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Intrinsic teaching challenges relating to practical investigations in some classrooms: An instructional design perspective

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The inquiry-based strategy in science education is widely recommended and incorporated in practical work. However, contextual and intrinsic teaching challenges associated with practical investigations (inquiry-based practical work), occur in resource-constrained physical sciences classrooms in South Africa. The intrinsic challenges have previously been identified from the perspective of the pedagogical content knowledge framework and the concerns-based adoption model. In this article we present a novel approach, investigating the intrinsic challenges from a viewpoint of instructional design. The multi-method technique was used to collect data which was analysed by combining the deductive and the inductive approaches in thematic analysis. The findings consist of intrinsic teaching challenges in the initiation, planning, and implementation phases of practical investigations. Examples of the challenges include practical work being considered to have a confirmatory role, inadequacies linked to addressing learner safety, and unfamiliarity with well-known instructional models. While new challenges were identified, the findings add a new perspective to intrinsic challenges relating to practical investigations in the context of physical sciences education in South Africa. Also, the findings enhance global knowledge about the complexity of intrinsic teaching challenges linked to practical investigations. In addition, the findings inform teacher support while suggesting lines of future research linked to practical investigations in resource-constrained physical sciences classrooms in South Africa and beyond.

Keywords: inquiry-based practical work; inquiry-based science education (IBSE); instructional design; intrinsic teaching challenges; practical investigations; South Africa

Introduction

Challenges associated with instructional design in various environments like personal learning (Väljataga & Laanpere, 2010) and online learning (Watson, Loizzo, Watson, Mueller, Lim & Ertmer, 2016) are discussed in educational research. In the study reported on here we focussed on intrinsic challenges to practical investigations in the context of physical sciences in South Africa.

There has been sustained calls for science learning experiences to mirror scientific inquiry (American Association for the Advancement of Science, 1989; Manz, 2015). Consistent with the calls, several national, regional, and international organisations recommend inquiry-based science education (IBSE) as a strategy for promoting scientific practices, critical thinking and problem-solving in nursery, and primary through high school science education (European Commission, 2015; InterAcademy Partnership, 2010; National Research Council, 2012; Organization for Economic Co-operation and Development, 2019). In response to these calls, IBSE has been incorporated in curricula in countries around the world, including, China (Dai, Gerbino & Daley, 2011), South Africa (Department of Basic Education [DBE], Republic of South Africa [RSA], 2011), Australia (Kidman, 2012), and the United States of America (National Science Teachers Association, 2007).

In an IBSE context, learners experience phenomena and engage in scientific practices as they ask questions, design investigations, gather and analyse data, engage in scientific reasoning, develop explanations, and share their findings and ideas (Minstrell & Van Zee, 2000; National Research Council, 2006; Quintana, Reiser, Davis, Krajcik, Fretz, Duncan, Kyza, Edelson & Soloway, 2004). Although IBSE is widely regarded as an efficient way to promote critical thinking and scientific literacy, some studies indicate that this strategy is less effective than the direct instructional strategy (Klahr & Nigam, 2004). However, it has been argued that these studies do not appreciate the role of scaffolding in the use of inquiry-based teaching strategies (Hmelo-Silver, Duncan & Chinn, 2007), coupled with the multiple ways in which the term inquiry has been defined. The definitions include inquiry as an instructional strategy and a learning outcome consisting of the development of epistemological understandings of science and the gaining of scientific practices (Bybee, 2000; National Research Council, 2007). It has been noted that a bigger part of the related literature shows that IBSE is comparable to (Leonard, 1983), or more effective than direct instruction (Blanchard, Southerland, Osborne, Sampson, Annetta & Granger, 2010).

IBSE implementation strategies range from confirmation, structured, guided, to open inquiry, in order of increasing learner involvement in asking questions, coupled with collecting and interpreting data (Blanchard et al., 2010). For example, in confirmation inquiry, learners investigate questions posed to them to reach an outcome that is available in advance, whereas using open inquiry, learners investigate their own questions to arrive at an answer that they do not know in advance. However, for many researchers (Olson & Loucks-Horsley, 2000; Zion & Mendelovici, 2012), IBSE implementation strategies exclude confirmation inquiry.

