planning and facilitation of constructivist practical work however requires advanced teacher knowledge and skills as well as an adequate supply of science equipment. These requirements are not adequately fulfilled in many classrooms especially in resource-constrained schools.

Against the above background, teachers in FET classrooms especially in resource-constrained schools need to be strengthened to better deal with the challenges linked to practical work. In this regard, this study will examine the use of lesson study which is a collaborative and innovative professional development model. The focus will be to develop the blueprint of a professional development process to support teachers in the planning and facilitation of constructivist practical work in FET physics classrooms in resource-constrained schools.

The study has been planned to take place during the period spanning from April until September 2015, at different times to be arranged with participating physics teachers. The research will consist of two major parts the first of which is a needs assessment involving the observation of how practical work is currently carried out in FET physics classrooms. Also, participating teachers will be individually interviewed in relation to the challenges they face on practical work. The data collected will be used to refine plans for implementing the lesson study. In the second part of the study, teachers will be involved in planning and facilitating practical work through lesson study. The planning sessions will take place at times and venues that will be decided by teachers in consultation with the school principal and will be based on the CAPS for physical science. Using normal practical work hours, the teachers will then carry out and observe in the classroom, the practical work they have jointly planned.

During and after the planning and classroom sessions, data will be collected about the design, implementation and impact of the lesson study on participating teachers. The data will be gathered through observation and by way of interviews with teachers only. The interviews will be audio recorded so that the researcher may be able to ensure at a later stage that participants' views are correctly captured. The information on the tape will not be reproduced or used for any other reason. The data collected will be used to determine how lesson study may be used to support South African FET physics teachers in resourced constrained FET classrooms in the planning and facilitation of constructivist practical work.

The proposed study is likely to benefit both teachers and learners in ways including the following:
1. Teachers will enhance their knowledge, skills and strategies concerning the planning and facilitation of constructivist practical work in physics, based on hands-on equipment and computer simulations
2. From the professional learning community the study will initiate, teachers will be able in 2016 to gain professional development (PD) points through SACE
3. Through the development of improvised science equipment and their use along with computer simulations, it is expected that there will be increased availability and use of hands-on and simulated equipment for practical work
4. The experiences of learners on practical work should thus be enhanced

In proposing to carry out the above study, I undertake to ensure that any data collected will be confidential and that neither the school nor participating teachers will be named in the report. Also, the school and participants are free when deemed necessary to withdraw from the study without any consequence. As required by the Department of Education, a letter of informed consent will be given to FET physics teachers. Through the letters, teachers will be asked to take part in the research voluntarily. Though learners will not be asked to provide data, they and their parents or guardians will be provided with letters of information about this study.

Having thus described the study let me now request your permission to have the study carried out in your school. Your support in this regard will be highly appreciated by me and the University of Pretoria. Please indicate your willingness to grant the requested permission by signing in the space provided below.

Yours faithfully,

Fru Vitalis Akuma (Researcher) Email: fruvit@yahoo.com	……………………….. (Signature of the researcher)	Date: ……………….
Dr Ronel Callaghan (Supervisor) Email: Ronel.Callaghan@up.ac.za	……………………….. (Signature of Supervisor)	Date: ……………….
…………………….. (Head of Department)	……………………….. (Signature of Head of Department)	Date: ……………….

CONFIRMATION OF REQUEST TO CONDUCT RESEARCH AT THE SCHOOL

I Prof/Dr/Mr/Mrs/Ms, …………………………………………. the principal of ………………………………….. (name of school) hereby grant Mr Fru Vitalis Akuma permission to conduct research at this school on the above stated topic.

…………………………… Date: …………………………..
(Signature of principal)

Appendix L: Informed consent of physical science teachers

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Tel 012 420 3111 Fax 012 420 4555
http://www.up.ac.za

Date ……………………………….

……………………………………..

Dear Physical Science Teacher,

RE: Informed consent of teacher

I am a registered student of the University of Pretoria. As part of my PhD degree study, I am interested in carrying out a research project on the topic “Lesson study for supporting constructivist practical work in further education and training physics classrooms in resource-constrained schools.” After obtaining permission from your principal to conduct the research in your school, I now want to ask for your consent to participate in the study. However, let me first introduce the study.

Some teachers face challenges when it comes to enabling physical science learners carry out practical work and construct knowledge by themselves. This is however recommended by the National Curriculum and Assessment Policy Statement (CAPS). This approach to practical work, which may be described as constructivist, requires an adequate supply of science equipment and advanced teacher knowledge and skills. In this regard, this study will examine the use of lesson study, a professional development model that brings teachers together as a group to discuss lessons they have jointly planned and observed in actual classrooms.

During the study, research and professional development activities will occur at different times to be arranged with participating physical science teachers. The study has been planned to take place from July until September 2015 and to continue in the first term of 2016. The first segment of the research will be a needs assessment involving the observation of practical work and individual interviews with teachers regarding the challenges they face in relation to practical work. The data collected will be used to refine plans for implementing lesson study. During the study, teachers will be involved in planning and facilitating constructivist practical work. The planning sessions take place at times and venues that will be decided by participants in consultation with the school administration and will be based on the CAPS for physical science. Using normal practical work hours, the teachers will then carry out and observe the practical work they have jointly planned. During and after the planning and classroom sessions, data will be gathered through observation and by way of focus group interviews with teachers only. The interviews will be audio recorded so that the researcher may be able to ensure at a later stage that participants' views are correctly captured.

The proposed study is expected to be of benefit to participating teachers in more than one way. First, the study is expected to enhance teachers' knowledge, skills and strategies on the planning and facilitation of constructivist practical work. Secondly, participants will have the opportunity to develop equipment and practical skills that will remain useful in the planning of practical work after the end of the study. Also, due to their participation in the professional learning community (through lesson study) that this study will initiate, participants will be able to gain professional development (PD) points through SACE.

Having thus described the proposed study let me now request your consent to participate on a voluntary basis. Your support in this regard will be highly appreciated by me and the University of Pretoria. If you agree to take part in the research, please sign in the space provided below.

Yours faithfully,

Fru Vitalis Akuma (Researcher)	……………………….. (Signature of the researcher)	Date: ……………….
Dr Ronel Callaghan (Supervisor)	……………………….. (Signature of Supervisor)	Date: ……………….

<u>CONFIRMATION OF REQUEST TO CONDUCT RESEARCH AT THE SCHOOL</u>

I, ………………………………………… (your name) hereby agree to take part in the research project titled: Lesson Study for Supporting Constructivist Practical Work in Resource Constrained Further Education and Training Physics Classrooms.

I understand that as part of the research, I will be interviewed individually and alongside other participating teachers before, during and after professional development. Each interview which will last about 30 minutes will take place at a venue and time that will suit me or the group, will not interfere with school activities or teaching time and will be audio-recorded. I am also aware of the fact that before professional development, three of my regular practical work sessions will be observed for the duration of a period by the researcher who will remain objective and non-invasive. I equally understand that any lesson plans and worksheets associated with these practical work sessions will be copied and analysed by the researcher. During professional development, my classroom may also be selected for observation by other teachers in a non-invasive manner.

I also understand that in the conduct of the research, the researcher will abide by the following principles

- *Voluntary participation* in research, implying that participants may withdraw from the research at any time
- *Informed consent*, meaning that participants must at all times be fully informed about the research process and purposes, and must give consent to their participation in the research
- *Safety in participation*; put differently, that participants should not be placed at risk or under harm of any kind
- *Privacy*, meaning that the *confidentiality* and *anonymity* of participants should be protected at all times
- *Trust*, which implies that deception and betrayal of participants in the research process or its published outcomes will be avoided

……………………………
(Signature)

Date: …………………………..

Appendix M: Informed consent of demonstrator

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http://www.up.ac.za

Date ……………………………….

……………………………………..

Dear Laboratory Manager,

RE: Informed consent

I am a registered student of the University of Pretoria. As part of my PhD degree study, I am interested in carrying out a research project on the topic "Lesson study for supporting constructivist practical work in further education and training physics classrooms in resource-constrained schools." The principal of _____ (Name of high school), with whose physical science teachers you collaborate in the context of practical work, earlier granted permission for the conduct of this research. Before asking your consent to participate, let me first introduce the study.

Some teachers face challenges when it comes to enabling physical science learners carry out practical work and construct knowledge by themselves. This is however recommended by the National Curriculum and Assessment Policy Statement (CAPS). This approach to practical work, which may be described as constructivist, requires an adequate supply of science equipment and advanced teacher knowledge and skills. In this regard, this study will examine the use of lesson study, a professional development model that brings teachers together as a group to discuss lessons they have jointly planned and observed in actual classrooms.

The study has been planned to take place from July until September 2015 and to continue in the first term of 2016. The first part of the research is a needs assessment involving the observation of practical work and individual interviews with teachers regarding the challenges they face about practical work. Based on your experience form working closely with physical science teachers in relation to the planning and conduct of practical work, you may be aware of some of these challenges. As a result, I want to have an interview with you. The interview will be audio recorded so that I may be able to ensure at a later stage that your views were correctly captured. The data collected from you and teachers will be used to refine plans for implementing the lesson study. Through this means of professional development, it is expected for example, that teachers' knowledge, skills and strategies concerning the planning and facilitation of constructivist practical work would be enhanced.

