Teaching practices linked to the implementation of inquiry-based practical work in certain science classrooms

Fru Vitalis Akuma[a*] and Ronel Callaghan[a]

[a]Department of Science, Mathematics and Technology Education, Faculty of Education, University of Pretoria

* Correspondence to: Fru V. Akuma; Email: f.v.akuma@gmail.com

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Abstract

Around the world, there have been curricula reforms involving the incorporation of the inquiry-based teaching and learning strategy in secondary school science education in general and in practical work in particular. Research in Inquiry-Based Practical Work (IBPW) has focused, for example, on aspects of the strategy itself, on teacher professional development, and on classroom teaching and learning based on the strategy. However, the question of the extent to which teaching practices linked to the implementation of practical work are actually inquiry-based, was still to be answered. In order to draw on the answer to this question to inform professional development practice and research, we focused on the case of physical sciences classrooms in two resource-constrained South African schools. In this regard, we used a conceptual framework based on the Interconnected Model of Teachers’ Professional Growth and including a framework of teaching practices. In the data collection, we used a multi-method case study approach and in order to analyse the data, we combined the inductive and deductive approaches in thematic analysis. The results show that in the initiation, planning, and classroom implementation phases of practical work, many of the teaching practices of participants were inconsistent with inquiry-based teaching and learning, although some other practices were consistent with this type of teaching and learning. At the same time, some of the consistent practices were at a rather low level of implementation. We have discussed the theory-, practice-, and research-based implications of these results, in relation to the implementation of IBPW in resource-constrained physical sciences classrooms in South Africa and internationally.

Keywords: inquiry-based practical work, teaching practices, resource-constrained schools, Interconnected Model of Teachers’ Professional Growth, instructional design, science education

1 INTRODUCTION

The practical work component in science education has evolved over the course of its long history. First, this component has been seen as an extension of the presentation of the accepted facts and ideas already covered in theory lessons (Toplis & Allen, 2012). However, the processes and skills involved in science have more recently been considered a part of the curriculum with the same status as the theoretical component (Watson, Swain, & McRobbie, 2004). In line with this evolution, strategies for implementing practical work range from a worksheet (teacher)-driven strategy at one end, to an open-ended learner-driven strategy at the other end (Kidman, 2012; Kim & Chin, 2011). The teacher-driven strategy is confirmation-based practical work. Though this strategy is adequate for developing such basic skills as observation; collecting and organising data; in addition to inferring (Zion & Mendelovici, 2012), the strategy has been criticised for being largely inconsistent with how scientists work (McComas, 2005). The criticism is in line with the common conviction among people in the science education community that the learning of science should be less about the acquisition of scientific facts and information, and more about the understanding and application of scientific concepts and methods. This emphasis on methods can be traced to the work of Dewey (Dewey, 1910) who contended that scientific knowledge is the product of inquiry.

Scientific inquiry is reflected in inquiry-based learning. Such learning is consistent with the social constructivist learning perspective which emphasises the idea that knowledge is actively constructed by the learner, in contrast to being transmitted directly from the teacher to the learner (Zion & Mendelovici, 2012). Thus, the Inter-Academy Panel, a global organisation of science academies, promotes science education in which learners engage in such scientific practices as raising questions, collecting data, drawing conclusions and discussing their findings (Inter-Academy Panel, 2012). In many countries science curricula encourage teachers to involve learners in inquiry-based science learning (National Research Council, 2000).

Against the background of the preceding discussion, we focus in this paper on Inquiry-Based Practical Work (IBPW) which as educators know, is a relatively new strategy in practical work in science education. This type of practical work consists of experiences in which learners collaboratively manipulate a combination of hands-on and/or computer-based science education equipment and materials, or existing data sets, in order to better understand the natural world as they engage in scientific practices through structured, directed or open inquiry (Author, 2001).

Researchers have explored a number of broad areas regarding the IBPW strategy in science education in secondary schools. Among the areas are aspects of the strategy itself, classroom teaching and learning based on this strategy, and science teacher professional development. Research in science teacher professional development in IBPW has focused among other aspects on the formulation of research questions by teachers (Hasson & Yarden, 2012) and the use of interactive computer simulations to facilitate student inquiry (Donnelly, O'Reilly, & McGarr, 2013). Studies in the area of classroom teaching during IBPW include teachers descriptions and conceptualisation of this type of practical work in their classrooms (Gyllenpalm, Wickman, & Holmgren, 2010) and the use of virtual laboratories to foster guided inquiry (Donnelly et al., 2013). Also included is the identification of the difficulties teachers experience when implementing open inquiry (Zion, Cohen, & Amir, 2007). However, little research exists that provides empirical evidence of how teachers translate inquiry into practice (Lin, Hong, Yang, & Lee, 2013). In particular, studies that focus on teaching practices linked to the implementation of IBPW are scarce in the science education research literature.

Teaching practices are affected by the context in which teachers perform their work (Wallace, 2003). Thus, we focused in this study on the implementation of IBPW in South African physical sciences classrooms. The South African physical sciences curriculum (Department of Basic Education, 2011b) advocates the teaching and learning of science through inquiry and requires learners to be involved in practical investigations (IBPW). However, the number of South African Grade 12 physical sciences learners who pass at a level to enter science-based university courses was only 36.9% in 2014 (Department of Basic Education, 2016a). Some researchers have blamed the low learner performance, in part, on the inadequate implementation of practical work, particularly in resource-constrained schools (Mji & Makgato, 2006; Sedibe, 2011).

Against the background discussed in the previous paragraph, Dudu and Vhurumuku (2012) examined the practices of two South African physical sciences teachers in urban high schools, when implementing investigations (inquiry-based practical work). This leaves out the initiation and planning phases of this type of practical work and the case of resource-constrained schools. These are schools that are located in communities with a low socioeconomic status (Ganchorre & Tomanek, 2012). Thus, we formulated the following research question to serve as a guide in this study:

To what extent is IBPW being implemented in selected resource-constrained South African physical sciences classrooms?

An understanding of teaching practices (in this case linked to the implementation of IBPW) is essential in the development of teacher education and professional development programmes that respond to the challenges that science teachers face in the classroom (Wu, 2009). Also, teaching practices are critical in terms of supporting learners in the framing of research questions and in the design and conduct of investigations, in addition to data collection, and the drawing of conclusions (Dudu & Vhurumuku, 2012). Thus, the purpose of this study was to draw on the answer to the research question to inform teacher professional development practice and research.

2 CONCEPTUAL FRAMEWORK

2.1 Overarching theoretical basis: Interconnected Model of Teachers' Professional Growth

For the purpose of examining everyday teacher practice in order to inform professional development efforts, a systemic perspective to human or teacher development is useful. Bronfenbrener's theory of human development (Bronfenbrenner, 1979) is an example of such a perspective. However, this theory does not specifically focus on teacher professional development, unlike the Interconnected Model of Teachers' Professional Growth of the Teacher Professional Growth Consortium (1994). The model is shown in Figure 1.