In our research, IBSE is considered in the context of learning activities that are practical in nature and are referred to alternatively as, for example, practical enquiry activities (Toplis & Allen, 2012), science investigations (Kennedy, 2013; Ramnarain, 2011), practical investigations (DBE, RSA, 2011; Dudu & Vhurumuku, 2012), and inquiry-based practical work (Kim & Tan, 2011). Inquiry-based practical work is the product of integrating inquiry and practical learning experiences (Tsakeni, Vandeyar & Potgieter, 2019). This type of practical work can be defined as experiences in which learners observe objects and natural events as they engage in scientific practices such as asking investigable questions, suggesting explanations, gathering and analysing data, coupled with communicating their findings (Mkimbili, Tiplic & Ødegaard, 2017; Sesen & Tarhan, 2013). This is unlike confirmation-based practical work, which, in the view by Bowen, Picard, Verberne-Sutton and Brame (2018), does not involve inquiry.

Practical investigations have been recommended as an aspect of science education at all levels in many countries (Bowen et al., 2018; National Science Teachers Association, 2007; Radovanović & Sliško, 2014). In view of the calls to implement inquiry, one would expect that practical work in schools typically follow an inquiry-based approach. However, it has been noted, for example, that school science laboratories remain places for carrying out routine activities (Lunetta, Hofstein & Clough, 2007) confirming known results rather than doing inquiry. Learners are seldom challenged to reflect on methods and findings (Abrahams & Millar, 2008).

In South Africa (where this research was conducted), the Curriculum and Assessment Policy Statement (DBE, RSA, 2011:8), asserts that "Physical Sciences promotes knowledge and skills in scientific inquiry and problem-solving.…" Furthermore, the Curriculum and Assessment Policy Statement (CAPS) recommends the involvement of all learners in practical investigations, a term used locally to represent inquiry-based practical work. This is evident in, for example, the specific aims of the CAPS, which state that the aim of physical sciences education is to "make learners aware of their environment and to equip learners with investigating skills..." (DBE, RSA, 2011:8). However, resource-constrained classrooms dominate the South African educational landscape. As a result, physical sciences teachers in many of these resource-constrained classrooms exhibit a strong orientation toward confirmation-based practical work (Akuma & Callaghan, 2019b; Ramnarain & Schuster, 2014), which limits learners' opportunities to engage in investigations.

Some studies have been done about extrinsic teaching challenges linked to the implementation of practical investigations in resource-constrained physical sciences classrooms in South Africa (Ramnarain, 2016; Ramnarain & Hlatswayo, 2018). These are challenges associated with constraining contextual factors. However, not all the challenges relating to the design and enactment of practical investigations, are extrinsic. As an example of intrinsic challenges, it has been found that it is not easy for teachers to formulate investigable questions (Zion & Mendelovici, 2012). Intrinsic teaching challenges relating to practical investigations experienced in resource-constrained physical sciences classrooms in South Africa have been studied from the perspective of the pedagogical content knowledge framework (Ramnarain, 2016), and also from the perspective of the concerns-based adoption model (Oguoma, Jita & Jita, 2019). However, the challenges have not been studied from an instructional design perspective.

With our study we addressed this gap in knowledge about intrinsic teaching challenges. The purpose of the study was to investigate the intrinsic teaching challenges linked to the design and enactment of practical investigations, being experienced by the participating physical sciences teachers in resource-constrained schools in South Africa. The investigation was driven by the following three research questions (RQs):

RQ1. What initiation-phase intrinsic challenges do the teachers experience?

RQ2. What planning-phase intrinsic challenges do they face?

RQ3. What implementation-phase intrinsic challenges do they experience?