Having thus described the proposed study let me now request your consent to participate on a voluntary basis. Your support in this regard will be highly appreciated by me and the University of Pretoria. If you agree to take part in the research, please sign in the space provided below.

Yours faithfully,

Fru Vitalis Akuma (Researcher)	……………………….. (Signature of the researcher)	Date: ……………….
Dr Ronel Callaghan (Supervisor)	……………………….. (Signature of Supervisor)	Date: ……………….

CONFIRMATION OF REQUEST TO CONDUCT RESEARCH AT THE SCHOOL

I, ………………………………………… (your name) hereby agree to take part in the research project titled: Lesson Study for Supporting Constructivist Practical Work in Resource Constrained Further Education and Training Physics Classrooms.

I understand that as part of the research, I will be interviewed. The interview which will last about 30 minutes will take place at a venue and time that will suit me, will not interfere with my activities and will be audio-recorded.

I also understand that in the conduct of the research, the researcher will abide by the following principles

- *Voluntary participation* in research, implying that I may withdraw from the research at any time
- *Informed consent*, meaning that I must at all times be fully informed about the research process and purposes, and must give my consent to participate in the research
- *Safety in participation*; put differently, that I would not be placed at risk or under harm of any kind
- *Privacy*, meaning that my *confidentiality* and *anonymity* would be protected at all times
- *Trust*, which implies that deception and betrayal will be avoided in the research process or its published outcomes

…………………………… Date: …………………………..
(Signature)

Appendix N: Letter of consent for parents/guardians

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Tel 012 420 3111 Fax 012 420 4555
http://www.up.ac.za

Date ……………………………….
……………………………………..
……………………………………..

Dear Parent/Guardian,

RE: **LETTER OF CONSENT FOR PARENTS/GUARDIANS**

I am a registered PhD student of the University of Pretoria. As part of my study programme, I am interested in carrying out a research project involving the physical science class in which your child belongs. The topic of my research is "Lesson Study for Supporting Constructivist Practical Work in Resource Constrained Further Education and Training Physics Classrooms". The study focuses on examining how teachers in FET classrooms in resource-constrained schools may work together to overcome the problems that prevent them from carrying out practical work in a way that allows learners to better understand physics. Presently, many learners in the Further Education and Training level struggle in physical science and especially physics.

During the study, the classroom in which your child belongs will be observed during normal physics practical hours at different times over the second and third term. During observation, your child will be amongst the rest of the learners and will be taught only by his/her regular physics teacher. Also, your child will not be specifically requested by me to provide information. Nevertheless, I would like to promise that all the information I will collect about teaching and learning during practical work will be treated in a confidential manner and used only for the purposes of this research. In addition, the identity of your child will not be disclosed in the report from the research. The report will be made available to the school your child attends and the Department of Education. In what may possibly benefit your child, these parties may use the reported findings to improve practical work especially in FET physics classrooms in resource-constrained schools.

It is however important to note that you can decide that your child be part of the research study or not. If you decide that your child should participate in the study, you can still asked the child to withdraw from the study at any time if you deem it necessary. No one will be upset if you decide that your child is not participating at all or choose to withdraw he/she at some stage. Rather, we will still take good care of the child. However, if you want to be part of this research, please indicate so by writing your name below.

……………………………………… ……………………….. Date: ……………….
(Name of parent/guardian) (Signature of parent/guardian)

I and the University of Pretoria would like to thank you most sincerely for your assistance in this research.

Yours sincerely,

Fru Vitalis Akuma (Researcher)	……………………….. (Signature of the researcher)	Date: ……………….
Dr Ronel Callaghan (Supervisor) Email: Ronel.Callaghan@up.ac.za	……………………….. (Signature of Supervisor)	Date: ……………….

Appendix O: Letter of assent

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Tel 012 420 3111 Fax 012 420 4555
http://www.up.ac.za

Date ………………………………
……………………………………..
……………………………………..

Dear Physical science learner,

RE: **LETTER OF ASSENT**

I am a student of the University of Pretoria and I am interested in carrying out a research study. As you may know, research studies help us to discover new knowledge. Also, a research study can allow us to test new ideas. Whether to discover new knowledge or test a new idea we start with a question. Then we try to find the answer. The rest of this letter talks about the research I plan to carry out and the choice that you have to make to take part in it.

Presently, many learners in the Further Education and Training level struggle in physical science and especially in physics. Thus, the question I am interested in answering deals with how physical science teachers may work together to overcome some of the difficulties that prevent them from carrying out practical work in a way that can help learners like you to better understand physics.

During the study, I would like to first observe a few of your normal practical work sessions in physics. At a later stage, your teacher (who has agreed to be part of the research) will try out new ideas that he or she has planned with a few teachers of other physical science classrooms like yours. These teachers and I may come to observe the test practical work lesson. As much as possible, you will be able to carry out your practical work undisturbed. Nothing harmful is expected to happen to you during this research. On the contrary, it is expected that this study will enable you to gain understanding and skills in physics since it will be based on your curriculum and assessment policy statement (CAPS). Also, through the study, the participating teachers and I may find out how to improve practical work in physics classrooms.

It is however important to note that you can decide to be part of the research study or not. If you decide to take part, you can still leave the study at any time if you choose to. No one will be upset if you decide not to take part at all or choose to drop out of the study at a later stage. Also, we will still take good care of you. However, if you want to be part of this research, indicate so by writing your name below.

…………………………………………………………………...... Date: ……………….
(Name of learner)

Yours sincerely,

Fru Vitalis Akuma ……………………….. Date: ……………….
(Researcher) (Signature of the researcher)

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UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Dr Ronel Callaghan (Supervisor) Email: Ronel.Callaghan@up.ac.za	……………………….. (Signature of Supervisor)	Date: ……………….

Appendix P: One-to-one evaluation of context-specific PDF

Time of discussion ____________________ Duration _______________
Date ____________________ Place _________________
(Expert) pseudonym___________________
Details of Expert:

Position:	
Highest level of education (Bachelor, Masters, Doctorate):	
University/Institution where you work currently:	
Total years of experience in teacher profession development *research* in South Africa	
Total years of experience in *delivering* teacher profession development in South Africa*:*	
Total years of experience in inquiry-based *teaching and learning* in South Africa*:*	
Total years of *research* involving inquiry-based science education in South Africa*:*	

Section A: General introduction

- (My name is …... and I am a student of ……)

Thank you for accepting to take part in this discussion which will focus on a professional development framework (PDF) to support South African physical science teachers in resource-constrained schools, in the design and implementation of inquiry-based practical work. Here, a PDF is understood as the blueprint of a professional development process. A PDF thus contains the processes, ways and means through which professional development outcomes may be attained. The PDF is meant to be used by professional development providers and/or researchers. The version of the PDF we will discuss here is a tentative outcome of my study that I am interested in improving. First, I propose to present the PDF to you. For this purpose, I will give you a document titled *Table 1 Description and expression of components of professional development framework (PDF).* We will go over the document together. Thereafter, we will use four questions linked to the presented PDF as the basis of our discussion.

- In the discussion, there is no right or wrong answer. Everything you say will be considered confidential and used only for the purpose of the study. Your views will thus remain anonymous and will not be used against you in any way. You are thus requested to feel free to say what you really think and how you really feel. Also, you may decline to participate in the discussion at any time.

- The discussion needs more than one hour, but may be continued at a later time.

- Do you have any questions or comments before we proceed?

Section B: Introduction of professional development framework

The professional development framework (PDF) is shown in Figure 1. The framework consists of eight primary components. These components are attending to contextual factors, professional development goals, professional development phases, professional development strategy, teacher motivation, instructional design perspective, instructional functions and learning perspective. These components of the professional development framework are described in Table 1 and simultaneously linked to the PDF (Figure 1).

