Characterising extrinsic challenges linked to the design and implementation of inquiry-based practical work

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Abstract

Inquiry-based science education has been incorporated in science curricula internationally. In this regard, however, many teachers encounter challenges. The challenges have been characterised into those linked to the personal characteristics of these teachers (intrinsic challenges) and others associated with contextual factors (extrinsic challenges). However, this level of characterisation is inadequate in terms of appreciating the complexity of the challenges, tracking of their development, and discovering knowledge within specific categories. Against this background, the purpose of the research presented here was to characterise extrinsic challenges linked to the design and implementation of *inquiry-based practical work*. In order to do so, we used a conceptual framework of teaching challenges based on Bronfenbrenner's ecological theory of human development. The data gathered using a multi-method case study of practical work in two South African high schools, was analysed by combining the data-driven inductive approach and the deductive *a priori* template of codes approach in thematic analysis. On this basis, the extrinsic challenges linked to the design and implementation of inquiry-based practical work that participants are confronted with, were found to consist of macrosystem challenges (such as a restrictive curriculum) and microsystem challenges. At the latter level, the challenges are material-related (e.g., lack of science education equipment and materials) or non-material-related (such as time constraints and the lack of access to interactive computer simulations). We have discussed the theory-, practice- and research-based implications of these results in relation to the design and implementation of inquiry-based practical work in South Africa and internationally.

Keywords

Inquiry-based practical work; Extrinsic teaching challenges; Characterisation; Bronfenbrenner's ecological theory

Introduction

The purpose of the research presented here is to characterise extrinsic challenges linked to the design and implementation of inquiry-based practical work (IBPW). However, we begin with an overview of practical work in school science, leading up to how the term IBPW is understood in this paper.

Overview of Practical Work in Science Classrooms in Schools

Part of the literature (e.g., Hofstein & Mamlok-Naaman 2007; Tobin 1990) is unclear about the effectiveness of practical work in enhancing the conceptual understanding of learners. Nevertheless, practical work is considered by many people as a key aspect of science education and is implemented in schools in many countries around the world (Abrahams & Millar 2008; Harlen 2010). This is not surprising as this strategy in science education serves learners' needs in a number of ways. For example, a survey involving 3626 ninth-year learners about their opinions regarding how chemistry and physics (in this case, physical science) are taught yielded demonstrations and practical work as the second most popular group of teaching methods (Lavonen et al. 2004). Through practical work, teachers can support their students in the creation of understandable and meaningful knowledge (Lavonen & Laaksonen 2009). Thus, Secker and Lissitz (1999) found that practical work can positively affect the achievement of science learners.

The lack of unanimity in the science education community regarding practical work is not limited to its usefulness in conceptual development. The same is true of a definition of practical work, in addition to an approach and the resources that could be used in its implementation. Thus, it is useful to consider the different perspectives. Amongst other aspects, this allows IBPW to be clarified as the type of practical work on which this paper focuses.

According to Millar (2011), practical work consists of experiences in which learners observe and/or manipulate physical objects and materials, in contrast to virtual objects and materials. In light of this, Sweeney and Paradis (2004) note that learners cannot fully understand the essence of scientific inquiry without having opportunities in which they acquire data themselves prior to analysing this data. At the same time, practical work may not be restricted to traditional laboratory experiences, considering for instance that computer-based learning can be more effective in some situations (Hodson 1998). In this regard, interactive computer simulations are useful. These are computer applications which allow users to manipulate a computer representation of a theoretical system or the natural world (Weller 1996). These applications allow learners to observe phenomena including those that are dangerous to manipulate directly, that are too large, invisible or too expensive (Fan & Geelan 2012; Khan 2008; National Research Council 2005).

In addition to computer-related objects and materials, improvised Science Education Equipment and Materials (SEEMs) are another type of objects and materials useful in practical work in science classrooms in schools. Improvised SEEMs include equipment created by resourceful teachers from basic materials for use in combination with these basic materials in practical work (e.g., Ndirangu et al. 2003; Ogoh 2014). This is useful when conventional hands-on SEEMs are less environmentally friendly, lacking, too hazardous to use in the classroom or suitable in teacher demonstrations only (Di Fuccia et al. 2012; Ens et al. 2012; Ogoh 2014; Poppe et al. 2011; Rettich and Battino 1989). In light of the preceding discussion, we see that hands-on conventional and improvised SEEMs complement each other and computer-based SEEMs (e.g., interactive computer simulations) in practical work. In light of this, reformers advocate the use of hands-on practical investigations supported by simulations and/or other technological tools in order to allow learners to better understand essential concepts in science (National Research Council 2005; Schneider et al. 2005).

Against the background previously discussed, practical work could be defined as experiences in which learners interact with materials or secondary sources of data (including computer-based sources), in view of observing and understanding the natural world (Lunetta et al. 2007). However, 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 2005). Thus, it can be considered that for the purpose of observing and understanding the natural world, practical work may involve hands-on experiences as well as the manipulation of computer-based (such as simulated) materials and equipment, in addition to existing data sets.

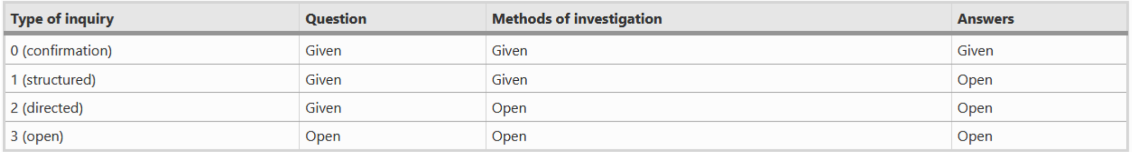
Many approaches are available for implementing practical work. These approaches range from a worksheet/teacher-driven to a learner-driven approach (Kidman 2012). Based on the former approach, learners execute procedures given to them by their teacher, with limited thought and without much purpose (Anderson 2007; Kim & Tan 2010). As such, they focus on task completion at the expense of thinking about the global goals and the learning outcomes (Schamel & Ayres 1992). Although adequate for developing basic skills such as observation, collecting and organising data, in addition to making inferences (Zion & Mendelovici 2012), this approach to practical work (which is in line with the transmission-oriented approach in science education) has thus been criticised for not reflecting the work of actual scientists (McComas 2005). As a result, there have been reforms around the world focussing on practical work in science classrooms (Gott & Duggan 2007). The reforms are in favour of the infusion of inquiry-based teaching and learning in practical work. Many people (e.g., Kennedy 2013; Sadeh & Zion 2012) recommend that the inquiry-based teaching strategy be combined with other strategies (e.g., direct instruction) in science classrooms. This is despite a number of perceived drawbacks linked to the implementation of inquiry-based science education. For example, some teachers have safety concerns and fear losing classroom control (Deters 2004). Teachers also have concerns linked to time constraints and the grading of learners engaged in inquiry (Anderson 2007; Deters 2004). However, inquiry-based teaching has a positive effect on learning in terms of allowing learners to better understand scientific procedures and concepts than rote learning (e.g., Lee & Krapfl 2002; Minner et al. 2010). In addition, inquiry-based teaching increases learner interest, motivation and their engagement in science (National Research Council 2005; O'Neill & Polman 2004). Furthermore, inquiry-based teaching and learning is seen as reflecting the practices of actual scientists (Dudu & Vhurumuku 2012).

There are several inquiry-based learning practices that reflect the practices of actual scientists. These practices include engaging science learners in investigating the natural world as they pose researchable questions, investigate the questions, in addition to formulating evidence-based explanations and justifications of their assertions (Hofstein & Lunetta 2004; Quintana et al. 2004). 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). These science learning practices have recently been reformulated by reformers (National Research Council 2012).

The reformulated practices include asking questions, developing and using models, planning and carrying out investigations, analysing and interpreting data, constructing explanations and engaging in evidence-based arguments. These practices are echoed in the New Generation Science Standards (NGSS, NGSS Lead States 2013) which advance a vision of scientific literacy based on an understanding of not only core disciplinary ideas but also crosscutting concepts. The standards also promote skills and knowledge linked to scientific and engineering practices. For example, based on the NGSS, scientific investigations begin with a question and scientific knowledge is tentative, in addition to being based on empirical evidence.

In terms of allowing learners to experience the previously discussed reform-based learning practices, different inquiry-based teaching strategies are not equally capable. Various categorisations of the teaching strategies exist. The categorisations include the levels of openness framework (Herron 1971; Schwab 1962). This well-known categorisation (McComas 2005) considers four categories of inquiry-based teaching strategies, numbered 0, 1, 2 and 3, respectively. The categories are described in Table 1 in terms of the combination of elements that the teacher provides the learners. The names for these categories (confirmation, structured and so on) also included in the table are based on Bell et al. (2005) who provide descriptive names in the place of the numbered categories.