It is vital to appreciate the challenges that teachers experience as they carry out curriculum reforms (Oguoma et al., 2019) that involve the incorporation of inquiry in practical work. Our study can shed light in this regard and inform the provision of appropriate teacher support in instructional design linked to inquiry-based practical work, which is referred to as practical investigations as noted earlier. To be able to provide such support, there is a need to understand the challenges that teachers are confronted with (Harris & Rooks, 2010). In addition to the practice-based implications, our research suggests lines of future research in relation to the findings.

Conceptual Framework

Instructional design: Case of practical investigations

The focus in our study on intrinsic teaching challenges in relation to the design and enactment of practical investigations makes instructional design a suitable basis. Instructional design involves selecting, organising, sequencing and assessing content and experiences, coupled with the tools needed to assist learners in the attainment of set goals (Burns, 2011). The instructional design literature (Dick, Carey & Carey, 2001; Peterson, 2003) provides examples of instructional design models. However, the science laboratory instructional design (SLID) model (Balta, 2015) specifically focuses on practical work. In this study, the SLID model is used in relation to how practical investigations may be designed and enacted, and as a basis for investigating the associated intrinsic challenges.

The phases of the SLID model consist of initiation, planning, execution-guidance-evaluate, evaluation, and feedback (Balta, 2015). Herein, we refer to the execution-guidance-evaluate phase simply as the implementation phase. The focus in the presented research was on the initiation, planning, and implementation phases; thus on research questions RQ1, RQ2, and RQ3, respectively. In the initiation phase, and among other aspects, the teacher selects the delivery strategy for the practical work. The choice, in this case, is between open, directed, and structured inquiry. According to Zion, Cohen and Amir (2007), with regard to structured inquiry, the teacher states the problem, poses the question, formulates the hypothesis, and designs the investigation. The learners then implement the plan, gather and analyse data, and draw conclusions. In a guided inquiry, the teacher only poses the question, while in open inquiry, learners determine the aspect of a phenomenon that they want to investigate, formulate the associated investigation question, and design the investigation. The role of the teacher is to facilitate, focus, challenge, and encourage the learners to engage in this type of activity. In the planning phase, the teacher's attention shifts to safety considerations and the formation of learner groups. They also identify learning needs and develop assessments in addition to designing and producing support materials. One can add the selection of virtual and physical science education equipment and materials.

The implementation phase involves the carrying out of practical work in the classroom with the teacher providing feedback and guidance (Balta, 2015). In this regard, different instructional models could be used. The models include the predict-observe-explain learning cycle (White & Gunstone, 1992), and the engagement, exploration, explanation, elaboration and evaluation (5e) instructional model (Bybee, 1997). Also included is the orientation, conceptualisation (questioning/ hypothesis generation), investigation (exploration/ experimentation and data interpretation), and conclusion model (Pedaste, Mäeots, Siiman, De Jong, Van Riesen, Kamp, Manoli, Zacharia & Tsourlidaki, 2015).

The evaluation phase of the SLID model presents an opportunity for learners to present their practical work experiences (Balta, 2015). In the feedback phase the teacher reflects, for example, on group formation and assessment instruments in addition to the delivery strategy based on the outcomes of the previous phase. The preceding paragraphs illustrate how practical investigations may be designed and enacted.

Investigating teaching challenges linked to design and enactment of practical investigations

A teaching challenge has been defined as being a condition that presents a science teacher with difficulty when progressing towards an objective (Schoepp, 2005). In our research the objective of the teacher would be to design and enact practical investigations successfully. Science teachers have experienced challenges when implementing inquiry activities, including practical investigations (Stephen, 2015; Zion et al., 2007). Researchers have identified intrinsic teaching challenges relating to practical work and classified them, although the classifications are few (Akuma & Callaghan, 2019a; Nivalainen, Asikainen, Sormunen & Hirvonen, 2010). Broad classes of intrinsic challenges that have been identified in international literature include initiation-phase, planning-phase, implementation-phase, and summative evaluation-phase challenges. However, this is not the case in the South African literature. These classifications, which are in line with the instructional design perspective, are useful in achieving the purpose of our research. In the next section we focus on the context in which the intrinsic challenges were investigated, and how data were gathered and analysed.