Table 1

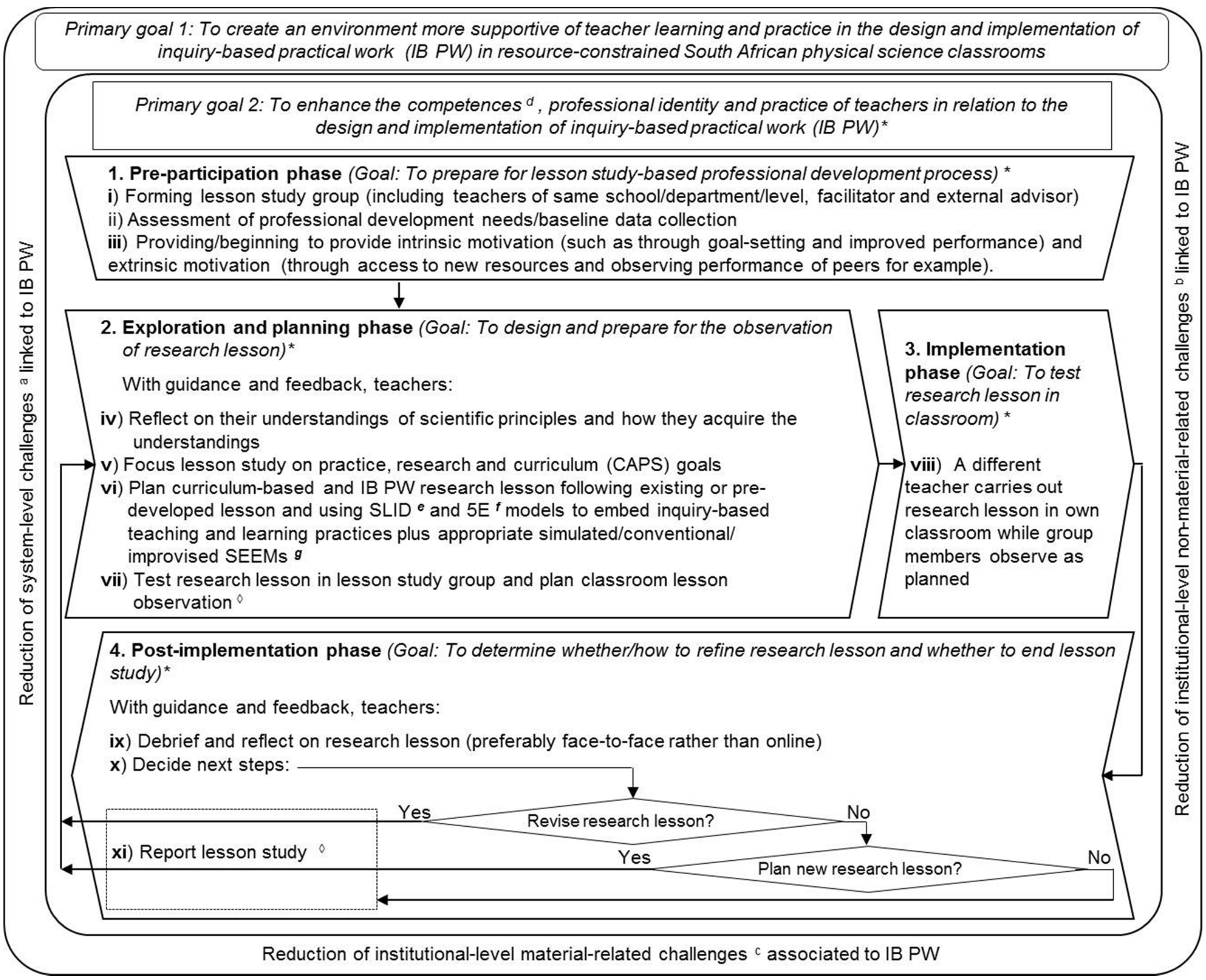
Description and expression of components of professional development framework (PDF)

Component of PDF		Description of component	Expression of component in PDF
A.	Attending to contextual factors	Dealing with extrinsic challenges linked to the design and implementation of IBPW*.	This involves reducing system-level and institutional-level extrinsic challenges. Details in this regard are found in the shell of the PDF and in the legend of Figure 1
B.	Professional development goals	The intended outcomes of the professional development process in terms of teacher learning and practice as well as the creation of a supportive environment	The outcomes are *italicized* and identified as a goal in Figure 1: • *Primary goal 1* deals with the creation of a supportive environment • *Primary goal 2* deals with teacher learning and practice and is broken down into *secondary goals* for the different phases of professional development
C.	Professional development phases	The stages in a professional development process consisting of primary and secondary phases	• Primary phases are numbered 1 to 4 in Figure 1 • Secondary phases are numbered i) to xi) in Figure 1
D.	Professional development strategy	The sequence in which activities in a professional development programme are planned or implemented. In this case, lesson study is the professional development strategy. On this basis, teachers collaboratively learn to improve instruction	Consists here of a sequence of seven phases included among the secondary professional development phases. The secondary phases due to lesson study consist of i) and v) to xi) in Figure 1.
E.	Teacher motivation	Attracting teachers and sustaining their involvement in the professional development process. Motivation has an intrinsic and an extrinsic component.	Intrinsic and extrinsic teacher motivation begins in secondary phase iii) in Figure 1
F.	Instructional design perspective	This is how IBPW may be designed and implemented	In this regard, the PDF combines the SLID and 5E models described in the legend of Figure 1 under [e] and [h].
G.	Instructional functions	measures needed to bridge and complete phases of a learning programme	These consist here of: - reviewing learning periodically (marked with a lozenge (◊) in Figure 1) - providing learning goals on a continuous basis (marked with an asterisk (*) in Figure 1)
H.	Learning perspective	This is the theory on which learning is based. The theory is a description of how learning occurs	The social cognitive theory is used here. This learning theory holds that people acquire knowledge, skills, beliefs, attitudes, strategies and attitudes by observing other people (vicarious learning) as well as

			through actual performance (enactive learning). Teachers may also be enhanced by engaging in reflection. These ways of learning are involved in the exploration/planning, implementation and post-implementation phases in Figure 1.

* IBPW = Inquiry-Based Practical Work

The context-specific professional development framework (PDF) in Figure 1 contains other details not described in Table 1. Regarding reading the PDF diagram, it is worth noting that the arrows indicate the flow of the professional development process reflected in the PDF. The PDF and the formative evaluation questions follow.



See legend and title of figure on the next page

Legend:

[a] consisting of a restrictive curriculum, mandatory work plan and lack of district support towards use of simulations
[b] consisting of inadequate access to simulations, time constraints, and learner use of tablets for non-practical work related activities
[c] consisting of inadequacy in science education equipment and materials, their procurement and also facilities

[d] consisting of knowledge [h], skills [i], values [j] and practices [k]

- [h] consisting of CK, PK, TK, TPK and PCK
- [i] consisting of practical skills and skills linked to laboratory safety
- [j] including desire for continuous learning, innovation and excellence
- [k] in relation to inquiry-based learning (e.g., asking questions, constructing explanations and engaging in evidence-based arguments)

[e] SLID = Science Laboratory Instructional Design model (Phases: Initiation, Planning, Implementation (based on 5E [g] instructional model in this case), Evaluation and Feedback)
[f] 5E instructional model (Phases: Engagement, Exploration, Explanation, Extension and Evaluation)
[g] SEEMs = Science Education Equipment and Materials

* Providing learning goals on a continuous basis (Primary goal 2 lies in enhancing teacher competences and professional identity in order to reduce intrinsic challenges [l] linked to designing and implementing IB PW)

◊ Reviewing learning periodically

[l] including misconception about notion of prior knowledge, misconception relating to role of practical work, difficulties linked to improvised SEEMs and unfamiliarity with instructional models

Figure 1 Proposed PDF to support teachers in designing and implementing inquiry-based practical work

Section C: Formative evaluation of professional development framework

i) Expected practicality

1. How appealing is the appearance of the diagram of the PDF? How may this aspect of the PDF be improved?

2. How clear to understand is the terminology used in the PDF? Please provide any suggestions in this regard.

3. How easy (or not) is it likely to be for users (such as professional development providers) to understand the PDF? Please explain.

4. In your opinion, how acceptable is the PDF likely to be among professional development providers in South Africa? Please provide suggestions, if any, towards improving the acceptability of the PDF.

5. In your opinion how cost-effective (i.e., the cost-benefit ratio) of implementing the PDF in relation to South African physical science education?

ii) Expected effectiveness

6. How effective (if at all) can the PDF be in achieving *Primary goal 1*? Expected effectiveness: Reason:

7. How consistent in relation to *Primary goal 2* are the experiences that participants will gain based on the PDF? Identify any inconsistencies.

8. On the basis of the PDF, are the professional development experiences that participants will gain likely to be adequate in relation to *Primary goal 2*? If not, please suggest the additional professional development experiences that are needed.

9. Please add any other way not involved above in which the effectiveness or practicality of the PDF may be improved.

Appendix Q: Published review paper

Eurasia Journal of Mathematics, Science & Technology Education, 2016, **12**(10), 2697-2717
doi: 10.12973/eurasia.2016.1305a

Framework for reducing teaching challenges relating to improvisation of science education equipment and materials in schools

Fru Vitalis Akuma & Ronel Callaghan
University of Pretoria, SOUTH AFRICA

•Received 21 January 2016•Revised 14 March 2016 •Accepted 14 March 2016

The science education budget of many secondary schools has decreased, while shortages and environmental concerns linked to conventional Science Education Equipment and Materials (SEEMs) have emerged. Thus, in some schools, resourceful educators produce low-cost equipment from basic materials and use these so-called improvised SEEMs in practical work. However, scattered in the literature are diverse challenges linked to the production and/or use of improvised SEEMs. Thus, the purpose of the literature review presented here was to design a framework useful in the reduction of these challenges. In this regard, we systematically gathered, characterised and clarified the challenges, in addition to collecting and reflecting on ways of reducing them. This enabled us to design the framework which focuses on educator learning and practice in the improvisation of SEEMs under specified conditions. Regarding the implementation of the framework, we have discussed the role that stakeholders including professional development providers and researchers may play.

Keywords: educator learning, framework, improvisation challenges, low-cost equipment, practical work

INTRODUCTION

In this paper, we present a literature review whose primary purpose was to design a framework to guide the reduction of teaching challenges relating to the production and use of improvised Science Education Equipment and Materials (SEEMs) in practical work in secondary schools. We use the term 'improvised SEEMs' to refer to low-cost equipment, self-created models as well as equipment and materials for conducting small-scale experiments which need smaller quantities of chemicals. Improvised SEEMs may be produced by resourceful educators from basic materials (e.g., plastic bottles and straws). The equipment and such materials may then be used

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in practical work in their classrooms. It is in relation to the challenges that educators may encounter in this regard that we set out to design the framework. However, in view of providing context, we begin with a brief discussion of practical work and ways of producing and/or supplying SEEMs in secondary schools.