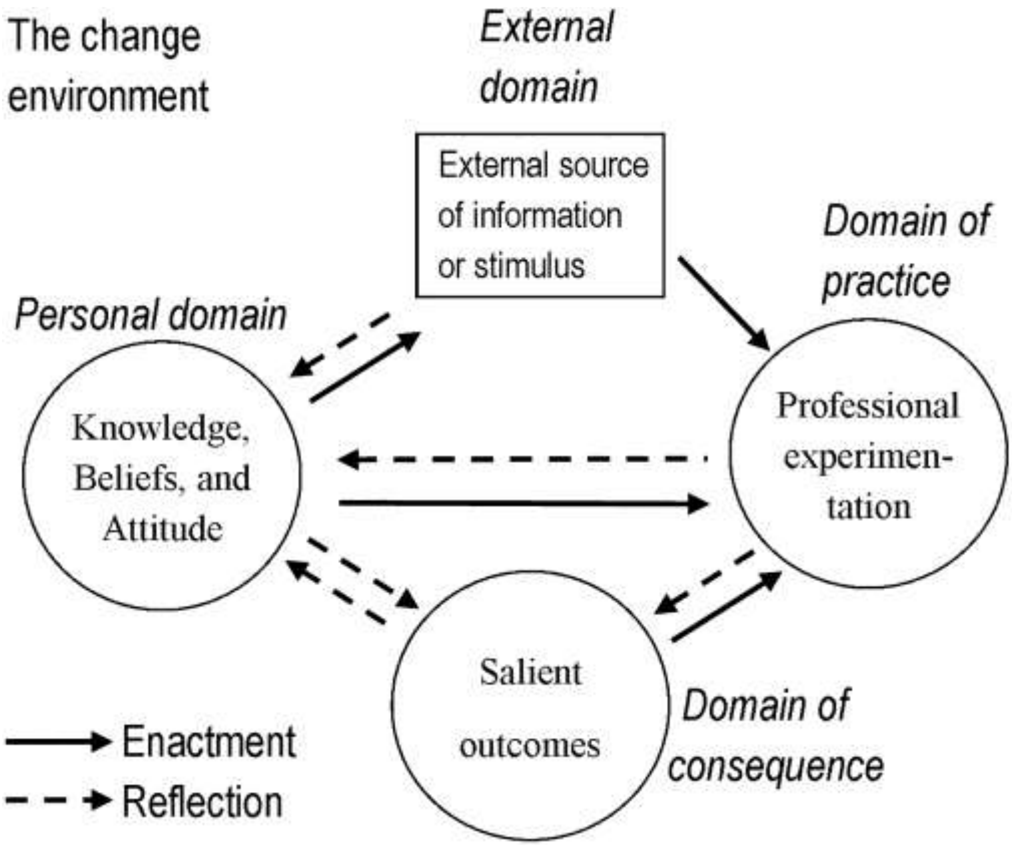


Figure 1 Interconnected model of teacher's professional growth (Teacher Professional Growth Consortium, 1994)

Based on the model in Figure 1, effective teacher development occurs through enactment and reflection in four interacting domains which make up the teacher's world. The domains are the external domain consisting of external sources of information, stimulus and support; the domain of consequence containing salient outcomes; the domain of practice which includes classroom experimentation; and the personal domain consisting of teacher knowledge, attitudes, and beliefs.

By experimenting with a new strategy (a change in the domain of practice), new knowledge or a new belief could be acquired (a change in the personal domain), giving rise to a change in perception of salient outcomes linked to classroom practice in the domain of consequence (Clarke & Hollingsworth, 2002). However, there are multiple pathways for teacher professional development between the four domains of the Interconnected Model of Teachers' Professional Growth. The development occurs within the constraints and affordances of the enveloping professional development environment (Hollingsworth, 1999).

2.2 Implementation of the Interconnected Model of Teachers' Professional Growth in this study

2.2.1 External domain and domain of consequence.

The role of these domains in this study will be seen towards the end of this paper. This is in conjunction with the results of the study.

2.2.2 Domain of practice and Inquiry-Based Practical Work (IBPW).

The new strategy that participating physical sciences teachers would have been experimenting with in the domain of practice is IBPW. This strategy, which we have defined in the third paragraph of the introductory section of this paper, could be further described with reference to inquiry-based teaching and learning. This type of teaching and learning engages learners in the investigation of the physical world by posing questions, investigating them and based on empirical data obtained first-hand or drawn from existing data sources, explaining, and justifying assertions (Hofstein & Lunetta, 2004; Quintana, Reiser, Davis, Krajcik, Fretz, & Duncan, 2004). In fact, as reformulated by the National Research Council (2012), there are eight scientific practices to call upon in combination or individually as needed, in the context of K-12 classrooms. The practices consist of asking questions, developing and using models, planning and conducting investigations, analysing and interpreting data, using mathematical and computational thinking, formulating explanations and engaging in evidence-based arguments; in addition to obtaining, evaluating and communicating information.

For implementing scientific practices in the classroom, different teaching strategies exist. The difference among these strategies is the relative amount of student-led versus teacher-led activities occurring during the inquiry activity. The strategies are contained in Table 1, the first three columns of which are due to Schwab (1962) and Bell, Smetana, and Binns (2005). Author (2001) added the fourth column in order to incorporate some of the scientific practices advocated by the National Research Council (2012) into the description of the different teaching strategies. We have added the practices B and H in order to incorporate the full range of these scientific practices.

Table 1: Categorisation of inquiry-based strategies in school contexts

Level of inquiry	Question	Methods of investigation	Answers	Scientific practices* accommodated
0 (Confirmation)	Given	Given	Given	C (ii) and D
1 (structured)	Given	Given	Open	C (i and ii), 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

* Consist of:
A = asking questions
B = developing and using models
C = (i) planning and (ii) carrying out investigations
D = analysing and interpreting data
E = using mathematics and computational thinking
F = constructing explanations
G = engaging in evidence-based arguments
H = obtaining, evaluating and communicating information

The scientific practices in Table 1 overlap with those advocated in science curriculum documents in South Africa where this study was carried out. Curriculum developments in this country mirror worldwide reform trends in science education (Ramnarain, 2014). For example, the South African physical sciences curriculum aims among other aspects to equip learners with such investigative skills relating to chemical and physical phenomena as communicating, designing an investigation, interpreting, drawing and evaluating conclusions, and formulating models (Department of Basic Education, 2011b).

With reference to Table 1, we use the term inquiry in this paper to encompass Levels 1 to 3, while excluding Level 0. The use of the term in this study is in the context of practical work where Level 0 (Confirmation inquiry) is the worksheet (teacher)-driven strategy. This strategy has been criticised as seen in the first paragraph in the introductory section of this paper. Thus, confirmation inquiry is excluded from the use of the term Inquiry-Based Practical Work (IBPW) in this paper, in favour of open, directed, and structured inquiry. Structured inquiry like directed inquiry, is effective in conveying content, since the teacher can guide the learners to discover specific concepts (Olson & Loucks-Horsley, 2000). However, structured inquiry is inadequate in enabling learners to think autonomously and develop the capacity to think critically and scientifically, in addition to developing appropriate attitudes (Kaberman & Dori, 2009; Lord & Orkwiszewski, 2006; Zion & Mendelovici, 2012). Open inquiry in which the teacher defines only the knowledge framework within which the inquiry is to be conducted, simulates and reflects the work of actual scientists (Zion & Mendelovici, 2012). However, before teachers can implement more open levels of inquiry in the classroom, they first need to be able to implement the less open levels (Donnelly et al., 2013).

It is against the background of the preceding discussion that we adopted the definition of IBPW from Author (2001) as stated in the third paragraph in the introductory section of this paper. This type of practical work is not common in resource-constrained South African physical sciences classrooms. In this regard, Ramnarain and Schuster (2014) found that teachers in these classrooms exhibit a strong orientation toward confirmatory practical work following expository science instruction. The answer of the research question in this study should reveal the teaching practices associated with such an orientation.

2.2.3 Personal domain and teaching practices.

Based on the Interconnected Model of Teachers' Professional Growth (Figure 1), experimentation with IBPW could have led to changes in the personal domain of physical sciences teachers. This is in terms of their professional knowledge, attitudes and beliefs. However, educational beliefs and teaching practices are intertwined (Mansour, 2009), while teaching practices are considered as teacher knowledge in action (Ritchie, Tobin, Sandhu, Sandhu, Henderson, & Roth, 2013). Thus, in this study, we incorporate teaching practices in the personal domain of the model in Figure 1. These practices consist of what the teacher does and also what the learners do during teaching and learning (Vhurumuku, Holtman, & Mikalsen, 2004). In this regard, and despite the importance of resources, the most important factor is the teacher who needs among other aspects to design instruction in such a way as to enhance learning (National Research Council, 2000).