Methodology

Research Context and Strategy

This research was conducted in Gauteng, a north-eastern province of South Africa. Schools in this province are located in socioeconomically diverse communities (Ramnarain & Fortus, 2013). Like elsewhere in South Africa, ordinary schools in Gauteng are classified in quintiles ranging from one to five, based on the poverty of the host community and infrastructural factors (Grant, 2013). In the classification, quintile 1 schools are the poorest schools, whereas quintile 5 schools are the least poor. Quintile 1 to 3 schools, which are no fee-paying schools, are considered as resource-constrained schools for the purposes of this research. In 2011, 73.4% of the Gauteng schools were no-fee paying schools (DBE, RSA, 2012).

We used a case study strategy in our research as it is suitable when engaging with and when reporting on an educational practice that occurs in a complex setting (Chadderton & Torrance, 2011). In the context of this research, the practice is that of the designing and enactment of practical investigations in which the focus is on the intrinsic teaching challenges. Convenience sampling was used to select two secondary schools (School A and School B) to participate in the case study. The schools, which are both quintile 3 (no fee-paying) schools, were used simply for their geographical proximity and availability during the period of the research. Although two schools were used, the intention was not to compare the data from these schools. Rather, this was to have more participating physical sciences teachers in the research, given that these teachers tend to be few in one school. The principal of each of the quintile 3 secondary schools in the study provided informed consent regarding the participation of the school.

In both schools the practical work aspect of physical sciences education was the only interest in this research. Physical sciences teachers in School A planned and conducted practical work all by themselves, whereas their counterparts in School B did so with the support of a demonstrator from a non-profit partner institution. The institution provides a resource centre which serves as a platform for accessing science education equipment and materials (SEEMs) (The Skills Portal, n.d.). The role of the visiting demonstrator was to assist physical sciences teachers of School B with the provision of lacking SEEMs and with their enactment in the classroom during practical work.

We obtained informed consent to voluntarily participate in this research from the demonstrator and four physical sciences teachers (all male) in School B, in addition to two physical sciences teachers in School A (both female). The letters of consent included a commitment by the researcher to abide by the principles of informed consent, voluntary participation, safety in participation, privacy, and trust as described in the research literature (Bryman, 2001; Lodico, Spaulding & Voegtle, 2006).

Except for one teacher, all participants provided the solicitated biographical information. Based on the information, participants had a degree in science in addition to a postgraduate certificate in education or an undergraduate degree in science education. Considering an education degree or a teaching diploma as the minimum teaching qualification (Ramnarain & Fortus, 2013) five of the six participants in this research were qualified educators. While the participating teachers were all full-time Grades 10 to 12 teachers, two were the head of the physical sciences departments in their respective schools. The teachers who provided their biographical information had teaching experiences of 19, 16 (two teachers), 5, and 2 years respectively. We used all six classrooms in which these teachers were teaching during the period of this research (four in School B and two in School A). The class sizes ranged from 29 to 53 (the average being 40) learners. The parents or guardians of learners in the participating classes voluntarily gave their consent for the respective learners to participate in this research.

Data Collection

Since using multiple methods (and sources) increases the credibility of the findings of a study (Samaras, 2011), we combined interviews, classroom observations, and artefacts in our data collection. In School B, which employed a demonstrator, this person was also interviewed as an additional source. Details regarding the data collection follow.

Classroom observation

Classroom observation was based on an observation protocol. However, few practical lessons were available for observation in both schools. As has been noted by Dudu and Vhurumuku (2012), by requiring the assessment of only two practical activities per grade, the curriculum may be giving the wrong indication to teachers who appear to interpret this guideline to mean that they are limited to two practical activities in their teaching. During the research, we observed five of the six participating physical sciences teachers in a total of six classes. The number of lessons we observed per participant ranged from zero (one teacher) to two (three teachers). The observation time ranged from 1 hour to nearly 2 hours. The observed practical lessons covered physics and chemistry topics, namely, the measurement of velocity and acceleration, exothermic and endothermic reactions, electrical conductivity in aqueous solutions, and internal resistance of a battery.