Table 1. Categorising school-based inquiry (Bell et al. 2005; Herron 1971; Schwab 1962)



Type 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

Based on Table 1, there are four categories of inquiry-based teaching strategies: type 0 (confirmation), type 1 (structured), type 2 (directed) and type 3 (open). The table is useful in clarifying the term IBPW as used in this paper. In light of this, we use the term IBPW to refer to practical work involving one or more of the last three types of inquiry in Table 1. Such practical work allows combinations of the previously enumerated inquiry-based learning practices to be incorporated in practical work. Specifically, we use the following understanding of the term IBPW in this paper (Akuma 2017):

Inquiry-based practical work (IBPW) consists of experiences in which learners collaboratively manipulate hands-on SEEMs and possibly computer-based SEEMs and existing data sets as well, in order to gain an understanding of the natural world, as they engage in inquiry-based learning practices through structured, directed or open inquiry. Thus, in our understanding of IBPW, we exclude practical work that is limited to type 0 (confirmation) inquiry. This is because such practical work is in line with the teacher/worksheet-driven approach to practical work, which though useful in developing certain basic skills, has been criticised as discussed earlier. At the same time, in using the term IBPW, we consider the term *inquiry* as used in the United States to be identical to the term *investigation* as used in the United Kingdom for instance.

Investigations (inquiry-based practical work) can be beneficial to learners in several ways. This is despite the fact that in a number of studies on the effect of inquiry-based science instruction, investigations were statistically significant negative predictors of science achievement (Areepattamannil 2012; Areepattamannil et al. 2011; Lavonen & Laaksonen

2009). For example, Areepattamannil (2012) found that the use of models or applications (an inquiry-based learning practice) is a statistically significant positive predictor of interest in science and science achievement. Many studies have shown that investigations (in this case, IBPW) and hands-on science activities are capable of enhancing such higher-order learning skills of learner as argumentation and metacognition (e.g., Conklin 2012; Dori & Sasson 2008; Dori et al. 2004; Kipnis & Hofstein 2008). In fact, inherent in investigations and hands-on activities is the "potential to enhance students' conceptual and procedural understanding, their practical and intellectual skills, and their understanding of the nature of science" (Hofstein et al. 2008, p. 59). In addition to the cognitive benefits, investigations (IBPW) have affective benefits for learners. For example, investigations and hands-on science activities support learners in the development of a positive attitude towards science and in sustaining their motivation (Hofstein & Mamlok-Naaman 2007; Osborne and Dillon 2008). Against the background previously discussed, this paper focuses on inquiry-based teaching and learning in the context of practical work (IBPW).

Purpose and Rationale of Paper

Inquiry-based teaching and learning have been recommended by many reformers and infused internationally in science curricula in general and especially in practical work (Gott & Duggan 2007; Kidman 2012; National Science Teachers Association 2007). In this regard, South Africa is not an exception. For example, the physical science curriculum of this country partly aims at equipping learners with investigative skills in relation to physical and chemical phenomena (Department of Basic Education 2011). The skills include hypothesising, designing an investigation, formulating models, in addition to formulating and evaluating conclusions. These skills reflect the inquiry-based learning practices mentioned previously. However, in many science classrooms in this country and internationally, practical work is inadequately designed and implemented (Childs et al. 2012; Hodson 1991; Kind et al. 2011). The classrooms include South African physical science classrooms especially in resource-constrained schools (Sedibe 2011; Singh & Singh 2012). These schools which also exist in other countries are schools in communities with a low income (Anderson et al. 2012; Ramnarain 2016; Raval et al. 2014). That being said, a survey showed that physical science teachers in such South African schools exhibit a strong orientation towards expository science instruction followed by confirmatory practical work (Ramnarain & Schuster 2014).

Normally, teachers are faced with a complex and dynamic classroom environment (Leinhardt and Greeno 1986). The introduction of inquiry in the classroom increases the complexity. Thus, the design and implementation of inquiry-based (practical) science lessons are a complex process (Van Rens et al. 2010). Thus, research has shown that science teachers in South Africa and many other countries find inquiry-based instruction challenging to implement in their classrooms (Alhendal et al. 2015; Ramnarain 2011; Ruhrig and Höttecke 2015). The challenging nature of inquiry-based science instruction can cause teachers to avoid or resist curricular reforms linked to inquiry (Ritchie et al. 2013).

With reference to physics education, Nivalainen et al. (2010) noted the lack of a comprehensive description of the challenges that teachers face when planning (designing) practical work. Similarly, other researchers (such as Crawford 2007) have argued that the literature does not present a clear picture of just how challenging it is to implement inquiry in science classrooms (in this case, during practical work). Some studies in reform-based science education (such as Ødegaard et al. 2014; Roehrig & Luft 2004), have mostly been limited to identifying the inherent challenges. However, researchers have noted that an understanding of the challenges that science teachers encounter is needed in order to appropriately support them in relation to the challenges (Davis et al. 2006; Harris & Rooks 2010). This is in line with Goldman (2005) who noted that an improved understanding of the circumstances that facilitate or (in this case) impede change is useful towards the design and sustenance of improvements in the field of education. Here the focus is on the constraining circumstances (teaching challenges).

The detailed characterisation of a phenomenon (in this case, teaching challenges) is useful in revealing its complexity and also in tracking its development (Rozenszajn and Yarden 2014). This is in addition to providing value and coherence (El-Deghaidy et al. 2015). Moreover, the identification of discrete categories of a concept (in this case, the challenges) is useful to researchers as they can then design research instruments to uncover knowledge within the specific categories (Abell 2008). In the context of the production and/or use of improvised SEEMs internationally (Akuma & Callaghan 2016) and also in relation to the implementation of inquiry-based science education in schools in low-income communities (Ramnarain 2016), the teaching challenges have been characterised broadly into those linked to the personal characteristics of teachers (intrinsic challenges) and others associated to contextual factors (extrinsic challenges). Intrinsic challenges include the lack of motivation, inadequate practical skills and inadequate pedagogical content knowledge linked to inquiry (Pruitt 2014; Stephen 2015; Tsuma 1998; Zion et al. 2007). Going further, Akuma and Callaghan (2016) characterised intrinsic challenges in relation to the phases of instruction as preparation-phase, implementation-phase and assessment-phase challenges. They also considered material-related and non-material-related extrinsic challenges. However, there is limited data on the characterisation of extrinsic challenges in science education.

A number of extrinsic teaching challenges have been enumerated in the science education research literature. For example, it has been noted that teaching is affected by the curriculum, time and the availability of supplies and facilities (National Research Council 2005). In the specific case of inquiry-based science education, extrinsic challenges include large classes, school ethos, resource adequacy, professional support, in addition to limited learner ability and exposure to inquiry (Ramnarain 2014, 2016; Ramnarain & Schuster 2014). In the context of the ecological theory of human (in this case, teacher) development (Bronfenbrenner 1979) discussed subsequently, the extrinsic challenges discussed in the preceding texts reflect the physical characteristics (objects), social characteristics (persons) and cultural characteristics of the educational environment (framework). In this regard, the challenges are material-related (linked to physical characteristics such as resource adequacy) or non-material-related (linked to social or cultural characteristics such as professional support). In terms of the educational framework, the challenges arise at the school level (such as large classes and school ethos) or beyond (in the case of the curriculum).

The number, nature (material-related or not) of the extrinsic challenges and their origins (in terms of the level of the educational framework in which they arise) are indicative of the complexity involved in the design and implementation of inquiry-based science education. We also see that a characterisation of extrinsic challenges is possible, though the extrinsic challenges are not specific to Inquiry-Based Practical Work (IBPW). Thus, the purpose of the study presented here was to characterise extrinsic challenges linked to the design and implementation of IBPW. In the in-depth study, we considered the case of resource-constrained South African physical science classrooms as an example. Against this background, the research questions involved in this study consist of the following:

1. What specific extrinsic teaching challenges affect the design and implementation of IBPW in physical science classrooms?

2. What are the categories in which the challenges fall in terms of their nature and the different levels of the educational framework in which they arise?

Theoretical and Conceptual Framework

In this section, we present a theoretical basis within which the design and implementation of IBPW can be located. On this broad basis, we then consider what the design and implementation of IBPW can entail and also how the associated extrinsic challenges could be characterised in a systemic manner.