2.3 Framework of teaching practices linked to the implementation of IBPW

2.3.1 Instructional design models and the Science Laboratory Instructional Design model.

Instructional design models are useful in providing a framework of teaching practices. There are many instructional design models in the literature (Dick, Carry, & Carry, 2001; Peterson, 2003; Posner & Rudnitsky, 2001; Smith & Ragan, 1999). However, the Science Laboratory Instructional Design (SLID) model (Balta, 2015) focuses on practical work and is thus more useful in this study. The five phases of this model consist of Initiation, Planning, Executeguide-evaluate (herein Classroom implementation), Evaluation, and Feedback. Each of these phases which we consider in this paper as the primary phases in the implementation of Inquiry-Based Practical Work (IBPW) contains a number of teaching practices as seen in the subsequent discussion.

2.3.2 Initiation-phase practices.

In the Initiation phase, the teacher sets goals and analyses learners and content, in addition to selecting a delivery strategy (Balta, 2015). Teachers need to provide the goals of practical work if learners are to benefit adequately from the experience (National Research Council, 2005). For example, without specific learning goals, the complexity of some simulations can overwhelm learners (Urban-Woldron, 2009). Regarding strategy, the teacher selects one of the levels of inquiry, one to three, in Table 1. The selection enables subsequent phases of practical work to be inquiry-based.

2.3.3 Planning-phase practices.

In the Planning phase, the teacher takes safety precautions and the formation of learner groups into consideration (Balta, 2015). He/she also considers the assessment of the learning needs and the development of assessment instruments, in addition to the design and production of materials including appropriate worksheets. We could add the selection of resources including interactive computer simulations from among the existing ones.

2.3.4 Classroom implementation-phase practices.

Unlike in the last two phases, learners are active in the Classroom implementation phase of the Science Laboratory Instructional Design model which involves the conduct of practical work in the classroom with teacher guidance and feedback (Balta, 2015). There are constructivist ways of providing learner guidance, organising the interaction among learners, and interacting with them during group learning (McComas, 2005). These and other aspects of the Classroom implementation phase can be organised using instructional models. Such models can assist teachers in sequencing and organising inquiry-based learning experiences in their classrooms (National Research Council, 2000). Thus, examples of these models are worth considering. A learning cycle is an instructional model which is often employed by many teachers in the conduct of their lessons and is useful in providing learners opportunities to engage in scientific inquiry (Dogru-Atay & Tekkaya, 2008; National Research Council, 2000). Learning cycles include the predict, observe and explain learning cycle (White & Gunstone, 1992) which can serve as a bridge between traditional and more inquiry-based teaching (Rushton, Lotter, & Singer, 2011). Also included are the engagement, exploration, explanation, elaboration, and evaluation (5e) instructional model. This is a learning cycle that makes various inquiry processes visible (Van Rens, Pilot, & Van der Schee, 2010) and assists science teachers in the structuring and enhancement of their teaching (Svendsen, 2015). The 5e learning cycle has achieved widespread success in education (Zuiker & Whitaker, 2014). In this paper, we find the phases of the 5e learning cycle useful in providing a detailed description of the teaching practices in the Classroom implementation phase of the Science Laboratory Instructional Design model.

In the engagement phase of the 5e learning cycle, the teacher engages learners in short and simple activities designed to assess their prior learning, promote curiosity and identify any misconceptions that they possess (Bybee, Taylor, Gardner, Van Scotter, Powell, Westbrook et al.,, 2006). 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). When learners formulate their own questions (in the case of open inquiry), the teacher ensures that the questions are clear and can be investigated (Ramnarain, 2011). In the exploration phase, learners use their prior knowledge to develop hypotheses, in addition to designing and planning preliminary investigations as they explore questions and possibilities, for example (Bybee, 2009). Depending on the delivery strategy selected in the Initiation phase, the scientific practices in Table 1 that could be incorporated in this instructional phase are B, C, D or E. The explanation phase gives the teacher the opportunity to make concepts, skills, and processes clear and comprehensible to learners (Bybee et al., 2006). Though this phase is teacher-led and involves direct instruction (Bybee, 2009), the teacher initially gives learners the opportunity to provide their own explanations and to portray their own understanding (F in Table 1) and skills, before introducing scientific terminology and explanations (Bybee, 2009; Bybee et al., 2006). Regarding the elaboration phase, the teacher encourages learners to apply their learning to explore further, carry out a new activity or solve a numerical problem (Bybee, 2009). Practice G in Table 1 could be incorporated in this phase or in the next phase. In the evaluation phase of the 5e learning cycle, the teacher encourages learners to reflect on their new understandings and abilities while providing feedback (Bybee, 2009; Bybee et al., 2006). However, this informal evaluation runs across all the phases of the learning cycle (Bybee et al., 2006) and is formative evaluation. In the evaluation phase of the 5e model, the teacher also formally evaluates the progress of learners towards the attainment of intended learning goals (Bybee, 2009). This is summative evaluation which could be addressed in the next phase of the Science Laboratory Instructional Design (SLID) model which is the Evaluation phase.

2.3.5 Evaluation-phase practices.

Regarding the Evaluation phase of the SLID model, Balta (2015) notes that it responds to the fact that during the Classroom implementation phase, there is usually insufficient time for learners to prepare a laboratory report. However, practical work is also often reported orally in some classrooms (Ottander & Grelsson, 2006).

2.3.6 Feedback-phase practices.

In the Feedback phase, and based on the outcomes of the previous phase, the teacher could revise the group formation, delivery strategy, needs assessment, and evaluation instruments

(Balta, 2015). In general, he or she could revise the materials used in the lesson (Seel & Glasgow, 1998).

The framework of teaching practices linked to the implementation of Inquiry-Based Practical Work (IBPW) in the preceding discussion could be summarised as seen in Figure 2.

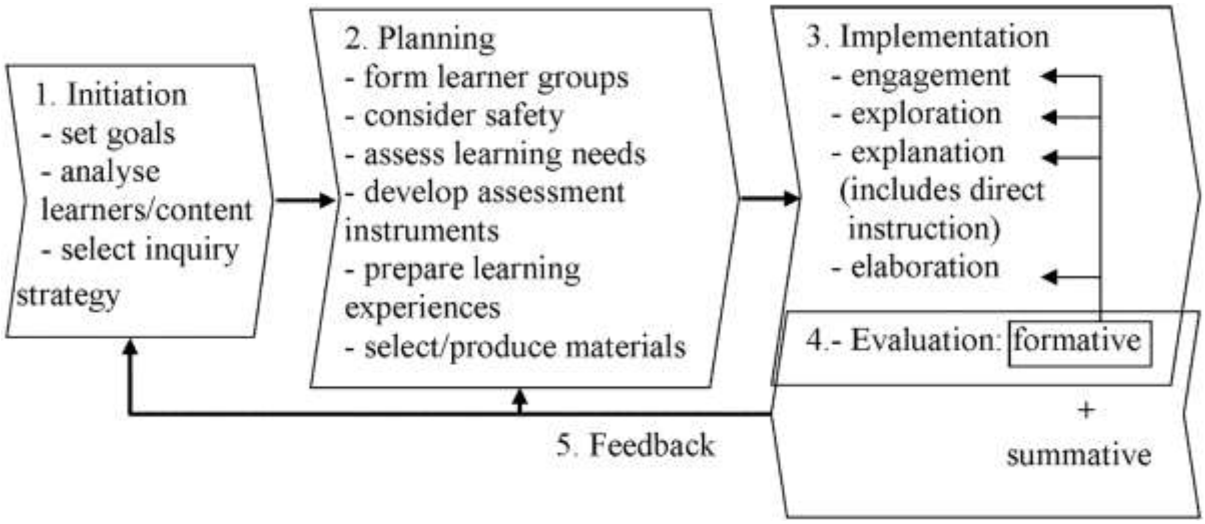


Figure 2 A framework of teaching practices linked to the implementation of IBPW

The framework in Figure 2 is useful as a basis to examine teaching practices linked to the implementation of IBPW. In this regard, we focused on the first three numbered phases in the figure.