Overview of practical work

Around the world, practical work is considered an essential aspect of science education by researchers, scientists, educators and learners (e.g., Abrahamsa & Millar, 2008; Lee, Guo, & Ho, 2008; Nivalainen, Asikainen, Sormunen, & Hirvonen, 2010). This is in line with the rationale for practical work provided by many people involved in science education (e.g., Kerr, 1963; Wilkinson & Ward, 1997 cited in Kidman, 2012; Lynch, 1986; Tamir, 1991). The rationale includes 1) enhancing learners' interest in science, 2) allowing learners to develop practical, thinking and problem-solving skills, 3) enabling the misconceptions of learners to be identified and addressed, 4) assisting in nurturing scientific values and attitudes in learners, and 5) giving learners the opportunity to develop their procedural knowledge and to investigate the physical world.

Millar (2011) considers practical work as consisting of activities in which learners individually or collaboratively engage in manipulating and/or observing real materials and objects as opposed to simulated ones (e.g., interactive computer simulations). However, some researchers (e.g., Eilks, Prins, & Lazarowitz, 2013; Hodson, 1998) hold that practical work may not be limited to traditional laboratory activities, given that in many situations, computer-based learning (e.g., using data-logging and simulated equipment) may be more effective. In actual fact, real (hands-on) and simulated SEEMs have their respective merits and thus complement each other in practical work (e.g., De Jong, Linn, & Zacharia, 2013; Urban-Woldron, 2009).

State of the literature

- Although there is a decrease in many science education budgets, coupled with shortages and adverse environmental effects of conventional Science Education Equipment and Materials (SEEMs), improvised SEEMs are playing a significant and increasing role in practical work in many secondary schools.
- However, some science educators even in ill-equipped classrooms seldom produce and/or use improvised SEEMs (e.g., self-created models, small-scale experiments and low-cost equipment).
- At the same time, diverse teaching challenges linked to the production and/or use of improvised SEEMs, as well as ways of reducing these challenges are scattered in the literature.

Contribution of this paper to the literature

- The literature may be extended by gathering, characterising and clarifying the diverse challenges educators are exposed to in terms of the production and/or use of improvised SEEMs.
- Also, it is helpful to collect in a systematic manner and reflect on the adequacy of certain recommended ways through which the challenges may be reduced.
- It is also useful to focus on the above contributions to address the lack of a framework for providing guidance in the reduction of the challenges linked to the production and/or use of improvised SEEMs in many science classrooms.

Science education equipment and materials

Many classrooms in industrialised and less developed countries lack essential conventional hands-on SEEMs (e.g., Childs, Tenzin, Johnson, & Ramachandran, 2012; Ens, Olson, Dudley, Ross, Siddiqi, Umoh et al.,, 2012; Nivalainen et al., 2010; Singh & Singh, 2012). This may be explained by the fact that even in industrialised countries such as Germany and Japan, conventional SEEMs are costly, coupled with the fact that in many industrialised and less developed countries science education budgets have decreased (Poppe, Markic, & Eilks, 2011; Schaffer & Pfeifer, 2011; Set & Kita, 2014). This is also the case in the former Soviet Union countries of Georgia and Moldova (Kapanadze & Eilks, 2014). In many less developed countries, including Kenya and Nigeria, conventional hands-on science education equipment and materials tend to be imported, difficult to obtain and expensive (Bhukuvhani, Kusure, Munodawafa, Sana, & Gwizangwe, 2010; Ezeliora, 1998; Ndirangu, Kathuri, & Mungai, 2003).

Against the above background, various alternative methods have been used around the world to gain access to conventional SEEMs. These methods include borrowing from or using facilities outside individual schools (e.g., mobile laboratories, local museums and science centres), using a micro-scale (small-scale) approach in carrying out conventional experiments, as well as improvisation at school level or at a central production unit (Bradley, 1999; Di Fuccia, Witteck, Markic, & Eilks, 2012; Musar, 1993; Singh & Singh, 2012; Sussman, 2000; Tran, Scherpbier, Van Dalen, & Wright, 2012). Though all the above ways of producing or gaining access to science education equipment are useful, this paper focuses on equipment improvisation in schools. This is because, as observed by Ndirangu et al. (2003), many schools function as islands.

The improvisation of SEEMs is a strategy that has been used in science education for many years, as evidenced by the literature (e.g., Barbara & Sam, 1957; Fagle, 1958; Set & Kita, 2014). Based on this strategy, resourceful science educators produce equipment, including physical models from basic materials and use this equipment and materials in practical work in their classrooms (Gilbert, Justice, & Arsela, 2003; Ndirangu et al., 2003; Ogoh, 2014). Basic materials that have been used in industrialised and developing countries in the production of science education equipment include syringes, plastic bottles, scrap timber from the school workshop, aluminium foil, tin cans, food colouring, baking soda, cabbage juice used as a chemical indicator, glycerine, and plastic bags and straws (Ens et al., 2012; Gilbert et al., 2003; Nyaumwe & Mavhunga, 2005; Sussman, 2000; Tran et al., 2012; Wilke & Tronicke, 2007, 2008). However, improvised equipment includes both equipment initially meant for other purposes (as evidenced by the above list) and equipment that is modified for use in practical work (Alonge, 1979; Di Fuccia et al., 2012; Kapanadze & Eilks, 2014; Von Borstel, 2009). Such materials are readily available to science educators (Stephen, 2015; Wood, 1990).

Educators may produce and/or use improvised science education equipment for a number of reasons. Normally, improvised science education equipment has been considered as equipment that may be used when the ideal (conventional) ones are lacking (Eniajeyu, 1983; Ogoh, 2014). However, educators may also produce and use their own SEEMs when commercially available SEEMs are less environmentally friendly, too hazardous to use in the classroom, or suitable only in educator demonstrations (Di Fuccia et al., 2012 on Germany; Ens et al., 2012 on the United States; Poppe et al., 2011 on Germany; Rettich & Battino, 1989). An example of a hazardous conventional material (reagent) is Syto13 or ethidium bromide, needed for staining during gel electrophoresis, which is an important technique in molecular biology taught in some high schools (Ens et al., 2012). However, Ens et al. further state that these hazardous reagents can be replaced satisfactorily using methylene blue available in pet supply stores. Educators have also produced improvised equipment to respond to learning difficulties. An example is Rogerson and Cheney Jr (1989), who developed a physical model for use in teaching the dynamics of protein synthesis. The improvisation of SEEMs also provides a means of linking science education to the real-life experiences of learners (Kyle, 2006; Stephen, 2015).

Improvised science education equipment (e.g., small-scale experiments) has been found by educators and researchers on different continents to be useful in various areas of science education in secondary schools. This includes measuring conductivity and understanding ion interactions in water (Seng, Kita, & Sugihara, 2007; Set & Kita, 2014 on Japan and Cambodia), as well as in studying DNA molecules, visualising the electrolysis of water and investigating energy transfer using a generator (Davis, Athey, Vandevender, Crihfield, Kolanko, Shao et al.,, 2014; Ens et al., 2012; Fletcher, Rommel-Esham, Farthing, & Sheldon, 2011 in United States). In one hundred schools studied by Ndirangu et al. (2003) in Kenya, departmental heads judged improvised science education equipment as largely adequate in modelling concepts, satisfactory in visual appeal as well as being usable over a reasonable duration, in addition to contributing significantly to science education equipment stocks.

Purpose and rationale of this paper

Against the above background, it is not surprising that researchers, curriculum designers, teacher educators, policy documents and organisations involved in science education have urged educators in ill-equipped classrooms to be resourceful in terms of producing and using improvised Science Education Equipment and Materials (SEEMs, e.g., Department of Basic Education, 2011; Ezeasor, Opara, Nnajiofor, & Chukwukere, 2012; KIE, 1992; Ndirangu et al., 2003; Nyaumwe & Mavhunga, 2005; Ogoh, 2014; Sussman, 2000; United Nations Educational Scientific and Cultural Organisation, 1979). In line with such calls, the use of improvised SEEMs (e.g., small-scale experiments) is an increasing trend in practical work in science classrooms in Germany (Di Fuccia et al., 2012). However, despite the willingness of some educators to improvise equipment for practical work (Childs et al., 2012), improvised SEEMs are seldom used in many ill-equipped science classrooms in secondary schools (Ezeasor et al., 2012; Sedibe, 2011; Singh & Singh, 2012). This result shows, first of all, that the improvisation of SEEMs is a strategy that can be better implemented in these classrooms. At the same time, it indicates that many science educators probably face challenges relating to the production and/or use of improvised SEEMs. A challenge, according to Schoepp (2005), is a condition that poses a difficulty in terms of progressing towards or attaining an objective. The objective in this case is the production and/or use of improvised SEEMs in practical work in science classrooms in secondary schools.

A number of researchers (e.g., Bhukuvhani et al., 2010; Ezeasor et al., 2012; Stephen, 2015) have mentioned certain challenges that educators are exposed to relating to the production and/or use of improvised SEEMs. However, these teaching challenges are scattered in the literature and have so far been considered in a manner that is largely descriptive and not systemic. Also, though relevant ways of reducing individual challenges have been suggested by various researchers (e.g., Collard & Looney, 2014; Ndirangu et al., 2003), the field of science education lacks a framework for guiding the reduction of the challenges in a systematic manner. Thus, the primary purpose of the literature review presented here is to design a framework useful in guiding the reduction of teaching challenges relating to the production and/or use of improvised SEEMs in practical work in science classrooms in secondary schools.