The observation protocol contained items on several aspects of instructional design. The aspects included goal provision (National Research Council, 2006) and phases of instruction (Bybee, 2009). This was in addition to how the teacher provided information (teacher guidance), the nature of learner-learner interactions, and the nature of learner-teacher interactions (McComas, 2005; Scharmann & Smith, 2001). An example of the items is: “How does the teacher guide learners?” (e.g., use of direct answers, indirect answers, hints, and/or suggestions).

Artefacts

Seven worksheets and a snapshot of one practical task written on the chalkboard were collected for analysis. The artefacts provided data about the initiation and planning phases of practical work, which occurred before the implementation phase in which observations took place.

Individual interviews

We used one interview protocol for the six physical sciences teachers in Schools A and B, and another interview protocol for the demonstrator in School B. While both protocols were semi-structured, the interview protocol for the demonstrator contained items on his views regarding the implementation of practical investigations by the teachers at School B. The second interview protocol contained items on the experiences of physical sciences teachers at both schools regarding the implementation of practical investigations. An example of the items on the protocol for teachers is: "Some people believe that learners' prior knowledge and experiences are sufficient in the beginning of practical work. What is your opinion?"

Given that the demonstrator was used as a source of data about the four physical sciences teachers at School B, the items on the demonstrator's interview protocol were designed to uncover intrinsic challenges being experienced by these teachers, not the demonstrator himself. One example of these items is: "What are the phases (steps), if any, that teachers of this school follow when carrying out practical work? What usually happens during each phase (step)?"

The other items included in the two interview protocols were designed to gather data regarding the experiences of teachers with respect to the use of different SEEMs in practical work and the selection and production of improvised SEEMs. How participating teachers normally responded to learners was also included.

Each interview (with the demonstrator and the six physical sciences teachers) lasted about half an hour. In addition to the questions on the two interview protocols, follow-up questions were used to solicit details and clarification. All seven individual interviews were conducted only after the classroom observations considering that when the interviewer had observed the practice under discussion, interviewees provided responses that were less rhetorical in nature (Abrahams & Millar, 2008).

Data Analysis

Firstly, we produced verbatim transcripts of the individual interviews. We then subjected the transcripts to verification by participants, to guard against researcher bias and to enhance the validity of the research findings. Next, we used a combination of the inductive approach in thematic analysis (Boyatzis, 1998) and the deductive *a priori* template of codes approach (Crabtree & Miller, 1999) in the data analysis. In the context of the latter approach, we developed a codebook containing *a priori* primary categories for classifying the intrinsic teaching challenges associated with the design and enactment of practical investigations. The *a priori* primary categories of challenges we used consisted of initiation-phase (RQ1), planning-phase (RQ2), and implementation-phase (RQ3) challenges. Under the implementation-phase challenges primary category, the secondary categories we used included engagement- and exploration-phase challenges, respectively. As an illustration, a portion of the codebook with a code in relation to one primary category (initiation phase) and a secondary category (engagement phase) of the challenges linked to practical investigations are shown in Table 1.

Table 1 Excerpt of code book used to frame inductive data analysis

Category of intrinsic challenge	*A priori* code	Code description	Data sources
Initiation phase	Strategy	Strategy chosen for practical work based on design of worksheet and as observed in the classroom (including whether PW[e] precedes or follows concept development): - confirmatory (recipe type) or inquiry based (investigation) - if inquiry based, type of inquiry involved	OP0.a, OP0.b[a], WS[b], IPE2[c]
Engagement phase	Phase inclusion Phase implementation	Whether phase is included in the enactment of PW[e] How this phase is carried out in terms of capturing learners' attention, accessing their prior learning, promoting curiosity, and identifying learner misconceptions	IPD5[d], IPE5, OP3.a, WS

Note. [a]OP0.x = Observation protocol, item number X.x. [b]WS = Worksheet. [c]IPTX = Interview protocol teacher, item X. [d]IPDX = Interview protocol demonstrator, item number X. [e]PW = Practical work.