Overarching Theoretical Basis: Bronfenbrenner's Ecological Theory of Human Development

In terms of considering extrinsic factors (challenges) that can influence teacher practice and learning in the design and implementation of IBPW, a human developmental perspective involving a systemic viewpoint and person-context interrelatedness is useful as a theoretical basis. Such a basis is provided by lifespan and ecological theories of human development (Baltes 1987; Bronfenbrenner 1979). Tinajero and Páramo (2012) note that developmental theories that are in line with the systems approach in human development adopt an approach that falls on a continuum ranging from the psychobiological-developmental approach (Gottlieb 1997) at one end to a developmental-contextual approach (Lerner 1991) at the other end. Approaches on the psychobiological extreme emphasise the biological level of the system and consider other levels in a more general manner. These approaches also focus on the exchange of energy or material between subsystems. On the other hand, approaches at the developmental-contextual extreme consider both social and cognitive phenomena and tend to concentrate on the exchange of information between individuals (Lerner 1991; The Carolina Consortium of Human Development 1996). Thus, theories on the developmental-contextual extreme emphasise the context of an individual. This is the aspect of interest in this study which focuses on extrinsic teaching challenges. The work of Bronfenbrenner (the ecological theory) lies towards the developmental-contextual extreme of the continuum of system approaches to human development (Tinajero and Páramo 2012).

Ecological Theory of Human Development: Innermost, Non-Contextual Component

Based on the ecological theory, reformulated as the bioecological model (Bronfenbrenner 1979), human development occurs in an environment consisting of several nested components (levels). The innermost component consists of factors associated to the personal characteristics of the individual (herein called individual level). The characteristics include physical appearance, past experiences, intelligence and skills, in addition to the motivation and temperament of the individual (Tudge et al. 2009). In the context of this study, the individual is a physical science teacher who is expected by researchers and reform documents to routinely design and implement IBPW in the classroom. What this activity can entail is considered in the following texts. As seen earlier, inadequacies in the personal characteristics of a science teacher can cause the teacher to face intrinsic teaching challenges. However, the focus here is on the extrinsic challenges. In terms of informing the characterisation of these challenges, the other levels (components) of the human development environment are critical.

Contextual Components (Levels) of Theory

Around the individual and his/her intrinsic characteristics (the individual level) are a set of four other environmental components (levels) with which he/she interacts. The first component is any environment (such as school and peer group) in which a developing individual (in this case, a physical science teacher new to inquiry) spends a good deal of time as he/she engages in interactions and activities (Tudge et al. 2009). In this case, the activities include the design and implementation of the IBPW. This activity is illustrated subsequently. For this purpose, the teacher interacts with the curriculum, learners, colleagues and school managers for example. The immediate surroundings in which an individual normally engages in such interactions and activities have its physical, social and cultural characteristics and are called microsystem (Bronfenbrenner 1979). More specifically, a microsystem consists of persons, symbols and objects (Bronfenbrenner 1994). In order for human (in this case, teacher) development to be effective, the interaction with the elements of the microsystem needs to occur fairly regularly over an extended period of time (Bronfenbrenner 1994). In addition to the microsystem, Bronfenbrenner (1979) notes that the human development environment contains more remote components (levels) consisting of the mesosystem, exosystem and macrosystem. While the mesosystem consists of connections amongst the microsystems to which an individual belongs, the exosystem consists of the social settings that indirectly affect, though do not contain the individual. The macrosystem is the overarching context incorporating any group (microsystem) whose members share belief systems, values and resources for example (Bronfenbrenner 1993). The macrosystem has expression in a microsystem to which an individual belongs.

As seen in the following texts, the contextual components (levels) of the theory previously discussed can assist in designing a framework to characterise extrinsic teaching challenges in general. In this case, the extrinsic challenges are those linked to the design and implementation of the IBPW. Thus, we first illustrate what this activity can entail.

Design and Implementation of IBPW

Instructional Design

While acknowledging the importance of resources in inquiry-based teaching and learning, the National Research Council (2000) points out that the most important element in effective science instruction is the teacher who must design instruction in a way that enhances the learning process. This statement highlights the importance of instructional design in the teaching and learning of science, in this case during practical work. In this section, we consider how IBPW could be designed and implemented from an instructional design perspective. Instructional design involves planning from a systemic perspective with the goal of increasing the relevance and effectiveness of instruction (Merril 1996; Reiser and Dempsey 2007). However, instructional design goes beyond planning as evidenced by a number of instructional design models. One example is the Analysis, Design, Development, Implementation and Evaluation (ADDIE) model (Peterson 2003) which has been widely used (McGurr 2008). Balta (2015) combined this model with other well-known instructional design models (such as Dick et al. 2001) in order to yield the validated Science Laboratory Instructional Design (SLID) model.

How IBPW Could Be Designed

The phases of the SLID model consist of Initiation, Planning, Implementation, Evaluation and Feedback. This model can serve as a guide in the design of the IBPW. In the initiation phase, the teacher carries out an analysis of learners and content, in addition to setting goals and selecting a practical work strategy (Balta 2015). As discussed earlier in relation to Table 1, the strategy could be structured, directed or open inquiry. However, considering that the IBPW takes more time than carrying out scripted practical work (Abrahams & Reis 2012), science teachers faced with time constraints may struggle in the choice of a practical work strategy. At the same time, science curricula often focus on the mastery of science content, at the expense of the development of the investigative skills of learners (Childs et al. 2012; Dai et al. 2011; Ottander & Grelsson 2006). Thus, some teachers may struggle in order to balance content coverage and the engagement of learners in inquiry-based learning practices. That said, during the planning phase, the teacher assesses learning needs, produces assessment instruments, considers safety precautions, prepares learning experiences and forms learner groups (Airasian & Russell 2008; Balta 2015; Wiggins & McTighe 1998). Also included is the design and production of materials. These materials include worksheets, in addition to any improvised SEEMs that are needed. However, time-starved teachers could use interactive computer simulations instead of hand-on SEEMs in the face of limited resources, in addition to safety and cleaning concerns (Kirschuner & Huisman 1998; Donnelly et al. 2013; Scalise et al. 2011). However, interactive computer simulations and other ICTs cannot supplant hands-on SEEMs in practical work (Khan 2011), since giving learners the opportunity to develop their practical skills is a learning goal in itself (Rutten et al. 2012). Having prepared the practical work, the implementation phase enables the teacher to carry out the lesson in the classroom while providing feedback and guidance (Balta 2015). In this regard, the teacher could use indirect questions, hints and suggestions and needs to avoid answering the questions of learners using direct answers (Blake & Pope 2008; McComas 2005; Urban-Woldron 2009). Balta also describes the last two phases of the SLID model. The evaluation phase responds to the inadequate time normally available in the implementation phase for learners to report on their practical work. Inquiry-based practical work demands more time than scripted (confirmation) practical work (Abrahams & Reis 2012). That being said, in the feedback phase, the teacher reviews the needs assessment, the production of assessment instruments, in addition to group formation and the selection of a practical work strategy. Actually, before a teacher can find more open forms of inquiry (e.g., directed inquiry) to be practical, the teacher needs to build a foundation (Donnelly et al. 2013). Here, the foundation lies in initially incorporating less open forms of inquiry such as structured inquiry in practical work.

How IBPW Could Be Implemented

The discussion in the previous paragraph illustrates how IBPW could be designed. As seen, the designing process includes the implementation phase of the practical lesson. This phase which occurs in the classroom can be designed with reference to an instructional model. This is because an instructional model is useful to a science teacher in terms of organising and sequencing inquiry-based learning experiences in the classroom (National Research Council 2000). For fulfilling this purpose, many teachers use a learning cycle (Dogru-Atay & Tekkaya 2008). Learning cycles include the Exploration, Invention, and Discovery model (Karplus and Thier 1967) and the resulting so-called 5E instructional model (Bybee 1997). Eisenkraft (2003) extended the latter model into the 7E instructional model. However, the 5E instructional model has achieved widespread success in the field of education (Zuiker and

Whitaker 2014). Also, the phases of this instructional model match the five phases which according to the National Research Council (2000) are common to instructional models and are useful as a general guide to inquiry teaching. Specifically, the 5E instructional model consists of the phases Engagement, Exploration, Explanation, Elaboration and Evaluation. The phases of this instructional model are outlined in the literature (Bybee 2009; Bybee et al. 2006b). For example the Engagement phase involves activities (physical or mental) aimed at assessing the prior learning of learners, promoting curiosity and identifying any misconceptions that they possess (Bybee et al. 2006a). Thus, there is the need for the teacher to analyse learners in the Initiation phase of instructional design. In the Exploration phase, learners explore possibilities and questions using their prior knowledge as a basis for developing hypotheses, as well as designing and planning preliminary investigations for example (Bybee 2009). Thus, the learners have opportunities to begin engaging in the inquiry-based learning practices presented earlier.