3 METHODOLOGY

3.1 Broad educational context

Before the first democratically-elected government took over in South Africa in 1994, the then apartheid education system consisted of separate education departments for Whites, Blacks, Coloureds, and Indians. In this educational system, there was an inequitable distribution of resources among the different departments. Thus, a legacy of the system is the enormous diversity in the availability of physical resources in schools. For example, White learners mostly attend suburban schools historically reserved for White learners, located in communities with higher socio-economic status, and with generally better facilities (Department of Basic Education, 2014). In contrast, Black learners predominantly attend township schools which are poorly resourced with scant facilities for practical work in science. In this country, the term “township” generally refers to an underdeveloped urban area that, from the late 19th century until the end of the apartheid system, was reserved for “non-whites” (Chisholm & Sujee, 2006).

Against the background in the previous paragraph, ordinary South African schools are classified in quintiles ranging from one to five, based on the poverty of the community in which the school is located and also on infrastructural factors (Grant, 2013). Quintile 1 schools are considered the "poorest" and quintile 5 schools the "least poor". Quintiles 1 to 3 schools are non-fee paying schools. For the purposes of this study, we considered these schools as resource-constrained schools.

This study was conducted in Gauteng, a north-eastern province of South Africa. Despite the fact that this is the most urbanized province in the country (Department of Basic Education, 2016a), it contains schools located in socioeconomically diverse communities (Ramnarain & Fortus, 2013). In this province, the percentage of public schools that are no-fee paying schools was 73.4% in 2011 (Department of Basic Education, 2012), while the learner-school ratio for ordinary public schools in Gauteng was 983 in 2016 (Department of Basic Education, 2016b).

3.2 Research strategy

In order to gather data, we used a case-study research strategy. This strategy is useful when observing a spatially restricted phenomenon (Gerring, 2007), while reporting and engaging with the complex settings of educational practice (Chadderton & Torrance, 2011) at a given point in time. The case selection criteria we used were based on the income level of the surrounding community, potential teacher access to a range of resources useful in Inquiry-Based Practical Work (IBPW) and the educational level (age of learners). In this last regard, we focused on high schools. Learners in these schools lie in the age range twelve to twenty years within which they normally gain most of their basic knowledge of science (Rutten, van Joolingen, & van der Veen, 2012). In order for participating teachers to be able to access a range of resources useful in IBPW (including interactive computer simulations), we used the Electronic Schools Project being piloted by the South African Department of Education in the province of Gauteng. In this project, there are seven high schools, in each of which computer technology for teaching and learning has been deployed by government. The technology includes tablet computers for all learners, Internet access, and interactive boards (E-boards). Teachers have been called upon to use simulations and/or other technological tools to support hands-on practical investigations in order to allow learners to better understand essential concepts in science (National Research Council, 2005).

Based on the case selection criteria we initially shortlisted all three quintile three high schools in the project, thereby eliminating high schools of a low quintile ranking. The elimination of these schools, which are poorer, was due to the fact noted by Nompula (2012) that many science teachers in resource-constrained South African schools who do not carry out inquiry in the classroom blame this on the lack of resources. That being said, the principal of each of the three selected schools consented to the participation of their school in this study. However, following a visit to each of the three shortlisted schools, we retained only two, based on proximity. This was in order to allow participating physical sciences teachers to more easily come together for a lesson study-based professional development process at a later stage.

The two selected schools (herein referred to as School O and School P) were both ordinary public secondary no fee-paying schools. There were more than 125 such school in

Gauteng in 2013 (Education Management Information Systems, 2014b). In School O and P, it was only the practical component of physical sciences education that was of interest in this study. Physical sciences, which is taught in high school in Grades 10, 11 and 12, consists of topics in physics and chemistry. The new Curriculum Assessment and Policy Statement document (Department of Basic Education, 2011b) states that physical sciences is a subject that "promotes knowledge and skills in scientific inquiry and problem solving; the construction and application of scientific and technological knowledge; an understanding of the nature of science and its relationships" (p.8). Though the selected schools teach this same curriculum, School O has a functional school-based science laboratory, while School P lacks one. What used to be the science laboratory of School P is now being used as an office for teachers with the available equipment stored in cupboards in this office. Physical sciences teachers in School O plan and carry out practical work all by themselves. This is unlike their counterparts in School P who plan and carry out practical work in collaboration with a demonstrator from a partner institution. The non-profit institution, among other services, provides a resource centre which serves as a platform for the borrowing and returning of science education equipment and materials, in addition to running mobile laboratories for schools that are severely resource-constrained or in rural areas (The Skills Portal, n.d). Thus, though in different ways, physical sciences classrooms in both Schools O and P could access science education equipment and materials.

All study participants provided informed consent to voluntarily participate in this study. The consent was granted based on consent letters in which we committed ourselves to abide by the principles of voluntary participation, informed consent, safety in participation, privacy, and trust. These concepts are described in the research literature (including Bryman, 2001 citing Diener & Crandall, 1998; Lodico, Spaulding, & Voegtle, 2006). Participating educators consist of two teachers in School O (both females) as well as four teachers (all males) and one demonstrator (male) in School P. Though one of the teachers refrained from providing his biographical information, the other educators had at least an undergraduate degree in science education or a degree in science coupled with a postgraduate certificate in education. In the South African qualifications framework, a teaching degree is a four-year qualification obtained through study at a university, whereas a teaching diploma is a three-year qualification achieved from a teacher training college (Ramnarain, 2014). Considering a teaching diploma or an education degree as the minimum teaching qualification (Ramnarain & Fortus, 2013), the participants in this study are thus qualified educators. This is not always the case in South Africa. The qualification of South African science teachers is generally low (Reddy, 2004). That being said, the participating physical sciences teachers were all full-time teachers in a combination of grades from 10 to 12 at their respective schools. Two of the teachers were the head of the physical sciences departments in their respective schools. The teachers who provided biographical information had teaching experiences of two, five, sixteen and nineteen years. All six classrooms in which these teachers were teaching during this study were used in the study. The class size ranged from 29 to 53, the average being forty learners. The provincial learner-teacher ratio in 2016 was 32.5 (Department of Basic Education, 2016b). That being said, parents/guardians of participating learners provided voluntary consent for the learners to participate in this study, based on consent letters that we sent through the learners.

3.3 Data collection

The case study approach used in this study allowed for the employment of a multi-method qualitative research methodology (Saunders & Tosey, 2013) in the data collection. This methodology was adopted to allow for the complementation and/or corroboration of the findings from the individual data collection methods. The methods include interviews with the six teachers. However, reliance on data obtained from teachers is inadequate in understanding their practice due to self-protection (O'Sullivan, 2006). Thus, the demonstrator was also interviewed. In addition, we used classroom observation, and the collection of learner worksheets for analysis. This combination of data collection methods allowed us to examine teaching practices linked to the initiation, planning, and implementation of practical work. Also, the use of multiple data collection methods and sources provided triangulation, thereby contributing to the validity of the results of this study. Details regarding the data collection methods follow.