In each of the *a priori* categories shown in Table 1, a specific intrinsic challenge identified in the data could be assigned after coding. To identity a challenge we used the definition of a teaching challenge provided by Schoepp (2005) presented in the section "Investigating teaching challenges linked to design and enactment of practical investigations." On this basis, we identified the individual intrinsic challenges in the data and assigned the challenges to the appropriate categories shown in the first three columns in Table 1. We carried out the identification of the challenges in the data from all three data sources as illustrated in the last column of the table.

Using the method of constant comparison based on Strauss and Corbin (1990), we proceeded with the inductive component of the data analysis. Specifically, in each *a priori* category, each individual intrinsic challenge was compared with previous challenges in the same category to find patterns and differences among the challenges. Thus, the intrinsic challenges identified across the different data sources could be deductively and then inductively classified.

Findings

In this section, we present the intrinsic challenges faced by participants in the design and enactment of practical investigations in participating resource-constrained physical sciences classrooms in South Africa. These findings are summarised in Table 2.

Table 2 Summary of intrinsic challenges associated with the design and enactment of practical investigations

Category	Specific challenge
Initiation phase[a]	Practical work considered to have confirmatory role
Planning phase[b]	Inadequacies linked to addressing learner safety: • belief that open inquiry is unsafe • no safety practices and procedures on display • no information on learner safety on worksheets
	Difficulties linked to improvisation of SEEMs[c] • effort and skills needed to produce them • perceived lack of effectiveness
Implementation phase[d]	Unfamiliarity with well-known instructional models
	Enhancing prior knowledge without upholding confirmation inquiry
	Facilitating group learning

Note. [a]Linked to RQ1. [b]Linked to RQ2. [c]SEEMs = Science education equipment and materials. [d]Linked to RQ3.

In the remainder of this section we discuss the content of Table 2, with reference to the RQs. In certain cases, we used the exact statements of participants and excerpts from worksheets.

RQ1: What Initiation-phase Intrinsic Challenges do the Teachers Experience?

Practical work considered to have a confirmatory role

According to all four teachers at School B, practical work is typically intended to support theory. This is reflected in the comment by Teacher B4:

> *What I actually do before a practical ... I teach them the concept that we're going to be testing in an experiment or we're going to be observing in an investigation ... And after we're done with the theory, then we go to the practical.*

We obtained a similar finding in School A, given that Teachers A1 and A2 considered practical work to have a confirmatory role in relation to textbook contents and theory lessons. Document analysis was largely in line with the interview findings. Only two of the collected worksheets contained aspects of structured inquiry. In one case it was only after the conclusion that the learners were asked, in the last item on the worksheet, to draw their experimental setup. Six worksheets were completely confirmatory in design. In this regard, the worksheets on endothermic reactions provided by Teacher B4 concluded as follows: "*The reaction has made the temperature of the system go down. The energy exchange is from the surroundings to system – the reaction is endothermic.*" The worksheet on exothermic reactions provided by Teacher B3 included a similar conclusion. Also, the worksheets for both practical lessons lacked focus questions.

RQ2: What Planning-phase Intrinsic Challenges do they Face?

Inadequacies linked to addressing learner safety

The interview data indicate that Teacher B4 was unsympathetic towards the idea of encouraging learners to design experiments to test their ideas, because of safety concerns. Another issue associated with safety revealed in the classroom observation was the lack of information on laboratory safety procedures and practices in the classrooms in School B and the science laboratory in School A. Document analysis also showed that worksheets lacked safety precautions in relation to learners. In this light, only one worksheet contained a precaution, which was, however, not on learner safety. The precaution stated as follows "Do not keep the switch on too long. It will heat the battery and cause it to run down." Also, although the practical work involved the use of a 9-V battery, rheostat, and electrical meters, learners were not asked, for example, to ensure that none of these items fell on someone's foot.