In order to achieve the above purpose, we consider it useful, first of all, to gather, characterise and clarify teaching challenges relating to the production and/or use of improvised SEEMs. Also useful is the gathering of relevant ways in the literature (e.g., Oladejo, Olosunde, Ojebisi, & Isola, 2011; Singh & Singh, 2012) for reducing specific challenges. Thus, in order to achieve the above purpose, we focus on answers to the following three research questions:

1. What are the different teaching challenges that educators are exposed to in relation to the production and/or use of improvised SEEMs?
2. How can the challenges be characterised and clarified?
3. What are relevant ways of reducing specific challenges?

CONCEPTUAL FRAMEWORK

The teaching challenges that science educators are exposed to relating to the improvisation of SEEMs may be characterised with reference to relevant extant categorisations of teaching challenges. Based on these categorisations, a framework of teaching challenges may be compiled. This framework may then be used to systematically gather the teaching challenges relating to the production and/or use of improvised SEEMs, as well as relevant ways through which the different challenges may be reduced. In terms of being able to clarify the teaching challenges, it is useful to consider the competences required of science educators.

Categorisation of teaching challenges

Relevant categorisations of teaching challenges exist in the context of constructivist teaching in general and problem- and inquiry-based teaching in particular. This is also the case in the context of information and communication technology (ICT) integration in teaching and learning. In the context of constructivist teaching, Windschilt (1999) grouped the inherent challenges into three categories: political challenges (e.g., getting learners to attain standardised outcomes), logistical challenges (e.g., lack of time) and pedagogical challenges (e.g., inadequate knowledge of ways of exploring content). In terms of enacting inquiry- and problem-based learning, some researchers (Chin, Goh, Chia, Lee, & Soh, 1994; Lee, Tan, Coh, Chia, & Chin, 2000) have categorised the challenges as internal (e.g., attitude and lack of knowledge) and external (e.g., classroom structure and time constraints). Similar categorisations are available in the context of the integration of ICTs (e.g., interactive computer simulations) in the classroom. One of these categorisations consists of educator-level challenges (such as resistance to change) and institutional- (school-) level challenges (e.g., shortage of equipment) (British Educational Communications and Technology Agency, 2004; Sherry & Gibson, 2002). Another categorisation of teaching challenges in the context of ICT integration in the classroom consists of intrinsic challenges (linked to an individual in this case a teacher) and extrinsic challenges, which are teaching challenges relating to an organisation (Hendren, 2000 cited in Al- Alwani, 2005; Ertmer, 1999). The last two categorisations of teaching challenges become identical if the term 'organisation' is considered to mean an institution (a school).

Though the above categorisations of teaching challenges originate in different pedagogical contexts, they have one commonality. This is the fact that teaching challenges consist of those relating to the characteristics of particular educators and those that are not linked to these characteristics. We may refer to these categories of teaching challenges simply as intrinsic and extrinsic challenges respectively.

With reference to the primary purpose of the literature review presented here, we consider it useful to further categorise intrinsic teaching challenges in terms of the phases of the teaching process. Phases of the teaching process may be derived from models of Instructional Design (ID). ID deals with systematic planning aimed at making instruction more relevant and effective (Merril, 1996; Reiser & Dempsey, 2007). Many ID models exist. However, the Analysis, Design, Development, Implementation and Evaluation model (Peterson, 2003) has been widely used (Balta, 2015; Magliaro & Shambaugh, 2006; McGurr, 2008). If we consider that the first three phases of this ID model are aspects of preparation, then according to the model, the ID process consists essentially of preparation, implementation and evaluation phases. These phases of ID are applicable to teaching, given that teachers are instructional designers. In fact, many people involved in education (e.g., Airasian & Russell, 2008; Wells, 1999) consider teaching to consist of three major interdependent phases which are preparation, implementation and assessment (evaluation).

In the preparation phase of teaching, the educator sets learning goals, prepares learning experiences, prepares learning materials (e.g., self-created models) and plans assessment (Airasian & Russell, 2008; Wiggins & McTighe, 1998). The implementation phase of teaching is where the planned lesson is implemented in the classroom. The third phase of teaching includes an evaluation of the degree to which learners have reached specified outcomes (Airasian & Russell, 2008). Thus, in principle, intrinsic teaching challenges may be categorised simply as preparation-phase, implementation-phase and assessment-phase challenges.

On the other hand, we can further categorise extrinsic challenges by borrowing from research into the integration of ICTs (e.g., interactive computer simulations) in the classroom. In this context, Pelgrum (2001) identified two categories of teaching challenges: those relating to a material condition and those that are linked to a non-material condition. Examples of these categories of teaching challenges from above are respectively the shortage of equipment (e.g., tools) and the lack of time.

The discussion in this section indicates that by borrowing from extant categorisations of teaching challenges, those linked to the production and/use of improvised SEEMs may be characterised with reference to Figure 1.

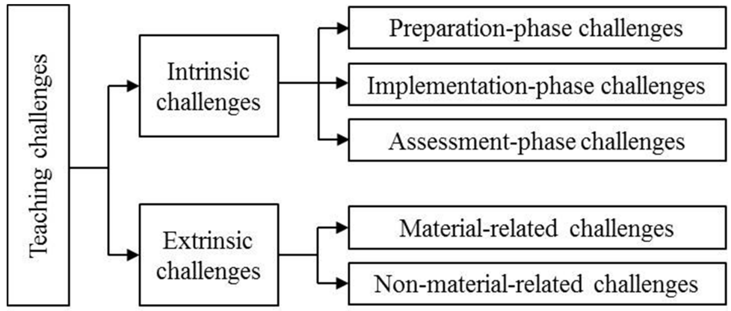


Figure 1. Conceptual framework of teaching challenges

In addition to being useful in characterising teaching challenges relating to the production and/or use of improvised SEEMs, Figure 1 also allows relevant ways of reducing specific challenges to be juxtaposed systematically with the related challenges. It remains to consider how the challenges may be clarified. We consider this as most useful in relation to intrinsic teaching challenges.

Clarifying intrinsic teaching challenges

The intrinsic teaching challenges that educators may face in the different phases of teaching in relation to improvised SEEMs, may be clarified with reference to frameworks of educator competence. Here, we consider a national framework of educator competence (Chong & Cheah, 2009) and the educator competence framework of the United Nations Educational, Scientific and Cultural Organisation (United Nations Educational Scientific and Cultural Organisation, 2011). These frameworks have knowledge, understanding, skills and values as categories of educator competences. Constituents of the values and skills needed by educators are outlined in Chong and Cheah (2009). Included in the skills category are pedagogical, reflective, personal and management skills. The values educators need to be equipped with include concern and care for learners, commitment and dedication to their practice, collaboration and team spirit, as well as the desire for innovation, continuous learning and excellence. Regarding the knowledge base of educators, its major components include knowledge of educational context, content knowledge, pedagogical knowledge and technological knowledge (Chong & Cheah, 2009; Mishra & Koehler, 2006; Shulman, 1986).

In order to be effective in their teaching, science educators need to be sufficiently knowledgeable and skilled (McComas, 2005; Onwu & Stoffels, 2005), in addition to possessing the above values. This is evidenced, for example, by the fact that science educators have been observed to encounter teaching challenges stemming from the lack of sufficient professional knowledge and skills (Newton, 2000; Windschitl, 1999). Educator competences thus provide a basis for clarifying the intrinsic challenges that science educators may face in relation to the production and/use of improvised SEEMs, in the different phases of teaching.

DATA COLLECTION AND ANALYSIS

In order to expand the data collection, we used relevant terms (e.g., improvised instructional materials, handmade science equipment, low-cost science equipment and inexpensive science equipment) in the full text of papers, to search the databases of several Web of Science journals as well as ERIC. The search was not restricted to specific countries, or to a particular methodological approach or theoretical perspective. However, we focused only on literature regarding secondary school classrooms, as we considered learners in these classrooms to be close to or to lie in the range of 12 to 20 years that Rutten, van Joolingen, and van der Veen (2011) consider as the age range within which learners acquire the most essential part of their basic knowledge of science. That said, observing the fairly scarce nature of relevant research-based evidence, we took into consideration the fact noted by Di Fuccia et al. (2012)

that the experiences of science educators covered in journals for educators and in conferences constitute a useful body of knowledge. This knowledge, which covers the other half of the knowledge spectrum, is useful for more fully understanding science teaching practices (McIntyre, 2005). In addition to conference papers, we located a few relevant documents from institutions or organisations involved in science education. In this way, we found 40 papers mostly from research-based journals and also from journals for educators. In addition, we obtained four publications from the other sources. This adds up to 44 sources that we initially considered in the literature review presented in this paper.

Following a preliminary review of the above sources, we found that 13 of them, although dealing with the subject of improvisation, were concerned with curriculum areas other than science or were not concerned with the improvisation of SEEMs. These sources were thus excluded from the literature review presented here. We also excluded one article for having limited data in terms of involving only two educators. Thus, we used 30 sources dealing with the subject of the production and/or use of improvised SEEMs as well as relevant ways of reducing the inherent challenges in school. This includes a conference paper and documents from institutions or organisations involved in science education (3), papers as well as laboratory experiments and exercises from peer-reviewed journals for educators (10), and papers from peer-reviewed academic journals (17). This last category of papers covered a range of research methods consisting of survey, observation, document analysis, interview as well as quasi-experimental and experimental research.