3.3.1 Classroom observation.

Eight practical lessons were observed in the six participating classrooms. Though we intended to observe more lessons, this was difficult to achieve as ten practical lessons were cancelled by teachers for various reasons including learners going on a trip and inadequate science education equipment and materials, in addition to the involvement of learners in a tree planting exercise. Due to such demands of daily school life and in line with the ethical principle of safety in participation, the observations were on appointment basis. On this basis, the teachers were better prepared for the observation of their practical lessons, though they were not aware of the contents of the Observation Protocol. What they knew from their consent letters about the observations and the entire data collection was that it was part of a needs assessment linked to the challenges involved in implementation of inquiry-based practical work. That being said, the same researcher observed the lessons, thus allowing for consistency in the observations. However, one lesson could not be observed due to the fact that this researcher could not reach the next school in time.

The observations were based on an Observation Protocol. This protocol was designed for the purpose of this study by the first author. The validity of the protocol was addressed through the design of items in line with the components of the framework of teaching practices linked to the implementation of Inquiry-Based Practical Work (IBPW) that is a component of the conceptual framework of this study. The protocol, which was then discussed with the second author, was semi-structured. Items on the protocol which pertained to the initiation and planning of practical work included: 1) What is the nature of the simulation (if involved)? (Urban-Woldron, 2009) and 2) What is the intended learning outcome as specified to learners? (National Research Council, 2005). Implementation phase items in the protocol included: 3) How are the following phases achieved (by the teacher, learners or on worksheets) a) engagement, b) exploration …e) evaluation? (e.g., Bybee, 2009). The last part of Item 3 can be seen towards the top of the excerpt of the Observation Protocol in Figure 3. The figure also shows other items for observing implementation-phase practices based on McComas (2005).

	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), Eisenkraft (2003), and 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):

Figure 3 Excerpt of observation protocol showing items and possible options

As seen in Figure 3, the items in the Observation Protocol were followed by possible options based on the related literature. This facilitated the lesson observation. For example, items were often completed simply by underlining the appropriate accompanying options.

The observations which were of the complete observer type, took place at different times in different classrooms over a period of six weeks. The observed lessons were based on different topics in physics and chemistry including the measurement of velocity, internal resistance of a battery and electrical conductivity of ionic solutions, in addition to exothermic and endothermic reactions. Prior to or following each observed lesson, the observer asked the teacher to provide information regarding the topic of previous and subsequent lessons respectively. This information, which was also recorded on the Observation Protocol for the observed practical lesson, allowed us to determine whether the practical lesson was used in concept development (inquiry-based) or had a confirmatory purpose.

3.3.2 Worksheets.

For each observed practical lesson, a copy of the worksheet used by learners was collected for analysis. In one case where the teacher used a task written on the chalk board, the task was written down by the researcher and added to the worksheets. The task and worksheets contained such evidence regarding the design of practical work as the provision of a learning goal, the presence of a central question, and the intended strategy (level of inquiry).

3.3.3 Teacher and demonstrator interviews.

The seven interviews were conducted with the help of two Interview Protocols developed for the purpose of this study in a similar manner as the Observation Protocol. The Interview Protocol for teachers contained semi-structured and open-ended items. Two of these items are as follows: 1) Tell me what you consider when designing or selecting practical work exercises so that learners can learn best and 2) What phases (steps), if any, do you follow when carrying out practical work? What usually happens during each phase (step)? The other items were designed to gather evidence regarding the experiences of participants with different resources for practical work, the involvement of learners in designing experiments to test their own ideas, how much content teachers taught prior to a specific practical work lesson, how they normally responded to learners' questions during practical work and their manner of interaction with learners involved in group work. Also included was the way they normally used computer simulations (if at all) in practical work.

The Interview Protocol for the demonstrator was designed in same manner and to reflect the items on the Interview Protocol for the teachers. However, the items in the protocol for the demonstrator were designed to gather data about the teachers and not the demonstrator himself. Two examples are as follows: 1) In what way(s) do the teachers [of physical sciences in School P] respond to the questions learners ask during practical work? 2) How do they [the teachers] normally interact with learners when the learners are working in small groups? On the Interview Protocol for teachers, this last item, for example, rather reads as follows: How do you normally interact with learners when they are working in small groups?

The questions on both Interview Protocols thus sought to gather evidence of the usual practices of teachers in order to either complement or corroborate data from worksheets and what was observed in classroom. On top of the questions on the protocols, the interviewer asked follow-up questions for clarification and soliciting details. The interviews, which lasted about half an hour each, were audio recorded so that they could be fully transcribed.

All seven interviews were carried out only at the end of the observation period due to the fact noted by Abrahams and Millar (2008) that when interviewees consider that the interviewer has observed the practice under discussion, they provide responses that are more effectively based on realities and thus less likely to be 'rhetorical' in nature. Conducting the interviews only after all observations was also designed to prevent the interviews from influencing the teaching practices that were being observed.

3.4 Data analysis

It is worth noting first of all that though two high schools were used, the data collected was analysed as a single data set, since participants from both schools were to subsequently and jointly take part in the same lesson study-based professional development process. Prior to the data analysis, the researcher produced verbatim transcripts of the seven individual interviews and subjected them to review by participants in order to guard against researcher bias while also enhancing the validity of the findings.

In order to proceed in the data analysis, we combined two approaches to thematic analysis. The first approach is the deductive *a priori* template of codes approach described by Crabtree and Miller (1999). In this case, we developed a code book of teaching practices involved in the implementation of IBPW ahead of the data analysis. The code book was based on the framework of teaching practices summarised in Figure 2. An excerpt of this code book is contained in Table 2.

Table 2: Excerpt of code book used in data analysis

Aspect of practical work		A priori code	Code description	Data source
Design practical work	Initiation phase	- Strategy	- Strategy selected for implementing PW: confirmatory or inquiry-based (investigation). Including whether PW precedes or follows concept development. - If inquiry-based, the degree of openness offered by the task in terms of Table 1	-IPT2[1], IPT11, WS[2], OP0[3] -OP Just before 0, WS, IPD2[4]
	Planning phase	- Preparing materials	- Deciding on when to use interactive computer simulations and discriminating between them - Whether hands-on equipment and materials are selected and/or designed and produced for use	-OP1b and c, IPT3a, b, IPD3a, b -IPT4, IPD4
Implement practical work	Engagement phase	- Inclusion - Execution	- Whether phase is included in the implementation of PW - How phase is implemented in terms of accessing prior learning, identifying learner misconceptions, promoting curiosity and capturing attention	-IPT5; IPD5 -OP3a
	Exploration phase	- Inclusion - Execution	- Whether phase is employed during PW - Role of learners (e.g., develop hypotheses and participate in planning investigation) - Teachers role (e.g., provides only essential procedures, serves as facilitator/provides guidance)	-IPT5, 9 and 10; IPD5,7 and 8 -OP3b, 4b and c

[1]IPTX = Interview Protocol Teacher item number X, [2]WS = Work Sheet, [3]OPX = Observation Protocol item number X, [4]ISDX= Interview Protocol Demonstrator item number X

Each teaching practice linked to the implementation of practical work in the data set was then coded as a category and assigned to the corresponding *a priori* code and phase of practical work, based on the code book. We kept a tally of each code as we proceeded across the three data sources/methods (teacher/demonstrator interviews, worksheets and classroom observation). The code book thus provided a framework within which we could proceed with the in-depth analysis of the data using the data-driven inductive approach of Boyatzis (1998).

In the inductive analysis of the data, we used the method of constant comparison (Strauss & Corbin, 1990). Thus, for each *a priori* category of practices, we compared each code with the previous codes in the same category in order to identify similar and different teaching practices in the data under that category. As an illustration, the left column of Table 3 contains four examples of codes in the Initiation-phase *a priori* category of teaching practices.