Difficulties associated with the improvisation of science education equipment and materials (SEEMs)

Teacher B1 regarded the improvisation of SEEMs fairly difficult in terms of the required effort and skills. Teacher A1 wondered whether the same outcomes could be attained using improvised equipment as in the case of the conventional equivalent of the equipment.

RQ3: What Implementation-phase Intrinsic Challenges do they Experience?

Unfamiliarity with well-known instructional models

Teachers at both schools did not use an instructional model in implementing practical that we could recognise. In this regard, we found from the observation data that none of the lessons had an engagement phase. Also, we found an explanation phase in one lesson only and an elaboration phase in only one other lesson. In addition, the explanation phase was often carried out through the provision of expected outcomes orally or using the worksheet before what should be the exploration phase. The latter is thus compromised as the inquiry is then confirmatory. This is exemplified in the excerpt below taken from the observation protocol completed during a practical lesson on Faraday's law taught by Teacher A2.

a) Predict/Engagement/orientation: "Missing"
b) Observe/Exploration/Investigation: Teacher presents Faraday's law before its exploration. They write $\varepsilon = -N\frac{\Delta\varphi}{\Delta t}$ [on the chalkboard] and ask learners to state Faraday's law in words based on the equation. This involves a lengthy question and answer session between the teacher and a few learners. When finally implemented, this phase [exploration] is thus a confirmation of the law.
c) Explain/Explanation: This phase is compromised by the commencement of the lesson with a presentation of Faraday's law.

Interview data were also in support of teachers being unfamiliar with the use of an instructional model to sequence and organise the conduct of practical work. For example, Teachers B1 and B2 considered the phases of a practical lesson to include grouping learners, checking prior knowledge, and providing the aims. While these so-called phases of a practical lesson can be linked to the first two phases of the 5e instructional model, for example, Teachers B3 and B4 did not provide any phases that we could associate with an instructional model known to us. For example, Teacher B4 rather spoke about steps such as aims, apparatus, method, and conclusion that learners follow when reporting their laboratory activity. Also, the "phases" that Teacher A1 observed in practical lessons were "collect the apparatus", "write your hypothesis", and "follow these instructions." However, based on document analysis, these phases of a practical lesson did not appear in this sequence during the lesson on electrical conductivity of aqueous solutions. The associated worksheet did not have space for learners to provide the investigated hypothesis until at the end of the worksheet where post-exploration questions were listed.

Enhancing prior knowledge without upholding confirmation inquiry

When asked about the adequacy of learners' prior knowledge when engaging them in practical work, all participating teachers (School A and School B) noted that their knowledge was inadequate. The opinions of the teachers are reflected in the words of Teacher B3:

> *I think the best way is what we normally do – we'll go through first the theory and then we do the practical after. I think the theory is where we prepare them for the practical part. So that is the rule that I have always been taking ... But when we start with the practical, obviously I have to give them more information about what we are going to do, what we are expecting and just give them an introduction and the theory, the methods....*

Facilitating group learning

Classroom observations indicate that Teachers A2 and B1 each stopped the class on at least one occasion to provide additional information. Although this was not observed in the case of Teacher B3, this teacher noted in a similar light in their interview that "[i]*f I discover that most of them* [learners] *are doing something wrong or I want them to find out something, obviously what I will do is I will stop all the groups and try to emphasise the point*." On a separate aspect of facilitation we observed that Teacher A1 and B3 spent a relatively long time with certain learner groups at the expense of other groups. Whereas, when interviewed, Teacher A2 noted that "*with Grade 11 and 12, I just let them do everything*." Interview data also indicate that the same was true for Teacher B2 in Grade 12.