Based on the retained sources and using the afore-mentioned definition of a challenge from Schoepp (2005), we gathered teaching challenges that educators face in their teaching in relation to improvised SEEMs (e.g., low-cost equipment, self-created models and small-scale experiments). For each challenge, we searched the literature in terms of relevant ways of reducing the challenge. We then juxtaposed each teaching challenge with the corresponding recommended way/s of reducing the challenge. Finally, we individually assigned each challenge and its associated recommended way/s of reducing it to the appropriate category based on the framework in Figure 1. The results are presented and discussed below.

TEACHING CHALLENGES RELATING TO THE PRODUCTION AND/OR USE OF SEEMs

Intrinsic challenges

In this category, some educators face preparation-phase teaching challenges relating to motivation and skills as well as an implementation-phase challenge linked to their pedagogical knowledge.

Lack of motivation. Educators often lack the motivation to put additional effort into the preparation of practical work (Musar, 1993). Here, the preparation includes the production of self-created models, low-cost equipment or small-scale experiments. Many science educators have been noted for lacking the willingness or motivation to improvise science education equipment for their lessons (Ezeasor et al., 2012; Hakansson, 1983; Stephen, 2015; Tsuma, 1998). Thus, educators may need to be provided with incentives to motivate them as well as compensate them for the additional time they employ in the production of their own science education equipment (Holman, 1986; Ndirangu et al., 2003; Ogoh, 2014). This is because motivated educators put effort into improving learning activities, use creative ways of achieving learning goals and persist in carrying out tasks (Pintrick & Schunk, 1996). In this case, the task is that of producing small-scale experiments, self-created models or low-cost equipment for practical work in their classrooms. Though improved output is an effective intrinsic incentive, motivation is hard to sustain in the absence of extrinsic incentives (Gaible & Burns, 2005).

The lack of motivation in the above regard in many established science educators is in stark contrast to the fact noted in DomNwachukwu and DomNwachukwu (2006) that many candidate educators are motivated by the desire to make a difference and the love for children. These sources of motivation are consistent with such educator values as the concern and care for learners, as well as the desire for innovation and excellence. Thus, the lack of motivation to produce and/or use improvised equipment in the classroom may be due to a deficiency in such values. At the same time, the lack of motivation may be evidence of the existence of underlying challenges. For example, science educators may be unable to improvise science education equipment because they either lack an appreciation of the need to do so or lack the required skills (Tsuma, 1998).

Lack of creativity. Creativity, which involves doing something in new ways (NCERT, 2006; Tan, 2000), is considered important in science teaching by a number of authors (e.g., Shanahan & Nieswandt, 2009; Singh & Singh, 2012). In particular, this skill is required in the designing of improvised science education equipment (Ezeasor et al., 2012; Nyaumwe & Mavhunga, 2005). However, creativity is lacking among many science educators (Ezeasor et al., 2012; Kadzera, 2006; Stephen, 2015). This is in line with the fact that some science educators find it difficult to think as designers (Penuel & Gallagher, 2009). The creativity of educators may in general be enhanced in a collaborative manner by way of partnerships between creative professionals and educators (Collard & Looney, 2014). With specific reference to the improvisation of SEEMs, the creativity of educators may be developed through training programmes (Ezeasor et al., 2012).

Inadequate practical skills. In the preparation phase of teaching, educators have, among other activities, to prepare learning resources (Airasian & Russell, 2008; Wiggins & McTighe, 1998). In this case, the resources include improvised SEEMs (e.g., self-created models). According to Cribb and Gewirtz (2001), practical attributes are as important in teaching as intellectual capabilities. However, many educators lack the practical skills needed for producing improvised science education equipment (Bhukuvhani et al., 2010). This challenge can however be reduced. As noted by a number of authors (e.g., Munby, Cunningham, & Lock, 2000; Schön, 1991), practical competences (in this case practical skills) may be learned by doing tasks in educational contexts that are informal and based on problems encountered in real-life situations.

Inadequate pedagogical knowledge. Many educators are uncertain about how to use improvised SEEMs in practical work (Pimpro, 2005 cited in Bhukuvhani et al., 2010). Unlike the last three, this is an implementation-phase teaching challenge. In this context and based on Mishra and Koehler (2006), pedagogical knowledge includes knowledge of processes and methods or practices useful in motivating learners and implementing practical work.

Due to the degree of learner engagement involved, inquiry-based (IB) learning enhances the motivation and the attitude of learners towards science (Fairbrother, 2000; Osborne & Dillon, 2008; Rocard, 2007). In order to promote such learning, the educator creates situations in which learners are challenged to observe phenomena; raise questions regarding the phenomena; formulate relevant hypotheses; design and carryout experiments from which they collect and analyse data in order to either contradict or support their hypotheses in addition to drawing conclusions (Hattie, 2009). For providing learners with such IB experiences, improvised equipment (e.g., self-created models) are useful (Schmidt, 2003). Thus, a number of authors (Ezeasor et al., 2012; Musar, 1993) have recommended the training of pre-service and established science educators in the use of improvised SEEMs. In order to enhance such training, the European Union project, Student Active Learning in Science (SALiS), provided educators access to low-cost experimental techniques (Poppe et al., 2011) that are useful in the context of inquiry-based practical work in school classrooms (Kapanadze & Eilks, 2014).

In order to implement low-cost experimental techniques in IB practical work, science educators may use an Instructional Model (IM) as a guide. The National Research Council (2000) provides five phases common to IMs and useful for guiding IB teaching. The phases correspond to those of the 5E IM of Bybee (1997) which has been widely successful in educational contexts (Bybee, Taylor, Gardner, Van Scotter, Powell, Westbrook et al.,, 2006; Zuiker & Whitaker, 2014). The phases of this IM consist of Engagement, Exploration, Explanation, Elaboration and Evaluation. The first phase includes short activities which are based on an object (e.g., a self-created model), a situation, a real problem or an event and which are useful in puzzling learners, promoting curiosity among them, creating cognitive disequilibrium (Bybee, 2009; Bybee et al., 2006; Palmer, 2009) and thus motivating them. The

Exploration phase includes activities that provide learners concrete experiences as they investigate situations, materials and objects (Bybee, 2009). The remaining phases of the 5E IM are described for example in Bybee (2009) and Bybee et al. (2006).

In view of using improvised SEEMs (low-cost experimental techniques) in practical work based on the 5E IM, science educators need to be able to support collaboration and to guide inquiry (Schneider, Krajcik, & Blumenfeld, 2005). In this regard, we find it useful for the educator to possess knowledge on how to support learners in the formulation of questions that can be investigated, how to elicit these questions, ways of assisting learners in ensuring that their claims are data-based, ways of providing guidance or responding to the questions of their learners, as well as getting learners to work effectively in groups. Data on this aspect is available in the literature (e.g., Chin, 2004; Chin & Osborne, 2008; Cuccio-Schirripa & Steiner, 2000; Davis, 1999; Dillon, 1988; Piaget, 1985; Schneider et al., 2005). However, pedagogical knowledge on practical work is insufficient, as educators need opportunities to put this knowledge into practice (Nivalainen et al., 2010). In this regard, many educators face additional challenges.

Extrinsic challenges

Many science educators face material-related and/or non-material-related extrinsic teaching challenges linked to the production and/or use of ISEEMs.

Lack of training. The lack of professional training is a non-material-related teaching challenge educators may experience in relation to the effective use of improvised resources in science classrooms (Oladejo et al., 2011 citing Maduabunni, 2003). Some pre-service science educators studied by Singh and Singh (2012) claimed that their inability to improvise science education equipment stems from the lack of training. Thus, some researchers (Oladejo et al., 2011; Stephen, 2015) have recommended regular seminars and workshops in terms of strengthening established science educators on the improvisation of science education equipment through exposing them to local materials, as well as enabling these educators to acquire useful skills and strategies. On the other hand, some pre-service educators recommend the infusion of improvisation into science method modules in educator preparation programmes and the designing of an entire module on innovation and improvisation in science (Singh & Singh, 2012). They also consider the module useful for established science educators who may use the module as a short course. This is actually the case in Georgia and Moldova for example, where such modules have been accredited and where established science educators take part in Continuous Professional Development involving the incorporation of low-cost SEEMs in inquiry-based practical work (Kapanadze & Eilks, 2014).

Time constraints. Another non-material-related extrinsic challenge regarding the improvisation of science education equipment is the lack of time for educators to design and produce their own equipment (Ezeasor et al., 2012; Stephen, 2015). This challenge may be understood in terms of the fact that improvisation demands some patience and persistence on the part of especially educators new to its practice (Daramola, 1987; Fletcher et al., 2011; Sussman, 2000). However, science educators do not have to produce the science education equipment they need all by themselves. This is because they may be assisted in this regard by learners (Steward, 1983; Tobon, 1988). According to Ezeliora (1998), the involvement of learners is often minimal and limited to the provision of the raw materials needed by the educator for the improvisation of science education equipment. However, using suitable safety guidelines and equipment, learners have been involved in working collaboratively while developing their thinking and problem-solving skills as they participate in the production of science education equipment (Fletcher et al., 2011; Ndirangu et al., 2003; Sussman, 2000).