The preceding discussion of instructional design illustrates how IBPW could be designed and implemented in the classroom as the activity of interest in the context of ecological theory. The discussion indicates that this is not a straightforward task as it involves a cyclical (iterative) process with connected phases, each with a number of elements to be considered. Next, and in line with the ecological theory, we design a basis useful in the characterisation of the inherent extrinsic challenges.

Towards Characterising Extrinsic Teaching Challenges

The human (in this case, teacher) development theory outlined previously provides a number of theoretical levels at which teachers experience their professional environment. In principle, teachers could face challenges within these different levels consisting of the individual, microsystem, mesosystem, exosystem and macrosystem levels. Considering the microsystem for example, the challenges could relate to the physical (material), social and cultural (non-material) characteristics of the immediate surroundings in which teachers engage in interactions and activities. In this case, the activities include the design and implementation of the IBPW as noted and illustrated earlier. In this regard, the teacher interacts with learners, colleagues and school managers for example. That being said, and as seen in the following texts through a number of actual categorisations, there are a number of similar levels (categories) of teaching challenges in different pedagogical contexts. One of these contexts is that of the integration of Information and Communication Technologies (ICTs) such as interactive computer simulations in learning. In this regard, Jones (2004) categorises the teaching challenges into teacher-level challenges (e.g., deciding how to use interactive computer simulations) and institutional-level challenges (e.g., time constraints). Also, teaching challenges have been characterised into intrinsic challenges (i.e., linked to an individual teacher; for example inadequate knowledge and motivation) and extrinsic challenges (i.e., linked to an organisation; for instance lack of time and training). This is in relation to the integration of ICTs in learning (Ertmer 1999), the production and/or use of improvised SEEMs in practical work (Akuma & Callaghan 2016), in addition to the implementation of inquiry-based science education in South African schools in low-income communities (Ramnarain 2016). In relation to ICT integration in learning, Balanskat et al. (2006) further note the existence of teaching challenges faced by teachers at the system-level. These are challenges related to the broader educational framework.

Against the background previously discussed, teaching challenges could be characterised as intrinsic (individual-level or teacher-level) challenges and extrinsic (institutional-level and system-level) challenges. However, the focus here is on the extrinsic challenges. In terms of the ecological theory of human development, actual extrinsic challenges occur at the microsystem level (institutional-level challenges) and the macrosystem level (system-level challenges). However, these levels (categories) of teaching challenges can be further broken down in light of Pelgrum (2001) who considered teaching challenges relating to the integration of technology (such as simulations) in the classroom as linked to a material (physical) or to a non-material (such as social) condition. Examples of these two conditions include the scarcity of physical resources and the lack of time, respectively. Material-related & non-material-related extrinsic challenges also occur in relation to the production and/or use of improvised SEEMs in schools (Akuma and Callaghan 2016).

Based on the discussion of actual categorisations of teaching challenges in relation to the ecological theory of human development, we can design the framework of teaching challenges in Fig. 1.

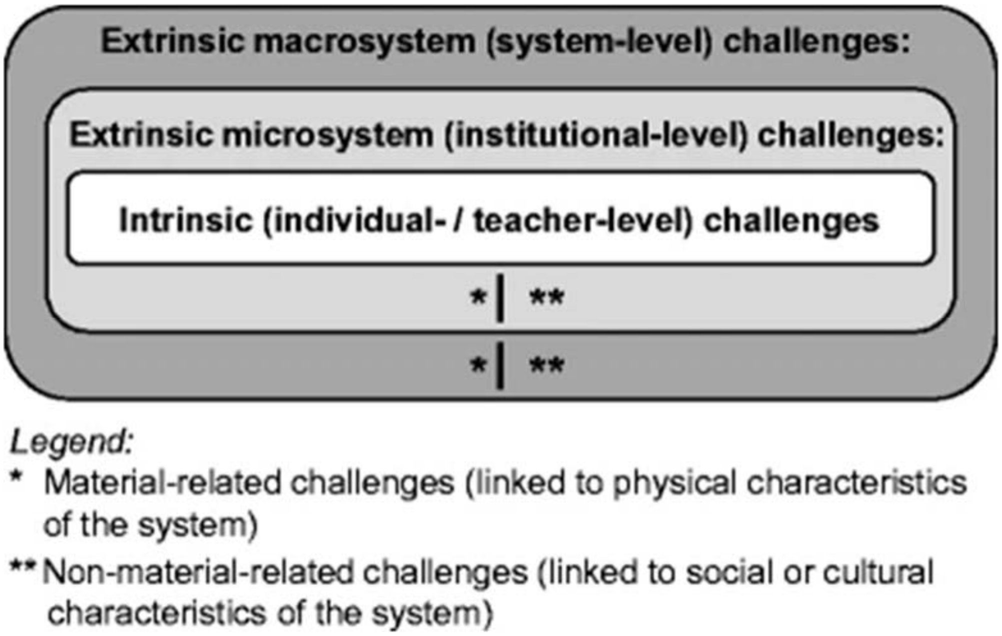


Fig. 1. Conceptual framework of teaching challenges

Figure 1 has been designed in concentric levels in line with the ecological theory of human development. The centre of the figure (intrinsic challenges) is associated to the innermost component of the human development environment (the individual, who is the physical science teacher in this case). However, it is the interaction of the teacher with the external components (levels) of the human development environment that can give rise to extrinsic challenges which are of interest here. The two external levels (on extrinsic challenges) reflect two of the external components of this environment (microsystem and macrosystem). That said, we consider the framework in Fig. 1 as a useful basis for characterising the extrinsic challenges that science teachers can experience in relation to the design and implementation of the IBPW. By characterising the challenges based on this framework, the nature and the different levels at which the extrinsic challenges originate can be identified. The next section describes how this has been achieved in this study.

Methodology

We begin by considering a suitable basis for the methodology. In this regard, there is often a gap between research in the field of education and the problems and issues of everyday practice (Anderson & Shattuck 2012). As a result, there is a credibility gap coupled with the need for research strategies that directly match the problems of practice under study, in addition to facilitating the uncovering of *usable knowledge* (Design-Based Research Collective 2003). Thus, though the study of extrinsic challenges linked to the design and implementation of the IBPW is of international relevance, the study is carried out here in a specific context. Details regarding the methodology follow.

Strategy and Participants

In our data collection, we use a multi-method case study research strategy. In this regard, we first consider the place of this research strategy in this study. A case study focuses on the observation of a spatially restricted phenomenon at a given point in time or over a prolonged duration (Gerring 2007). The occurrence of extrinsic challenges linked to the design and implementation of the IBPW in physical science classrooms in low-income communities may not be restricted to a particular region of South Africa or around the world. Thus, the use of a case study strategy here is rather linked for example to its observation function and to the fact noted by Chadderton and Torrance (2011) that a case study reports and engages with the complex settings of educational practice in order to uncover the meanings that the various participants construct. In this regard, interest here lies in addressing the extrinsic challenges associated to the complex process of designing and implementing inquiry-based practical work in the context of participating South African physical science classrooms in low-income and other communities.

In using the case study strategy here, the income level of the community, grade level and possible access to a range of resources useful in IBPW are the criteria we used in the selection of participating schools. The last criterion in the previous texts was included given that many science teachers in South African schools in low-income communities use the lack of resources as a reason for not carrying out inquiry in the classroom (Nompula 2012). However, as noted earlier, in the absence of an adequate supply of conventional SEEMs, applicable ICTs such as interactive computer simulations could be integrated in practical work when available. As also noted, some hands-on practical investigations are possible with improvised SEEMs. Thus, in order to increase the chances that IBPW is occurring in participating classrooms, we considered it useful to locate our study in physical science classrooms in low-income communities with donated ICT resources. As a result, we were drawn to the Paperless Classroom project of the South African Department of Education in the province of Gauteng in the northeastern part of the country. This project includes the distribution of tablets to learners and the provision of Smart Interactive Boards and Internet access in participating classrooms (Government Communication and Information System 2016). The project involves both primary and secondary schools. However, it was necessary to focus on the secondary schools in the project. This is because learners normally gain most of their basic knowledge of science within the age bracket of 12 to 20 years (Rutten et al. 2012).