Overall, the findings appear to reflect the words of the demonstrator who noted with reference to physical sciences teachers of School B: "*... there is a problem in terms of their* [teachers'] *actual capacity to deal with practical work ... practical* [work] *is just done so that it gets out of the way*."

Discussion and Conclusion

The primary question addressed in our research was about the intrinsic teaching challenges linked to the design and enactment of practical investigations experienced by physical sciences teachers in the participating resource-constrained schools in South Africa. In line with the RQs presented, the findings show initiation-, planning-, and implementation-phase challenges (cf. Table 2). The findings add a new perspective to the South African literature and reveal new challenges not previously reported globally. Existing perspectives in local literature include the pedagogical content knowledge framework (Ramnarain, 2016), and also the concerns-based adoption model perspective (Oguoma et al., 2019). The newly uncovered intrinsic challenges include "inadequacies linked to addressing learner safety" (planning phase), "enhancing prior knowledge without upholding confirmation inquiry", and "unfamiliarity with well-known instructional models" (implementation phase).

The findings increase the knowledge about the complexity of intrinsic challenges linked to practical investigations from a global perspective. Thus, the findings show that participating physical sciences teachers experienced some intrinsic challenges associated with the design and enactment of practical investigations that were different from those that science teachers elsewhere have been found to experience. The challenges provide an angle for considering the point made by Ramnarain (2011), that despite the strong emphasis on practical investigations in the South African physical sciences curriculum, practical work predominantly takes the form of teacher demonstrations.

While being illuminating, the findings have research- and practice-related implications in the context of science education in South Africa and beyond. It has been noted that research findings based on the routine pedagogical experiences of participating teachers allow efforts towards the enhancement of their competencies to be more effective (Holland, 2005). In this regard, let us consider the challenge of "unfamiliarity with well-known instructional models." This challenge raises questions about aspects of the professional knowledge of the participating teachers. Teacher knowledge includes knowledge about lesson planning and implementation (Koehler & Mishra, 2009). In this regard, instructional models are being used in science teachers' professional development (Zambak, Alston, Marshall & Tyminski, 2017) to enable teachers to structure and improve their teaching (Svendsen, 2015) as they design and enact inquiry-based learning experiences (Rushton, Lotter & Singer, 2011). While the experiences include practical investigations, examples of the relevant instructional models were identified in the section "Instructional design: Case of practical investigations."

The findings present several research-related implications. Firstly, the findings cannot be generalised because this was an in-depth study. Due to this limitation, similar in-depth studies could be carried out in other resource-constrained physical sciences classrooms in South Africa and beyond. Also, researchers may use the findings to inform their survey research for providing a picture of the intrinsic challenges across entire school districts, for example. In addition, although the findings reveal intrinsic challenges that teachers experience, it is not clear how the challenges arise. Moreover, it is unclear to what extent the challenges may contribute to sustaining an orientation towards confirmation-based practical work and teaching practices that are inconsistent with IBSE. The answer to these questions may be useful towards enhancing practical investigations in South Africa and beyond. We see that the current findings could serve as a springboard towards a better understanding of the problems that teachers experience when designing and enacting practical investigations.

In summary, findings on intrinsic challenges linked to practical investigations

- add an instructional design perspective regarding these challenges in South Africa
- quantitatively and qualitatively increase the complexity of these challenges globally
- allow for teacher support that is appropriate and linked to routine classroom experiences, and
- suggest several lines of future research in South Africa and beyond.

Physical sciences teachers, professional development providers, and researchers, for example, are encouraged to consider the current findings and these implications in their work. This should contribute towards improving instructional design linked to practical investigations, thus fostering widespread reforms involving the incorporation of an inquiry-based approach to promote scientific practices, critical thinking and problem-solving in science classrooms.

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Authors' Contributions

FVA conceptualised the research, designed the methodology, gathered and formally analysed the data and wrote the initial draft manuscript. EG played a validation role, while both authors carried out the review and editing of the manuscript.

Notes

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