Lack of tools and critical parts. This is a material-related extrinsic teaching challenge regarding which Musar (1993) notes that some critical parts like lenses or small devices such as ammeters needed in the production of improvised science education equipment may not be locally available. On the other hand, Stephen (2015) observed that some science educators lack tools for use in the production of improvised science education equipment. Financial resources are thus needed for acquiring the above items. However, many science educators lack the financial support they need from their managers towards producing improvised science education equipment (Ezeasor et al., 2012; Stephen, 2015). At the same time, Ndirangu et al. (2003), in their study involving 50 schools, found that a relatively small percentage (19.2 %) of managers experience difficulties relating to funding the production of improvised science education equipment in school. There is thus the need for greater educator engagement with management in terms of the provision of tools and critical parts for the production of improvised SEEMs.

The discussion in this section may be summarised as in Table 1.

Table 1:
Challenges linked to production and/or use of improvised science education equipment and materials and ways of reducing them

Major category	Secondary category	Teaching challenge	Way (s) of reducing challenge
Intrinsic	Preparation-phase	Lack of motivation	- Use of intrinsic and extrinsic incentives
		Lack of creativity	- Partnerships with creative professionals - Training
		Insufficient practical skills	- Learning by doing
	Implementation-phase	Inadequate pedagogical knowledge	- Training - Access to low-cost experimental techniques
Extrinsic	Non-material related	Lack of training	- Pre-service training modules - In-service workshops and seminars
		Time constraints	- Involvement of learners
	Material related	Lack of tools and critical parts	- Greater educator engagement with managers

Table 1 shows that the teaching challenges that many science educators face in relation to the production and/or use of improvised SEEMs though numerous and diverse in nature, are surmountable. Thus, the table may serve as a starting point towards designing a framework for guiding the reduction of the challenges.

FRAMEWORK FOR REDUCING CHALLENGES TO PRODUCTION AND/OR USE OF IMPROVISED SEEMs IN SCHOOLS

The third column of Table 1 shows that the intrinsic challenges that many science educators face relating to the production and/or use of improvised SEEMs stem from a shortfall in their competences. Specifically, the educators possess inadequate relevant values, knowledge and skills. Thus, a framework for reducing teaching challenges relating to the production and/or use of improvised SEEMs needs to have as one of its goals, to prepare or enhance educators in the above areas of competence. In line with this goal, the ways of reducing intrinsic teaching challenges focus on educator learning as seen in the fourth column of Table 1. Among them is training, the availability of which is in itself an extrinsic teaching challenge.

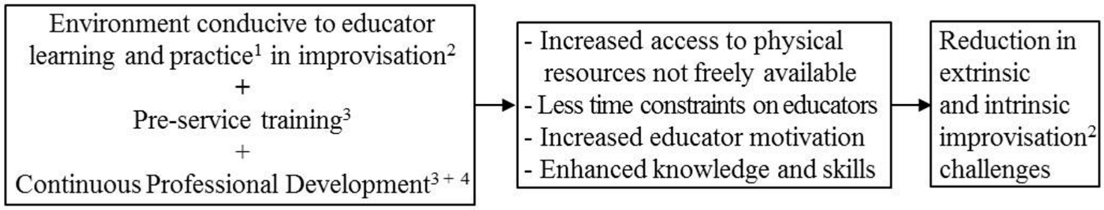
Training (in this case through modules, workshops and seminars), is useful in enabling educators to gain new ideas, skills and strategies (Gaible & Burns, 2005; Grant, 1996). However, training often occurs outside the school setting and context, in addition to using resources (in this case tools and basic materials) unfamiliar to educators (Fullan & Steigelbauer, 1991). This is unlikely to be the case in partnerships with creative professionals which allow for continuous learning in school settings. The continuous deepening of knowledge and skills is necessary for effective practice in any profession (Garet, Porter, Desimone, Birman, & Yoon, 2001). Thus, educator learning in the production and/or use of improvised SEEMs (e.g., self-created models and small-scale experiments) may consist of the training of mostly pre-service educators and mainly Continuous Professional Development of established educators.

The general goal in professional development of educators is to effect a change in their knowledge, skills, understanding, attitude and practice (Griffin, 1983). In line with the framework of educator competences discussed above, we may add a change in the professional values of educators. Professional development is a continuous process including not only training, but also practice, feedback and follow-up support (Organisation for Economic Cooperation and Development, 2009). Thus the term 'Continuous Professional Development' (CPD) is often used to describe such professional development. The CPD of science educators requires, among other aspects, collective participation in professional learning communities, content focus, methods similar to those needed in the classroom, an adequate duration as well as active learning (e.g., through learning by doing) and coherence (Desimone, Porter, Garet, Yoon, & Birman, 2002; Ingvarson, Meiers, & Beavis, 2005; Marx & Harris, 2006; National Science Teachers Association, 2006). Also, Capps, Crawford, and Constas (2012), based on a synthesis of the literature (e.g., Desimone, 2009; Penuel, Fishman, Yamaguchi, & Gallagher, 2007), identified other characteristics of CPD. These characteristics consist of opportunities for educator participation in authentic and modelled IB experiences and the planning of inquiry experiences for their lessons during workshops.

In addition to the above requirements, other aspects that appear to be critical in educator learning are motivation and the involvement of professional values. Fraser and Saunders (1998) highlighted the importance of professional values as an aspect in educator learning. These values, as noted earlier, include concern and care for learners, commitment and dedication to practice as well as the desire for innovation, continuous learning and excellence. Thus, CPD that enhances these values may enable educators to better pursue learning and practice in relation to the production and/or use of improvised SEEMs. However, Boyd, Banilower, Pasley, and Weiss (2003) note that a primary challenge relating to professional development is that of attracting educators and sustaining their interest. Thus, a framework for reducing teaching challenges relating to the production and/or use of improvised SEEMs needs to incorporate incentives, the enhancement of professional competences (values, skills and knowledge), as well as offer training and CPD.

The framework needs to also provide for the reduction of the other extrinsic teaching challenges than the lack of educator learning opportunities. These challenges are reflected in Table 1 which also shows possible ways through which the challenges may be reduced. Against the above background, we have designed the framework in Figure 2 to serve as guide in the reduction of challenges relating to the production and/or use of improvised SEEMs in schools, across the different categories in Table 1.

The requirements of the framework in Figure 2 are based on the preceding discussion in this and earlier sections. In Table 2, we have summarised the literature on which these requirements are based.



Legend:

[1] availability of intrinsic and/or extrinsic incentives, provision of tools and critical parts, as well as the involvement of learners in equipment production

[2] relating to production and/or use of low-cost science education equipment and materials (e.g., self-made models)

[3] including:
- instilment of professional values (e.g., care for learners, desire for innovation and desire for excellence)
- pedagogical knowledge enhancement: experiencing, planning and facilitating inquiry-based practical work based on 5E instructional model and incorporating low-cost experimental techniques
- skills development: creativity, designing and practical skills needed for producing low-cost science education equipment

[4] involving: collective participation in professional learning communities, content focus, adequate duration, active learning (e.g., through learning by doing), coherence and use of methods similar to those needed in classroom (e.g., inquiry-based learning)

Figure 2. Framework for reducing teaching challenges relating to production and/use of improvised science education equipment and materials in schools

We see from Table 2, that the framework in Figure 1 is backed by a significant segment of the literature. However, it is useful to note that this framework is generic.

Table 2:
Theoretical justification of requirements of framework in Figure 2

Requirement	Theoretical backing
Intrinsic and extrinsic incentives	Boyd, Banilower, Pasley, and Weiss (2003), Gaible and Burns (2005), Stephen (2015)
Provision of tools and critical parts	Musar (1993), Stephen (2015)
Learner involvement in equipment production	Steward (1983), Tobon (1988), Ezeliora (1998), Fletcher et al. (2011), Ndirangu et al. (2003), Sussman (2000)
Training	Gaible and Burns (2005), Stephen (2015), Grant (1996), Oladejo et al. (2011 citing Maduabunni, 2003), Singh and Singh (2012)
Instilment of professional values	Fraser and Saunders (1998), Chong and Cheah (2009)
Pedagogical knowledge enhancement	Chong and Cheah (2009), Mishra and Koehler (2006), Newton (2000), Windschitl (1999), Shulman (1986)
Skills development	e.g., McComas (2005), Onwu and Stoffels (2005), Newton (2000), Shanahan and Nieswandt (2009), Singh and Singh (2012), Ezeasor et al.(2012), Nyaumwe and Mavhunga (2005)
Continuous Professional Development	Garet, Porter, Desimone, Birman, and Yoon (2001), Organisation for Economic Cooperation and Development (2009), Capps, Crawford, and Constas (2012)

Thus, there may be opportunities available locally for fulfilling the requirements of the framework, and there may also be context-specific constraints on certain requirements. As examples, we consider variations in the context under which different science educators work and learn, as well as the needs of in-service and established educators.