Three of the seven secondary schools in the project are quintile three schools. In South Africa, ordinary public schools are categorised in quintiles from one to five, where quintile one schools are the *poorest* while quintile five schools are the *least poor* (Grant 2013). As opposed to quintile four and five schools, quintile one to three schools are non-fee paying schools. For the purpose of this study, we consider quintile one to three schools as school in low-income communities. Though the principals of all three of the quintile three high schools accepted to participate in this study, we selected two schools (herein, school O and school P) which are in close proximity and together have a suitable number of participants to eventually take part in a lesson study-based professional development process informed by this study. Lesson study brings teachers together in order to discuss lessons that they have collaboratively planned and observed in authentic classrooms (Lewis et al. 2006; Perry & Lewis 2009). The ideal size of a lesson study group is from six to ten teachers (Easton 2009). As seen in the following texts, the two schools used here contained six physical science teachers. That being said, the school districts to which the selected schools belong cannot be identified here for ethical reasons, given that one of the districts has only one quintile three paperless classroom project school.

In each selected participating school, the aspect of interest here was the practical component of physical science education. This includes SEEMs and facilities (laboratory and classrooms), in addition to the physical science curriculum, work sheets and other relevant documents; in line with the microsystem and the macrosystem levels of the ecological theory of human development. That being said, the two schools turned out to have certain differences as could be expected. One of the differences is that school O has a functional science laboratory, unlike school P. In school P, what used to be the science laboratory is now being used as an office for teachers. This difference is favourable to teachers of school O, unlike the next difference which is to the advantage of teachers of school P. Physical science teachers of school P are assisted with SEEMs and in the planning and implementation of practical work by a demonstrator (facilitator) from a partner institution. The non-profit partner institution (herein institution T) is affiliated to a local university. Amongst other services institution T provides is a computer laboratory for use by visiting learners and teachers in addition to a resource centre serving amongst other aspects as a platform for the borrowing and returning of SEEMs (The Skills Portal n.d.). The equipment includes motion detectors, light sensors and conductivity probes. In what concerns this study, institution T also runs mobile laboratories for schools that are severely resource-constrained or in rural areas. Though school P uses this service, this is unlike in school O where physical science teachers are fully responsible for planning and implementing practical work using school-based SEEMs only. The facilities and level of support available in the two schools are somewhat different, although this was not the focus of the present study. Instead, this study involved an investigation of the extrinsic challenges being routinely faced by teachers in the two schools in relation to the designing and implementation of the IBPW.

In order to recruit teacher participants for this study, we handed out consent letters to physical science teachers in both schools. In school P, we also gave a consent letter to the demonstrator (facilitator) from institution T. The letters noted that in the conduct of the research, the principles of voluntary participation, informed consent, safety in participation, trust, in addition to confidentiality and anonymity are to be observed at all times. On this basis, the two physical science teachers in school O (all females) as well as the demonstrator (male) and four physical science teachers in school P (all males) accepted to participate in the research. The teachers are all full-time physical science teachers in grades 10 to 12 at their respective schools and have a teaching experience of a number of years. The teachers in school O have two and sixteen years of teaching, respectively. Though one of the teachers of school P refrained from providing his biographical details, the other three had a teaching experience of five, sixteen and nineteen years, respectively. Excluding the teacher who did not provide his details, five of the six participating teachers are qualified teachers in terms of having at least a first degree in education or in a science major in addition to a certificate in education.

Data Collection

In this section, we present the techniques of data collection used and the associated data collection instruments. This is in addition to the procedure followed in the data collection.

Techniques of Data Collection

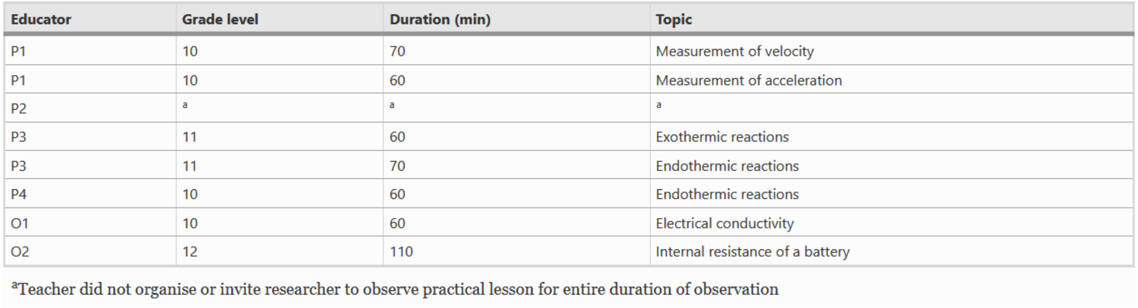
The use of multiple methods of data collection enhances the credibility and trustworthiness of research projects (Burian et al. 2010; Samaras 2011). Thus, we used individual interviews augmented with classroom observation and additional field notes. The interviews allowed for the collection of data about both the microsystem and the broader educational framework including the district (i.e., macrosystem). However, reliance on what teachers say (in the context of an interview) is inadequate in terms of understanding what they do (in this case, as they design and implement practical work), owing to inadequate understanding of definitions and expectations, in addition to self-protection (O'Sullivan 2006). At the same time, field notes allow for the recording of what is heard and seen outside the context of an interview (Arthur and Nazroo 2003). Thus, certain aspects of practice cannot be investigated without observing teachers and learners interacting in the classroom (Burstein et al. 1995). Based on the interviews, field notes and classroom observation, data could be obtained about the microsystem (individual schools) in relation to the design and implementation of inquiry-based practical work.

Data Collection Instruments

Using more than one instrument in order to collect data for the same objective allows the data collected using each instrument to complement, corroborate and verify the data collected using the other instruments (Lodico et al. 2006). This fact was implemented through the use of Observation Schedules (OSs) and Interview Schedules (ISs) designed for the purpose of this study. In other to further increase the sources of data, two ISs were designed: one for use with physical science teachers and the second IS for use with the demonstrator of school P.

The OS was designed to first of all record general details consisting of the teacher observed, the time of observation, the duration, observation count, the grade level and the topic of the practical work. This data is contained in Table 2.

Table 2. Certain details regarding observed practical lessons



Educator	Grade level	Duration (min)	Topic
P1	10	70	Measurement of velocity
P1	10	60	Measurement of acceleration
P2	[a]	[a]	[a]
P3	11	60	Exothermic reactions
P3	11	70	Endothermic reactions
P4	10	60	Endothermic reactions
O1	10	60	Electrical conductivity
O2	12	110	Internal resistance of a battery

[a] Teacher did not organise or invite researcher to observe practical lesson for entire duration of observation

Table 2 indicates in the first column that five of the six participating teachers were observed in a total of six physical science classrooms. The number of lessons observed per teacher ranged from zero (one teacher) to two (three teachers) with the minimum observation time being one hour. The practical lessons covered various topics of physics and chemistry as seen in the last column of the table. During the observation, as per the observation schedule, the venue (classroom or science laboratory) of practical work was noted. The level of inquiry in the practical lessons and the availability of various SEEMs in the classroom were also noted. The SEEMs included hands-on improvised and conventional SEEMs as well as technological tools such as interactive computer simulations. This data would allow inadequacies in SEEMs and facilities (institutional- or microsystem-level challenges) to be identified. However, for gathering data especially regarding the designing of practical work and also for complementing, corroborating and verifying the data, the ISs were useful.

The ISs were all semi-structured with open-ended items focussing on the experiences of the teachers and the observations of the demonstrator regarding teachers of school P, in relation to the design and implementation of practical work. In the case of the teachers, the IS contained twelve items including the following: (1) Based on your experience, how available in your school is each of the following types of equipment … (a) interactive computer simulations (simulated equipment), (b) conventional hands-on equipment, and (c) improvised hands-on equipment. (2) Tell me what you consider when designing or selecting practical exercises so that learners can learn best. (3) What do you think about allowing learners to design experiments to test their own ideas? The items allowed challenges such as the adequacy of resources and facilities, in addition to time and curricular constraints, to be revealed.

The ten items on the IS for the demonstrator reflected related items on the IS for teachers. However, where applicable, the items on this IS were directed at the physical science teachers of school P. In this way, the data from the IS for the demonstrator could complement, corroborate and verify the data from the other IS, in providing information regarding the teachers. Examples of the items on the IS for the demonstrator are the following: (1) Based on your experience, how available in this school is each of the following types of equipment … (a) interactive computer simulations (simulated equipment), (b) conventional hands-on equipment, and (c) improvised hands-on equipment. This item is identical to item (1) on the IS for teachers. Another example of the items on the IS for the demonstrator is (2) What are your experiences in relation to these teachers as concerns their selection and/or production of improvised equipment useful in practical work? This item on the IS for the demonstrator reflects the following item on the IS for teachers: What are your experiences, if any, with the selection and/or the production of improvised equipment useful in practical work? In this regard, the lack of training could be an impediment (Oladejo et al. 2011 citing Maduabunmi (2003); Singh & Singh 2012). That being said, item (2) for teachers was omitted in the IS for the demonstrator, given that the items on the IS for the demonstrator were directed at the teachers of school P. There was one other such an item.