Table 3: Sample codes and inductively generated categories in the Initiation-phase practices *a priori* category

Sample codes and associated tally	Inductively generated categories of teaching practices
1. "Provided goal/title of practical work reflects a problem" e.g., "To investigate the electrical conductivities of different ionic solutions"; /	Practices linked to central problem or question
2. "Provided goal/title of practical work does not reflect a problem" e.g., "Experiment Exothermic reactions"; ///// //	
3. " Lesson involved structured inquiry with a central problem provided at the outset"; /	Practices associated with practical work strategy
4. "Practical lesson taught following a theory lesson in which the associated central concept was taught"; ///// //	

In Table 3, Codes 1 and 2 are similar in that they are linked to a central problem or question. Thus, the inductively generated category of teaching practices for these codes is "Practices linked to central problem or question" as seen in right column in Table 3. However, Codes 1 and 2 each differs from Code 3 and Code 4. Thus as seen in the table, Codes 3 and 4 belong in a different inductively generated category of teaching practices in the Initiation-phase *a priori* category. Proceeding as such through all the *a priori* categories of teaching practices resulted in a range of characterised and tallied teaching practices linked to the implementation of IBPW in the participating physical sciences classrooms.

Once distinct teaching practices had been characterised, the full results of the data analysis could be written as seen in the next section. However, following the full results, we present a summary in which we categorise the teaching practices as being consistent with IBPW or not (Table 4). It is useful to illustrate how we made the distinction. The first teaching practice we observed in classroom was linked to the inclusion or not of a central problem or question in practical activities. The incorporation of a central question or problem is associated with goal setting which is one of the practices in the Initiation phase of the framework of teaching practices linked to the implementation of IBPW. Thus, we determine that the inclusion of a central question or problem is consistent with IBPW and that the omission of this aspect is not.

Table 4. Summary of teaching practices consistent or inconsistent with the design and implementation of IBPW[a]

Aspect of PW[b]		**Teaching practices consistent with IBPW**	**Teaching practices inconsistent with IBPW**
Design (initiate and plan) PW	Initiation phase (problem/question, strategy)	Most observed practical activities included a goal One observed practical activity involved structured inquiry	A central question or problem is hardly included in PW At least half of observed lessons followed a theory lesson involving concept development Majority of practical lessons observed were confirmatory in design Some teachers do not pay attention to strategy, reduce level of inquiry in practical activities or favor a confirmatory strategy
	Planning phase (safety, group formation, preparing materials)	Consideration of learner safety and provision of safety equipment, respectively, reported and observed in one instance Learner groups are formed prior to practical lessons Half of the participants select and/or produce improvised resources for PW	No safety precautions on worksheets nor safety rules and practices displayed in classrooms or in the laboratory Learner groups are generally large (10 to 11 learners in one observed case) Interactive computer simulations not incorporated in PW
Implement PW	Phases of a PW lesson	More than half of the participants report observing certain so-called phases in the conduct of PW (such as checking prior learning, grouping learners, formulation of hypotheses by learners and moving through the groups)	Two teachers didn't report any specific phases used in PW One participant reported demonstrating tasks in the beginning of PW The demonstrator noted that teachers don't use any logical sequence of phases in PW
	Engagement	One teacher reported the checking of prior learning and the provision of the aim of the practical lesson in the beginning of PW	Engagement phase was not observed in practical work
	Exploration	Routine use of group work and only brief teacher-learner interaction observed in half of the lessons Monitoring progress and provision of support and guidance during group work reported by more than half of the participants	Teachers sometimes insist on strict adherence to provided procedure Teachers observed to spent a relatively long time in individual groups in some cases Teachers sometimes stop the entire class during group work

Aspect of PW[b]	Teaching practices consistent with IBPW	Teaching practices inconsistent with IBPW
	Ensuring learner safety during group work reported by a teacher	to provide information, as observed and also reported
Explanation	Phase present in most observed lessons (e.g., through learner interpretation of their observations)	Occurs before exploration phase in half of observed lessons (e.g., through information provided orally or on worksheet or learners asked to interpret expected observations
Elaboration	Phase observed once and based on a numerical problem	Use of phase not reported, but observed once
Evaluation	Practiced in all practical lessons through formative interactions and submission of a written report	No postexploration questions provided in a minority of the observed lessons

[a] IBPW = Inquiry-Based Practical Work.

[b] PW = Practical Work.

4 RESULTS

4.1 Teaching practices linked to the design of practical work

4.1.1 Initiation-phase practices

Practices linked to central problem or question.

Though in most cases the practical activities observed in classroom included a goal, it is only in one case that the goal reflected a problem. The goal was "To investigate the electrical conductivities of different ionic solutions". The worksheet or task associated with the other activities simply carried a headline such as "Experiment Exothermic reactions" and "Task: Observation of Faraday's law". Also, none of the activities were based on a specified central question. In line with this observation, no teacher mentioned considering the inclusion of a question or problem to be investigated when asked about what they take into consideration when selecting or designing practical activities. Specifically, the teachers were split in the middle between unsure and citing other factors as seen in the following respective representative excerpts:

Teacher 1: [T]here are two types – formal and informal. The formal ones you don't decide... But with the ones that are informal, what I normally go for is I look for – I sort of build a sort of a model that is going to demonstrate a certain point to them… what can I make an example of . . . [Silence]

Teacher 2: Well – the practicals that we have to do with the learners are the recommended practicals from the Department of Education... [W]hen I approach a practical activity, what I look at – "Do I have all the resources that I need?" . . . I also consider – if the resources are adequate. . . .

Practices associated with practical work strategy.

One observed lesson involved structured inquiry with a central problem provided at the outset of the worksheet. However, the majority of the observed practical lessons were taught following a theory lesson in which the associated central concept was taught. This can be seen in the following two examples of lesson sequences from the Observation Protocols.

First example:

Lesson taught before practical work: Ions in aqueous solutions

Topic of practical work: Electrical conductivity

Lesson scheduled after practical work: Precipitation reactions

Second example:

Lesson taught before practical work: Electric current (Ohm's law and Faraday's law)

Topic of practical work: Faraday's law

Lesson scheduled after practical work: Electrical power

Also, the lessons were mostly either confirmatory in design or lacked a central question or problem. In one case, the worksheet asked learners to write the hypothesis investigated not at the outset of the activity, but rather as part of the post-exploration questions. These observations are congruent with the interview data. Though one teacher reported that she sometimes uses interactive computer simulations to investigate the predictions of her learners, another teacher reduces the inquiry level in existing practical activities as seen in the following excerpt:

> *Researcher:* ... What do you consider when selecting and designing practical exercises for your lessons?
>
> *Teacher:* ... [E]ven though in our CAPS [Curriculum and Assessment Policy Statement] document they will tell you that you must do this and this and this, but before then, I will just go and do it myself and check all the parameters that I need to limit. Because it can't be just open ended. So I need to know what to expect...

Two teachers reported using only a confirmatory strategy in practical work. This is expressed in the words of one of them as follows:

> Because, to me the issue of the practical, it means you have to go through the theory before you come to the practical. For example, if I am talking about the momentum, it means I have to go straight to the momentum theoretically, after that I do linear momentum as a practical.

However, the strategy involved was not among the aspects that the majority of the teachers mentioned that they consider when selecting practical activities.

4.1.2 Planning-phase practices

Safety-related practices.

One teacher mentioned safety as an aspect that he considers when selecting practical activities for use in the classroom. In one of the observed lessons, a teacher provided rubber gloves to learners working with chemicals. However, worksheets used by these and other learners were found to lack safety precautions. Also, we observed that safety rules and safe laboratory practices were not displayed in the laboratory (in the case of School O), or in the classrooms (in the case of School P).

Practices linked to group formation.

In all observed practical lessons, teachers used learner groups formed beforehand. However, in two cases, there were only two groups in a classroom consisting of 40 and 44 learners respectively.

Practices when preparing materials.