School culture is a factor in terms of educator motivation and the likelihood of their engagement in tasks that demand effort (Hayes, 1997). This includes the designing and production of low-cost science education equipment. Thus, the nature and magnitude of the incentives needed for attracting and sustaining the interest of educators in this regard is context-specific. In relation to the availability of assistance in the production and/or use of improvised SEEMs, some pressured science educators may be able to obtain help from other staff in addition to learners. This is because in order to support pressured science educators, some schools deploy Science Technicians, Laboratory Technicians or Teacher Aids, some of whom take part in practical work (Higgins, 2009; Kidman, 2012; Moor, Jones, Johnson, Martin, Cowell, & Bojke, 2006; Royal Society (The) & Association For Science Education, 2001). Though it may be possible for these professionals to assist science educators in designing and producing improvised science education equipment (e.g., self-created models), this option is not available in all schools, countries or parts of the world where schools cannot afford such staff. For example, only 11 % of junior secondary schools in Ireland use Laboratory Technicians (Higgins, 2009).

Context may also affect the CPD component of the framework in Figure 2. The need to carry out CPD in professional learning communities may be fulfilled using Lesson Study (LS) for example. LS brings educators together to discuss lessons they have jointly prepared and observed in actual classrooms (Lewis, Perry, Hurd, & O Connell, 2006; Lewis, Perry, & Murata, 2006; Perry & Lewis, 2009). However, though common in Japan, China and increasingly in Canada, the United States, Europe and Australia (Gaible & Burns, 2005), LS is still an emerging innovation (Lewis, Perry, & Murata, 2006; Perry & Lewis, 2009). Thus, in some other countries and parts of the world such as Africa, where Lesson Study is not common, educators may need more external support when using LS to fulfil the CPD component of the framework in Figure 2. However, where required, such support is normally provided by LS Advisors. These are typically “instructional superintendents" assigned to schools (Fernandez, 2002) and university professors, though they could also be specialists from a regional education agency or district curriculum specialists (Richardson, 2004).

Also, there may be a variation in the learning needs of educators in terms of their competences. For example, established educators naturally have more practical knowledge than pre-service educators, considering as noted by Van Driel, Beijaard, and Verloop (2001) that such knowledge results from teaching experience. Thus, the design of the CPD of science educators needs to be consistent with both their specific needs and the existing knowledge (e.g., Garet et al., 2001; National Science Teachers Association, 2006), in the context in which they work (Mansour, EL-Deghaidy, Alshamrani, & Aldahmash, 2014). It may be worth noting that in terms of varying the knowledge and skills that in-service educators may need to enhance in the context of the framework in Figure 2, as opposed to established educators, the literature may not provide clear direction. For example, Nivalainen et al. (2010) observed that though possessing more practical and theoretical knowledge of instructional approaches than their pre-service counterparts, some established science educators did not portray this in the planning of practical work. On the other hand, established educators studied science through more traditional approaches than today’s pre-service educators (Anderson, 2007). Thus, the competences to be enhanced in these two groups of educators have not been differentiated in the context of the framework in Figure 2. However, in terms of in-service educators, the competences highlighted in Figure 2 may be considered against a given teacher education programme.

DISCUSSION AND CONCLUSION

The literature review presented here had as its primary purpose to design a framework useful in guiding the reduction of the diverse teaching challenges linked to the production and/or use of such improvised SEEMs as self-created models and small-scale experiments in practical work in schools. In order to design the framework (Figure 2), we gathered in a systematic manner, the challenges and relevant ways of reducing them with the help of the conceptual framework of teaching challenges in Figure 1. In the process, and as reflected in Table 1, we identified two primary categories of challenges: intrinsic and extrinsic challenges. The intrinsic teaching challenges stem from a shortfall in the associated professional competences of educators in the domains of values, skills and knowledge. While being specific to practical work involving improvised SEEMs, this finding is consistent with prior research. For example, science educators have been observed to face (intrinsic) teaching challenges stemming from the lack of sufficient professional knowledge and skills (Newton, 2000; Windschitl, 1999). However, the literature presented in this paper goes further by highlighting the importance of professional values as well. In view of enhancing the competences (skills, knowledge and values) of science educators in relation to the preparation and implementation of practical work involving improvised equipment and materials, the framework in Figure 2 has thus been designed to serve as a guide.

In designing the framework, we augmented training which is a key recommended way of reducing specific challenges, based on the professional development research output. This research is included in Table 2 which illustrates the literature on which the framework is based. Basically, the framework in Figure 2 provides for broad-based educator learning as a way of reducing the intrinsic challenges linked to the production and/or use of improvised SEEMs. On the other hand, the framework responds to the inherent extrinsic challenges through the creation of an environment that is conducive to practice and educator learning. This is through the incorporation of a way of reducing each specific extrinsic challenge.

In line with the framework and based on their empirical study in Kenya, Ndirangu et al. (2003) recommended the exposure of pre-service science educators to the improvisation of science education equipment. Also aligned to the framework in Figure 2, is the fact that in countries including Germany and the former Soviet countries of Georgia and Moldova, the use of inexpensive (low-cost) alternatives to traditional materials is becoming part of educator preparation programmes (Di Fuccia et al., 2012; Kapanadze & Eilks, 2014). In fact, many voices in the field of science education (e.g., Bhukuvhani et al., 2010; Ezeasor et al., 2012; Musar, 1993; Singh & Singh, 2012) have recommended that not only pre-service but also practising educators be provided with training workshops or courses on the production, use and even maintenance of improvised science education equipment. However, the framework we have designed goes further in terms of specifying the enabling conditions for practice and educator learning in this regard. Thus, school managers, teacher educators and professional development providers may consider the implementation of this framework in their programmes. In doing so, the context under which the framework is being implemented may have to be considered, as illustrated by the discussion at the end of the last section.

Alongside the implementation of the framework in Figure 2 by practitioners, professional development researchers may evaluate it in view of providing empirical data towards its enhancement. Also useful in this regard is data as to why teaching challenges relating to the production and/or use of improvised SEEMs appear not to be present in industrialised countries. In addition, though the requirements of CPD are more or less well known to the science education community and are thus a part of the framework in Figure 2, this is not the case concerning a mechanism for educator learning in this context. In specific terms, there is need for data regarding the means, ways and processes that may be employed in view of arriving at CPD outcomes (Hewson, 2007). In this case, the immediate outcome is the enhancement of the competences of educators in relation to the preparation and implementation of inquiry-based practical work involving improvised SEEMs (e.g., self-created models, low-cost equipment and small-scale experiments). Data regarding the mechanism through which this outcome may be attained should facilitate the translation of the framework in Figure 2 into practice.

The discussion in the preceding paragraphs shows that the implementation of the framework in Figure 2 requires the efforts of many actors including science educators and learners as well as school managers, teacher educators, professional development providers and professional development researchers. Though the efforts of many role players are needed, their collective efforts can lead to significant educational and environmental benefits linked to

SEEMs. The educational benefits include the fostering of science inquiry through increased availability of SEEMs at a lower cost, reduced dependence of classrooms on hazardous conventional equipment and materials (e.g., ethidium bromide), increased educator ability to address learning difficulties (e.g., using self-created models) as well as reduced dependence of schools on external sources of SEEMs (e.g., mobile laboratories). The environmental benefits include a reduction in household waste through recycling (e.g., plastic bottles) and a reduction in the use of environmentally unfriendly conventional SEEMs.

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Appendix R: Interview transcripts

The following seven individual interview transcripts are available in electronic format as *Pre-intervention phase interview transcripts:*

Interview Educator O1
Interview Educator O2
Interview Educator P1
Interview Educator P2
Interview Educator P3
Interview Educator P4
Interview Demonstrator School P

Interview Educator O1 (Excerpt linked to question 1) in Appendix D)

Interviewer (**I**): Dear Educator thank you very much for creating this time to sit down with me so that we can have a conversation with respect to your experiences as far as practical work is concerned. When I talk about experiences I am referring to the planning and delivery of practical work in your classrooms in this school. I hope that you are comfortable and that we can continue.

Participants (**P**): I am comfortable. We can continue.
I: Ok. Thank you. You are a tablet school from what I have seen – you have e-boards and – yeah, you are a computer school more or less.
P: Yeah.
I: So, am interested in finding out first of all to what extent are computer simulations available for your use and that of the learners in the context of practical work.
P: Computer . . . ?
I: Computer simulations. What I mean by computer simulations – maybe I should explain…
P: … I know simulation from – PhET simulations, maybe.
I: They could be from various sources as long as they are computer applications that learners can manipulate to see what are the effects in terms of physical phenomena.
P: Ok. With Mam _____ (name of colleague) sorry to mention the name, but we have developed – or come across P-h-E-T simulation.
I: Ok. PhET simulations.
P: Yes, so they are so good in such a way that you can play around as you said manipulate different things, but we – I only have it on my laptop it is not loaded on the Smart Board because we are still in the process and the learners as well on their tablets do not have that because it needs your device to have a Java application and with our tablet it is impossible to install Java because some of the app they are blocked with the tablet, but with my personal laptop I can play around those simulations.
I: So for now they are only accessible to you. But, you are hoping that your learners may also be able to have access to it. But, in this case especially through the E-board, and not so much through their tablets, due to what you just said. Isn't it?
P: Yeah. And another thing is, with the Smart Board – the LED Board – I can be able to download the video and all of that, but I never – I don't know how to – I can download the video from my USB and put on the LED Board, but with the PhET simulation, I still wanna consult the people from – who are working with – so that they can be able to install that. Even if I can work it, they all – the learners can see if it is at least there on the LED Board. I can be able to access it there. I think it will be good as well.
I: Ok. Then let us also talk about some other resources that may be useful in practical work like conventional hands-on or physical equipment. In your experience, how available are they for your use in practical work and that of the learners? …