Data Collection Procedure

The data collection lasted six weeks. The use of such an extended period of time contributed towards enhancing the credibility of the research (Lodico et al. 2006). During the data collection period, eight practical lessons were observed in the two participating schools. Also, at least eight hours were spent each week in the offices used by the participating teachers of each school and the science laboratory in school O. As a result, there was interaction with participants on many occasions in the microsystem linked to the designing and implementation of the IBPW. This allowed for a better understanding of the school context (microsystem). It was also possible to learn from individual teachers about the practical lessons they are considering, in addition to the challenges and preparations liked to such lessons. Sometimes, lesson cancellations or new rearrangements were recorded. In course of these interactions, impediments that teachers face as a result of not only the school context (the microsystem in this case) but also due to the broader educational framework (macrosystem) were identified. Data in this regard includes the role of SEEMs and other factors on the cancellation or rescheduling of practical lessons. The data thus gathered was kept as field notes.

One difficulty linked to research based in naturalistic settings is that the researcher can be a *cultural stranger* in this setting (Thijs 1999). Also, the participants (in this case, teachers) can hesitate to open up completely to an outsider as the researcher. Thus, McKenney et al. (2006) note the importance of collaboration and mutually beneficial activities in order to gain the trust of participants and a detailed understanding of the research setting (i.e., insider perspective). However, McKenney et al. also note that when from outside the research setting, this enables the researcher to have a degree of objectivity and honesty that is not permissible for researchers based in the setting. This study benefited from both an insider and an outsider perspective in the manner discussed in the previous texts especially in relation to the collection of data through field notes and interviews.

The interviews with the demonstrator and physical science teachers of school P and school O were the last data collection method employed in line with 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. In the conduct of the interviews, guidelines from Legard et al. (2003) were useful. In terms of the venue, the interviews all took place in the respective schools in a place judged by the participant as offering the least distraction and disturbance. Given that participants were busy, the interviews were scheduled at times that were convenient for the participants. In two cases, the scheduled time was no longer available and the interview was rescheduled. Mostly one interview was conducted per day, giving the researcher time to prepare for the next interview, in addition to time to rest and thus to feel calm and alert on arrival at the interview. Prior to the commencement of each interview, the interviewee was informed that the interview is about their experiences linked to the design and implementation of practical work in physical science. Also, an effort was made to put the interviewee at ease, in addition to creating a climate of trust. In this regard, the ethical principles involved in the study were reiterated, although they were earlier specified in the consent letters. The principles include protection from harm as seen in the following excerpt from different interviews.

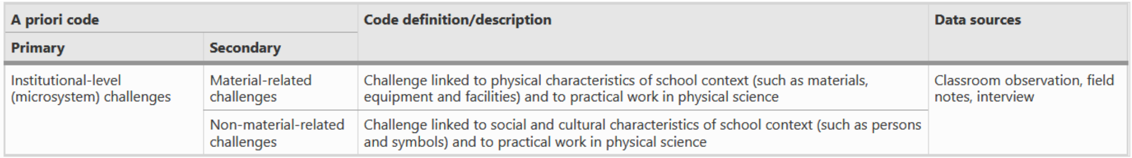
> First excerpt:Researcher: … We still have just a few questions then we are done, but I wanted to ask because the sun is now falling on you—would you want to move or we may continue?Participant: No, I am Ok.Second excerpt:Participant: … [W]hat can I make an example of … [Silence] I am running out of ideas now …Researcher: Maybe we can come back to that one latter in our discussion …

Also, prior to each interview, the interviewer recalled the need to audio record the interview in order that it could be fully transcribed as stated in the consent letters. However, the recording of the interview also enabled the researcher to focus during the interview on listening to the interviewee and thus to be able to ask follow-up questions. The questions were used when necessary, to further probe, explore and deepen responses. One example of such a question is the following: “You mentioned as you were responding to this question that it will be a good idea to introduce open-ended practical tasks. Do you mean the curriculum presently doesn’t cater for that?” However, despite using follow-up questions, the researcher refrained from influencing the views of the participant by concealing embarrassment and avoiding comments that reveal the interviewers own views for example. That being said, the approach of the end of each interview was signalled prior to the last question as seen in the following excerpt. “It’s remaining two questions before we are done. My last, but one question is…” Conducted as described, each of the individual interviews lasted more or less half an hour as promised by the researcher at the beginning of the interview.

Data Analysis

We produced verbatim transcripts of all seven individual interviews prior to the data analysis. Except in the case of the demonstrator who was not readily available, these transcripts were given to participants for verification. In the analysis of the data, we combined two approaches to thematic analysis. These approaches consist of the data-driven inductive approach (Boyatzis 1998) and the deductive a priori template of codes approach (Crabtree & Miller 1999). The inductive approach to data analysis uses detailed readings of raw data in order to derive a theory (Strauss & Corbin 1998) in the form of concepts, themes and models (Thomas 2006). That being said, using the deductive approach a researcher tests whether data are consistent with prior-identified or constructed theories, assumptions or hypotheses (Thomas 2006). In this case, the theory is essentially the ecological theory of human development augmented with categorisations of teaching challenges as reflected in Fig. 1. In line with the deductive approach, we developed a codebook of extrinsic challenges linked to the design and implementation of IBPW using the broad categories (levels) of extrinsic teaching challenges in Fig. 1. The levels consist of the system-level (macrosystem) challenges and institutional-level (microsystem) challenges as the primary categories. The latter level contains extrinsic challenges linked to the school context (microsystem), while the former contains challenges associated to the broader educational framework (such as the school district). Each of these primary levels of challenges contains two secondary levels: material-related and non-material-related challenges. The primary and secondary levels of challenges are a priori categories (codes) of extrinsic challenges linked to the design and implementation of IBPW in the codebook (Table 3).

Table 3. Excerpt of codebook used in framing inductive data analysis



A priori code		Code definition/description	Data sources
Primary	Secondary		
Institutional-level (microsystem) challenges	Material-related challenges	Challenge linked to physical characteristics of school context (such as materials, equipment and facilities) and to practical work in physical science	Classroom observation, field notes, interview
	Non-material-related challenges	Challenge linked to social and cultural characteristics of school context (such as persons and symbols) and to practical work in physical science	

In Table 3, the secondary levels of a priori categories (codes) of extrinsic challenges are a function of whether the microsystem challenge is linked to a material condition (e.g., conventional SEEMs) or not (e.g., support). The primary and secondary codes for extrinsic challenges possess attributes considered by Boyatzis (1998) as pertaining to a good code. The attributes consist of a name (label), a definition, a description of how to know when the code occurs, criteria for inclusion and exclusion in the code and examples useful in eliminating confusion. Also, codes need to reflect the purpose of the study, be mutually exclusive, be exhaustive and be conceptually consistent (Merriam 1998). The codes in the codebook we used (Table 3) could meet these criteria with the help of the framework in Fig. 1. That being said, cross-sectional coding as opposed to non-cross-sectional coding (Mason 2002) has been used here. When using non-cross-sectional coding, particular parts of the data are considered separately based on a different conceptualisation of categories (codes). However, when using cross-sectional coding, a common system of categories is applied across the whole data set. The use of cross-sectional coding here is reflected in the fourth column of Table 3.

On the basis of the a priori template of codes approach in thematic analysis described, the data analysis could proceed with the identification of the individual challenges in the data set. A challenge was considered as a condition that causes a difficulty to a teacher in terms of progressing towards an objective and/or attaining this objective (Schoepp 2005). Thus, an extrinsic challenge was taken here as a condition linked to the characteristics of the school context (microsystem) or the characteristics of the wider educational framework (macrosystem) that causes a difficulty to a teacher in terms of the design and implementation of IBPW. Based on this definition, individual extrinsic challenges were identified in the data set and then with the help of the codebook (Table 3), each challenge could be assigned to the appropriate primary and secondary a priori categories (levels). The challenges could thus be characterised in terms of the framework of extrinsic challenges in Fig. 1. Data from the different sources was thus available under the different a priori categories (codes) for the inductive aspect of the data analysis.