While a participant noted that she uses interactive computer simulations only in the absence of a conventional laboratory, this teacher did not provide any criteria she uses to discriminate between potentially useful simulations. The incorporation of interactive computer simulations in practical work was not observed in any of the participating classrooms. This observation was confirmed by the demonstrator in the case of School P as seen in the following interview excerpt:

> *Researcher:* ... Aren’t teachers and learners using these tablets in practical work?
>
> *Demonstrator:* … they [tablets] are not being used for practical work. They are just being used as textbooks …
>
> *Researcher:* Is it because the teachers do not find them useful, or is there something else that stops them from using the tablets in practical work?

Demonstrator: 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 …

However, the selection and production of improvised equipment was widely observed and/or reported amongst participants. Improvised equipment observed during one practical lesson consisted of steel nails used in the place of carbon rods that were not available. In two other instances, observation revealed the use of small-scale experiments and a runway intended for a different experiment. Also, a teacher reported using disposable cups to produce beakers, in addition to the rather unsuccessful use of a commercially available washing agent containing ammonium nitrate in an attempt to enable learners to experience endothermic reactions. Also reported was the acquisition of balloons for use in collecting hydrogen gas.

4.2 Teaching practices linked to the implementation of practical work

4.2.1 Practices associated with the use of instructional phases.

Two participating teachers did not identify any phases of a practical lesson when asked. The other teachers reported various sets of phases that they use in their practical lessons. In one case, the phases are the gathering of requirements by learners, the formulation of hypotheses, and the carrying out of instructions. Other phases reported consist of demonstrating the task at the beginning of a lesson, grouping learners, checking prior learning, providing the aim of the lesson, and moving through the different groups or stations. The following excerpt includes the response of the demonstrator regarding instructional phases that teachers of School P use in practical work:

> *Researcher:* I am also interested in learning from your experience in terms of the phases or the steps that teachers of this school use when they are carrying out practical lessons.
>
> *Demonstrator:* ...There is no sort of scientific way in terms of moving ... from the known to the unknown… [L]earners are just grouped in class and then the teacher will give instructions and you'll see that he or she might not even understand what is supposed to be done. And then at the end of the day it becomes a bit of a confusion and instead of the steps being logical, learners end up getting lost and then they wouldn't know where they are coming from and where they are going...

However, we also projected the teaching practices of participants that are linked to the implementation of practical work against the 5e instructional model.

4.2.2 Engagement-phase practices.

This phase was missing from all the observed practical lessons. However, one teacher reported the checking of the prior learning and the provision of the aim of the lesson as phases of a practical lesson.

4.2.3 Exploration-phase practices.

This phase of the 5e model was present in all the practical lessons that were observed. Activities that teachers were observed to carry out in this phase of the lesson included putting learners in groups and engaging the learners in small group work, in addition to moving around and interacting with different groups. In two instances, the teacher stayed relatively long with certain groups.

In terms of the contents of the teacher-learner interaction during group activities, the interviews with individual teachers revealed that this included listening to conversations, checking what learners were struggling with, and then telling them what to do (mostly without performing the action). Also included is the provision of feedback using guiding questions and indirect answers, in addition to scaffolding struggling learners as seen in the following interview excerpt that represents the views of two teachers.

> *Researcher:* ... [L]et me ask in what ways you respond to the questions that learners ask you during practical work.
>
> *Teacher:* If they're asking me a question that is going to give away the whole point of the experiment – like something they are trying to check for – I wouldn't answer them, but if it is a question that helps them in doing the – let's say they don't know how to move from point A to point B, then, yeah, I could try to assist them.

Other reported teaching practices occurring during this instructional phase consist of monitoring progress and ensuring learner safety. Other reported teaching practices are ensuring that learners strictly (or closely) carry out the procedure for the practical activity in order that they "can at least achieve near to the required result" and scaffolding struggling learners. As observed and also reported, teachers sometimes stop the entire class during group work in order to provide additional information or to see that learners do what the teachers want them to do.

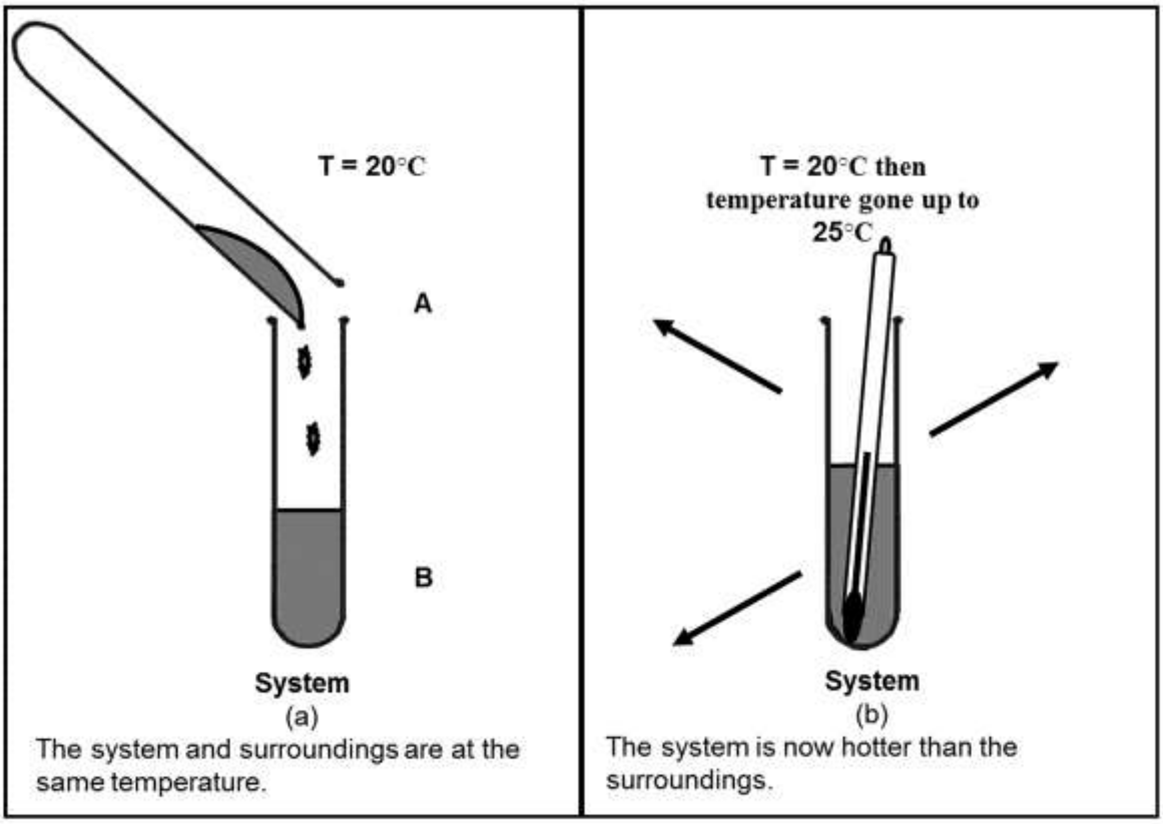
4.2.4 Explanation-phase practices.

This phase was observed in the position it occupies in the 5e learning cycle only in a minority of the practical lessons. In one of the lessons, the teacher asked different learner groups to interpret their observations to the class. However, in the majority of the lessons, the teacher made the expected results and their interpretation available to learners at the beginning of the lesson either orally or through the worksheet. For example, one teacher held a questioning session involving the interpretation of the expected observations prior to the exploration phase of the lesson. In a similar light, another teacher used a worksheet containing the expected results and the explanation as seen in Figure 4.

1. Prepare the following solutions:

A = Sulphuric acid (0.1 M)
B = Sodium hydroxide. Prepare the NaOH solution by adding 10 g to 50 ml water

2. Follow the instructions as shown in the drawing.



The reaction has made the temperature of the system go up. The energy exchange is from the system to surroundings – the reaction is exothermic.

Figure 4 Extract of worksheet containing expected observations and the explanation

An explanation formulated like the one at the bottom of Figure 4, but on endothermic reactions, was written on a worksheet used in a practical lesson in another classroom.

4.2.5 Elaboration-phase practices.

This instructional phase was present in only one of the observed practical lessons. The phase was implemented using a numerical problem that was done in the classroom.

4.2.6 Evaluation-phase practices.

All of the practical lessons that were observed included this phase through formative interactions between the teacher and the learners, especially during group learning. Also, most of the observed lessons had post-exploration questions on worksheets. Learners were to provide their answers to these questions in a report to be submitted after the practical lesson (summative evaluation). However, in two of the observed lessons there were no post-exploration questions for learners, neither on the worksheet nor otherwise given.

Having thus presented the entire results and in order to more concisely respond to the research question, we could summarise the results as shown in Table 4.

5 DISCUSSION AND CONCLUSION

In this study, we examined the extent to which teaching practices linked to the implementation of practical work in selected resource-constrained South African physical sciences classrooms are inquiry-based. The purpose of the study was to draw on the results to inform teacher professional development practice and research. Regarding the results, the third column of Table 4 contains teaching practices that are consistent with the implementation of Inquiry-Based Practical Work (IBPW). However, some of these practices have a low level of implementation. For example, structured inquiry and the elaboration phase of practical work were observed in only one out of eight lessons. In addition, the results show that in practical work, teachers are hardly calling upon the range of scientific practices (such as designing an investigation and formulating conclusions/explanations) advocated in reform and curricula documents in South Africa and internationally. Moreover, column four of Table 4 contains teaching practices that are inconsistent with IBPW.

With these results, this study contributes in responding to Lin et al. (2013) who noted the lack of empirical evidence on how teachers translate inquiry in practice. In this regard, the results show that in the studied resource-constrained South African physical sciences classrooms, the implementation of inquiry in practical work is largely inadequate. Also, the results enhance the picture regarding the level of implementation of inquiry in practical work in South African high schools. In a previous case study of two physical sciences teachers from metropolitan South African high schools, Dudu and Vhurumuku (2012) found that while one operated at Level 0 (Confirmation) inquiry, the other was at Level 2 (Directed) inquiry. In the present study of two resource-constrained high schools, almost all of the eight observed lessons involved Level 0 (Confirmation) inquiry. In addition to studying more teachers and focusing on high schools in a different socioeconomic context, this study differs from that of Dudu and Vhurumuku by considering the initiation and planning of practical work, and not just its classroom implementation. The results of this in-depth study also complement those of Ramnarain and Schuster (2014). Their survey partly showed that physical sciences teachers in South African schools in communities with low socio-economic status exhibit a strong orientation toward expository science instruction followed by confirmatory practical work. A similar orientation was observed in practical work in classes 9 to 12 in Bhutan (Childs, Tenzin, Johnson, & Ramachandran, 2012). While this study largely confirms this orientation, it reveals the kind of teaching practices that could be found in the classrooms of teachers with such an orientation.

While enhancing understanding as discussed in the previous paragraph, this study has theory-, practice-, and research-based implications. Regarding theory, the results support the extension of the Interconnected Model of Teachers' Professional Growth (IMTPG, Figure 1) through the addition of teaching practices in the personal domain of the model. In this regard, the results as reflected in Table 4 show a variation in teaching practices among the participants. For example, while only *one* teacher reported the checking of prior learning, *half* of the participants selected and/or produced improvised resources, and *most* observed practical activities that included a goal. The variation is evidence that teaching practices are a personal (individual) teacher characteristic. That being said, the incorporation of teaching practices in the personal domain of the model enabled this study to add to the existing theoretical uses of the IMTPG in science education research. Previous uses include Eilks and Markic (2011) and Kafyulilo, Fisser, and Voogt (2015).

Regarding the practice-based implication of this study, it is useful to first of all note in line with Bybee (1993) that, if the practices of teachers do not mirror curriculum innovations, the process of curriculum change wavers and ultimately fails. Though the third column of Table 4 suggests that the infusion of inquiry in practical work in South African physical sciences education has not failed, the fourth column suggests that this curriculum innovation is wavering in the study context. The results thus support and inform the implementation of the point noted by Pretorius, De Beer, and Lautenbach (2014) that the emerging pedagogy of South African science teachers needs urgent attention and that this can be addressed through focused professional teacher development programmes. In addition, Pretorius et al. lamented that professional development programmes in South Africa did not always address the needs of teachers. Column three of Table 4 to a lesser extent and column four to a greater extent, reflect the professional development needs of participants in relation to the implementation of IBPW. The results of this study could thus contribute in addressing the need and the shortcoming in science teacher professional development practice noted by Pretorius et al. Teacher professional development falls in the external domain of the model in Figure 1 which calls for information, stimulus, and support from outside the professional world of practice of science teachers. In Table 4, teaching practices that are consistent with the implementation IBPW, but with a low level of implementation in practical work, in addition to those that are inconsistent with the implementation of such practical work, span across the Initiation, Planning and Classroom implementation phases of the Science Laboratory Instructional

Design (SLID) model. In the Classroom implementation phase, the practices occur across three of the phases of the 5e instructional model. Thus, the SLID and 5e models could be introduced to participants as tools during their professional development. When the 5e instructional model is implemented in professional development programmes, this allows teachers to design their own inquiry-based science lessons (Zwiep & Benken, 2013). However, based on the Interconnected Model of Teachers' Professional Growth (IMTPG) in Figure 1, the teachers also need to enact the lessons that they have designed in the classroom and reflect upon their experiences. This could give rise to changes in the domain of consequence of the IMTPG, in terms of teaching practices.

It is however worth noting that, as per the IMTPG, efforts to enhance the teaching practices of the studied physical sciences teachers need to consider the constraints and affordances of the enveloping change environment. In this regard, a previous study of the same schools and teachers revealed the existence of microsystem- and microsystem-level material- and non-material-related extrinsic challenges linked to the implementation of IBPW (Author, 2001). The challenges include a mandatory content-focused work plan, inadequate supplies of science education equipment and materials, and the inaccessibility of interactive computer simulations. It would be beneficial to address these extrinsic teaching challenges ahead of any efforts to enhance the teaching practices of participants in the implementation of IBPW. In addition, prior attention needs to be paid to such systemic issues linked to South African teacher professional development as time allocation and extrinsic motivation (Author, 2001). Regarding such motivation, the South African Council of Educators runs a point-based system for monitoring teacher professional development (Department of Basic Education, 2011a). The aim of the system is to encourage teachers to participate in professional development, as job retention is linked to points gained by an individual teacher over several years. We encourage professional development providers to consider incorporating the results of this study in their programmes as suggested in the discussion in this paragraph.

Though the results of this study could contribute in informing professional development efforts as seen in the preceding discussion, in this regard, the results are however limited in their scope and cannot be generalised. Specifically, though resource-constrained physical sciences classrooms exist elsewhere in South Africa (Singh & Singh, 2012) and in other countries including the United States of America (Anderson, Anderson, Borriello, & Kolko, 2012) and India (Raval, McKenney, & Pieters, 2014), the results of this in-depth study cannot be generalised over teachers in these other classrooms. In scope, the study was limited to teaching practices linked to the initiation, planning, and implementation of practical work. This left out the summative evaluation and feedback phases of practical work design reflected in Figure 2. In order to address these limitations, similar studies could be carried out in South Africa and even internationally. These are the research-based implications of this study. We see that, in order to enhance teaching practices linked to the implementation of IBPW across many science classrooms in South Africa and also in other countries, a multi-stakeholder perspective involving researchers and professional development practitioners is needed.

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CONFLICT OF INTEREST STATEMENT

We are not aware of any financial interests regarding this research or any financial benefits that could result from the use of the data.

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