On the basis discussed previously, we then proceeded to an in-depth analysis of the data assigned to each a priori category (level) of extrinsic challenge, based on the data-driven inductive approach. In this regard, we used the method of constant comparison (Strauss & Corbin 1990). For this purpose, we compared each code in each a priori category based on Table 3 with the codes belonging to the same a priori category in order to identify similar and different extrinsic challenges in the data for that a priori category (level) of extrinsic challenges. In the manner discussed previously, the data in each a priori category of extrinsic challenges reflected in Table 3 was inductively analysed. The result was a range of distinct characterised extrinsic challenges linked to the design and implementation of IBPW in the participating schools. In the way discussed in the previous texts, a response could be found for both research questions simultaneously.

As seen, in terms of achieving rigour in the data collection and analysis, there has been the use of a combination of methods, sources, instruments and sites. This is in line with Van den Akker (1999) who discuss rigour in research in naturalistic settings such as the one involved in this study. However, in addition to the triangulation of sources in the data collection, a rich description of the phenomenon being considered also contributes to the validity of the research (Anfara et al. 2002).

Results

The extrinsic challenges linked to the design and implementation of Inquiry-Based Practical Work (IBPW) resulting from the data analysis have been arranged first in terms of the level of the educational framework in which each arises (macrosystem or microsystem) and then in relation to the nature of the challenge (material- or non-material-related). In some cases, we have used the exact words of some participants to present these results. In this regard, it is worth bearing in mind that the word “practical” used by some participants is slang for practical work.

Macrosystem (System-Level) Challenges

The extrinsic challenges in this category (level of the educational framework) arise from the overarching context around the design and implementation of practical work across different schools. The challenges are linked to the curriculum, the work plan of physical science teachers from the department of education and the support of district authorities. Thus, the challenges in this category happen to all be non-material-related in nature.

Restrictive Curriculum

In this regard, teachers P2 and P4 note that the physical science curriculum contains prescribed experiments that teachers must conduct with their learners. In the words of teacher O1, “[T]he practicals that we have to do with the learners are the recommended practicals from the Department of Education … these are the practicals that you must do—some are informal, others are formal”. Also, while responding to the question of whether learners should be allowed to design experiments in order to test their own ideas, teacher O1 noted that “… with the Grade 10 [learners], even the CAPS [Curriculum and Assessment Policy Statement] document says they cannot design their own experiment.” In addition, P1 stated the prescribed tasks provide a procedure for learners to follow and “[o]nce you give … the methodology (in a task) … it is closing everything”. Considering the completed observation schedules, this remark applies to seven of the eight practical lessons. The seven lessons involved confirmation inquiry (type 0 in Table 1), while the eighth one was based on structured inquiry. However, the curriculum is restrictive not only in terms of providing mandatory practical work that is less inquiry-based. For example, in responding to the question of whether learners should be allowed to design experiments, teacher O1 stated that the physical science curriculum “says that they [grade 10 learners] cannot design their own experiments. They need to be helped …”.

Mandatory Content-Focused Work Plan

Teacher P4 noted that the mandatory work plan from the Department of Education is not favourable in terms of allowing learners to design experiments to test their own ideas. The teacher explained that the work plan is heavily focused on theory lessons, leaving limited time for practical work. As the teacher further stated, the work plan allocates about two hours only for learners to conduct and report on their practical work. This is in line with the demonstrator who stated that teachers of school P often note that they are pressed for time.

Lack of District Support Towards Use of Simulations in Practical Work

Teacher P2 noted during interview that district authorities discourage the use of simulations in practical work as “... they [learners] just collect … the results [from the Internet] … without understanding”. Based on the field notes, the lack of district support was also mentioned by teacher O2 during an interview that had to be repeated because the audio recording failed. However, during the successful recording of the interview the following day, the teacher did not raise the point.

Microsystem (Institutional-Level) Challenges

Material-Related Challenges

Inadequate Facilities

The demonstrator noted that classroom space is limited in school P. As a result, learner groups tend to be large, with about ten to 11 learners per group. The demonstrator and three other teachers noted that the school also lacks a science laboratory. In this regard, teacher P4 stated that “we have got a dysfunctional lab”, while teacher P3 noted that “we never had a functional lab”.

Lack of SEEMs and Their Procurement

This constraint was noted by the demonstrator and by teacher P4. In the words of this teacher, “some sets are not complete, some are just broken, some … are not functional anymore.” The demonstrator stated that the micro-kits provided by the department of education are limited in number and in terms of the chemicals they contain. Concerning 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 are lacking in school, making him and his colleagues dependent on institution T in this regard. Thus, in one case, it was observed that the demonstrator had to bring the data loggers along with laptop computers and SEEMs requested by participants. Also, teachers P1 and P4 reported sometimes using improvised SEEMs in the face of the lack of conventional ones. This includes in the collection of hydrogen gas using balloons, as well as in certain activities in mechanics and physics where chemicals are not involved.

As also noted by both teachers of school O, conventional equipment is 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, 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. However, as noted by teacher O1, “it is a long process buying those materials that are not here, so we normally use whatever that we have—we compromise …”. The compromise consists of carrying out a teacher demonstration, showing a YouTube video or using improvised SEEMs.

All participating teachers of school P noted that their stocks of most chemicals have either been exhausted or have 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”. Thus, three of the four participating teachers of this school indicated that they have to depend on external sources for chemicals. One of these sources is neighbouring schools with larger stocks of usable chemicals from which these teachers borrow. Teachers of this school can also obtain chemicals from institution T with which the school partners in terms of practical work. On the other hand, teacher P4 reported sometimes using improvised chemicals such as hydrochloric acid meant for treating his swimming pool.

Non-Material-Related Challenges

Inaccessibility of Interactive Computer Simulations

This was noted by all the teachers as well as the demonstrator of school P. In the words of the demonstrator, “Those things [simulations] are not available—there are not readily available at this school”. However, teacher P4 noted that “[w]e’ve got some, but they are limited …. So it can simulate, but up to a certain point, maybe a 30 day trial period or maybe you find that it addresses only a few simulations, not the entire package of chemistry and physics. Like in this case, there’s only a simulation of an atom with electrons revolving around it. But, some other stuff—they [simulations] are just not there ….” In school O, though teacher O1 can access PhET simulations on her laptop, this is not the case in the classroom using the Smart Interactive Board. Also, her learners cannot access PhET simulations on their tablets. The teacher explains that these simulations require Java, whose installation on the tablets has been blocked.

Time Constraints

Teacher O1 notes that there are time constraints in terms of persuading grade 10 learners to design experiments in the laboratory. The teacher explains as follows: “… [L]et’s say it is a 1 hour 30 minutes period, and I say, “Learners design your own experiment” … Will I achieve whatever I wanted to achieve? No—the answer is no … The time does not allow … You know that kills time”. Teacher P4 also considers time as an impediment in terms of allowing learners to design experiments to test their own ideas. The teacher blames the lack of time on the tight nature of his work schedule as seen in the following interview excerpt:

> Researcher: … And what do you think about allowing learners to design experiments to test their own ideas?Teacher P4: [Silence] You see, with that one—as a scientist, yes, it’s great, but as a teacher at times … [Silence], it doesn’t really go well because other than you not having the time to do it, since you’re always pushing the work schedule, …

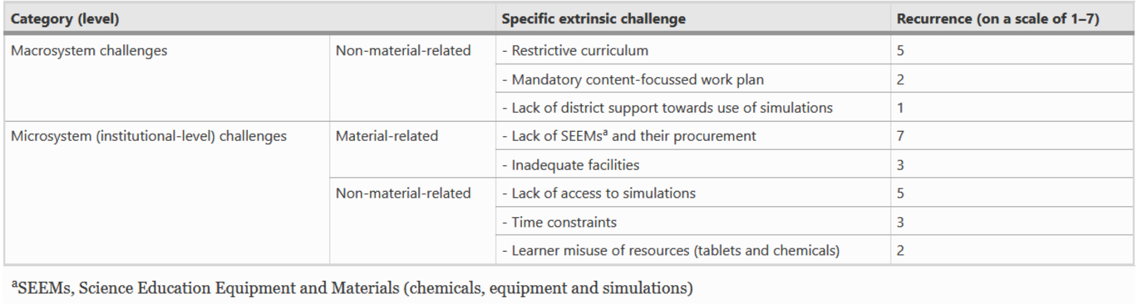
While stating that teachers often note that they are pressed for time, the demonstrator blames this partly on the allocation of much time to examinations which causes teachers to sometimes sacrifice practical work. He adds that a 55-minute period is normally inadequate and results in limited teacher-learner interaction during practical work.

Learner Misuse of Resources (Tablets and Chemicals)

Teacher P4 stated that due to poor planning on the part of learners, they often exhaust the chemicals they are provided with before the goal of the practical work has been attained. Also, the demonstrator noted that during practical work, learners tend to be busy with their tablets as monitoring is not very effective.

We have summarised the results as in Table 4. In each category (level of the educational framework), the challenges have been arranged in decreasing order of recurrence amongst participants.

Table 4. Extrinsic challenges being faced by the participants



Category (level)		Specific extrinsic challenge	Recurrence (on a scale of 1–7)
Macrosystem challenges	Non-material-related	- Restrictive curriculum	5
		- Mandatory content-focussed work plan	2
		- Lack of district support towards use of simulations	1
Microsystem (institutional-level) challenges	Material-related	- Lack of SEEMs[a] and their procurement	7
		- Inadequate facilities	3
	Non-material-related	- Lack of access to simulations	5
		- Time constraints	3
		- Learner misuse of resources (tablets and chemicals)	2

[a] SEEMs, Science Education Equipment and Materials (chemicals, equipment and simulations)

In the first two columns of Table 4, the characterisation of the extrinsic challenges in terms of the conceptual framework of teaching challenges (Fig. 1) is evident, due to the codebook in Table 3. However, in its third column, Table 4 contains the inductively identified individual extrinsic teaching challenges linked to IBPW. These individual challenges are in line with the human development environment outlined earlier. This is in the sense that they relate to the physical, social and cultural characteristics of the professional environment in relation to the designing and implementation of IBPW. Included in this environment are objects (such as the curriculum, work plans, SEEMs and facilities) and persons (such as learners). In this section, we have thus presented answers to the two research questions.

Discussion and Conclusion

Cognisant of the potential uses of the characterisation of a phenomenon, we addressed the scarcity of a characterisation of extrinsic teaching challenges in the international science education literature. Specifically, the purpose of the study presented here was to characterise extrinsic challenges linked to the design and implementation of the IBPW. In order to do so, we used a conceptual framework of teaching challenges based on Bronfenbrenner's ecological theory of human development (Fig. 1). In the in-depth data collection, we utilised a multi-method case study involving two high schools. The results which are reflected in Table 4 can be summarised as follows:

- Macrosystem (system-level) challenges: restrictive curriculum, mandatory content-focussed work plan and the lack of district support towards use of simulations
- Microsystem (institutional-level) material-related challenges: inadequate facilities, lack of SEEMs and their procurement
- Microsystem (institutional-level) non-material-related challenges: inaccessibility of simulations, time constraints and learner misuse of resources (tablets and chemicals)

It is useful to consider the results against the related literature. Firstly, the results contribute towards addressing a gap in the science education literature. The gap consists of the lack of a comprehensive description of the challenges that teachers face when planning practical work in physics (Nivalainen et al. 2010) and more generally, the lack of a clear picture of the challenges linked to the implementation of inquiry in science classrooms (Crawford 2007). While contributing to addressing the gap in the literature, the results reveal a characterisation of extrinsic teaching challenges. Akuma and Callaghan (2016), uncovered material- and non-material-related extrinsic challenges linked the production and/or use of improvised SEEMs in schools. This study expands the characterisation in a new context. The context is that of the design and implementation of IBPW. Here, the extrinsic challenges have been characterised along two dimensions consisting of the nature of the challenge (material-related or not) and the origin (in terms of level of the educational framework from which the challenge emanates). Along the first dimension, we see that in the present context, the majority of the extrinsic teaching challenges being faced by physical science teachers are non-material-related in nature. The majority of the microsystem extrinsic challenges are also in line with challenges frequently cited in relation to the implementation of inquiry-based science education in South Africa and internationally. However, a microsystem extrinsic challenge uncovered here that is not readily found in the literature is the lack of access to interactive computer simulations, in addition to learner misuse of resources (chemicals and tablets). In terms of the second dimension, though most of the challenges originate at the institutional-level (in the microsystem), teachers also face challenges emanating from the macrosystem. Thus, not only the teachers studied are affected, but also teachers in other classrooms of the school district and nationally. Scarce in the literature are the macrosystem extrinsic challenges consisting of a mandatory content-focussed work plan from the department of education and the lack of district support towards the use of simulations in practical work. Excepting this last macrosystem challenge which is applicable district-wide, the other two (including a restrictive curriculum) are applicable to all physical science classrooms in South Africa.

The results previously discussed and those of this study, in general, have theory-, practice- and research-based implications nationally and internationally. Regarding theory, Bronfenbrenner's theory of human development (used here) has been useful as the theoretical basis in empirical studies in diverse areas including families and their relationships (Riggins-Caspers et al. 2003) and in factors affecting the implementation of inquiry-based science education (Ramnarain 2016). This study has added to the uses of Bronfenbrenner's theory in science education research. Specifically, this study illustrates the usefulness of this theory in enhancing our understanding of extrinsic teaching challenges from a systemic perspective and in informing how the challenges could be addressed from the same perspective, as seen subsequently. In this regard, the theory could thus be considered in similar studies in South Africa and internationally. In terms of practice, constraining contextual factors (such as the extrinsic challenges uncovered here) need to be addressed in order to achieve successful inquiry-based classroom instruction in science (Ramnarain and Schuster 2014). This study informs the implementation of this recommendation. For example, through the characterisation of the extrinsic challenges in relation to the level of the educational framework at which the challenges emanate, key role players in addressing the challenges can be identified in a systemic manner. While this is applicable in any context following a similar studies, in this case, and at the macrosystem level, the role players include curriculum developers (in relation to a restrictive curriculum), educational planners (mandatory content-focussed work plan), and district authorities (lack of district support towards the use of interactive computer simulations). At the microsystem level, key role players include school managers (in relation to the lack of procurement of SEEMs, for example), in addition to Information Technology staff (lack of access to simulations) and physical science teachers (learner misuse of resources). The enhanced understanding of extrinsic teaching challenges provided in the way discussed in the previous texts by this study enables teachers facing extrinsic challenges to be supported appropriately. While this is in line with a number of researchers (Davis et al. 2006; Harris & Rooks 2010), the characterisation of the challenges provided here informs a systemic approach to the provision of the support. In fact, to address the extrinsic challenges linked to the design and implementation of IBPW needs the efforts of a number of key people at the institutional (microsystem) and macrosystem levels as expected from the ecological theory of human development of Bronfenbrenner (1979). Based on the fourth column of Table 4, curriculum developers, information technology staff and school managers are prominent amongst the role players.

The results of this study however raise further questions, giving researchers as well, a role to play in addressing extrinsic challenges linked to the design and implementation of the IBPW in School Africa and beyond. In the present context, the questions include how learners can best be assisted in using tablets and chemicals more effectively and how interactive computer simulations could be used in practical work in a way that is satisfactory to district authorities. This is in addition to whether similar microsystem extrinsic challenges occur in other South African schools. This last question reflects a limitation of this study as an in-depth study. In this regard, the question arises about the applicability of the resulting categorisation of extrinsic teaching challenges linked to the IBPW to other educational settings in South Africa and internationally. For example, are mesosystem- and exosystem-challenges also absent in other educational contexts and countries as in the present case? This last question is useful in terms of enhancing research into the extrinsic challenges associated with the design and implementation of the IBPW on a wider level. In fact (and independent of the said level), a detailed characterisation of a phenomenon (in this case intrinsic teaching challenges linked to the IBPW) is useful not only in revealing its complexity, providing value and coherence, but also in tracking its development and in uncovering knowledge within the individual categories (Abell 2008; El-Deghaidy et al. 2015; Rozenszajn & Yarden 2014).

Against the background discussed in the previous texts, we see that a multiple-stakeholder approach involving researchers and various practitioners is useful in order to address extrinsic challenges linked to the design and implementation of the IBPW in South Africa and in other countries in a systemic manner. At the local level, anywhere, design-based implementation research (Penuel et al. 2011) can be used in implementing such an approach. Such research which focuses on problems of practice from a multiple-stakeholder perspective (and is thus in line with the ecological theory of human development) includes the development and testing of innovations for improving teaching and learning. The innovation here could be a framework for reducing extrinsic challenges linked to the design and implementation of the IBPW in a systemic manner. The development and implementation of this innovation should allow for circumstances that better support reform-based practical science to be created in schools in South Africa and other countries.

Ethics declarations

There are no sources of funding to declare in relation to the research presented in this paper.

Conflict of Interest

The authors declare that they have no conflict of interest.

Ethics Approval and Consent to Participate

In order to recruit teacher participants for this study, consent letters were handed out to physical science teachers in the participating schools. In school P, a consent letter was also given to the demonstrator (facilitator) from institution T. The two physical science teachers in school O (all females) as well as the demonstrator (male) and four physical science teachers in school P (all males) accepted to participate in the research.

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