MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2021, 17(12), em2044
ISSN:1305-8223 (online)
OPEN ACCESS Review Article https://doi.org/10.29333/ejmste/11352

A Systematic Review Describing Contextual Teaching Challenges Associated With Inquiry-Based Practical Work in Natural Sciences Education

Fru Vitalis Akuma [1*], Estelle Gaigher [1]

[1] Department of Science, Mathematics and Technology Education, Faculty of Education, Groenkloof Campus, University of Pretoria, Private Bag X20, Hatfield 0028, SOUTH AFRICA

Received 3 June 2021 ▪ Accepted 23 October 2021

Abstract

There are many challenges associated with Inquiry-Based Practical Work (IBPW), scattered in the school and post-school natural sciences education research literature. The goal of the systematic review presented in this paper, was to gather the contextual teaching challenges in the said literature, and then to create a detailed multi-perspective description of these challenges. The result shows that, the challenges occur mostly in the northern hemisphere, the highest proportion is in the Upper- and Post-secondary education levels, and more than half of the challenges are in integrated natural sciences education settings. In addition, the challenges are deeply divided between the school- and system-levels of the education framework, with the emergence of seven categories that have not been reported before. While significantly increasing knowledge, the results can be used when supporting teachers implementing IBPW. This is in addition to informing future research, around teacher support and the further unravelling of the challenges.

Keywords: contextual teaching challenges, multi-perspective description, inquiry-based practical work, systematic review, school and post-school natural sciences education

INTRODUCTION

In this paper, we present a systematic literature review relating to Inquiry-Based Practical Work (IBPW), in school and post-school natural sciences education settings. We define this type of practical work as classroom, laboratory, or field activities, in which learners interact with natural phenomena, or with data about such phenomena. This is while enhancing their understanding of scientific inquiry as they develop scientific practices. This is based on a teaching and learning strategy that goes beyond verification inquiry and towards open inquiry. In this regard, however, there are contextual teaching challenges. We consider the challenges as factors in the educational environment (for example, an inadequacy in classroom space and managerial support), that hinder the efforts of any teacher, when implementing IBPW in that environment. The challenges restrict learner access to IBPW and the associated learning benefits. The goal of the review we present in this paper, was, first, to gather the challenges which are scattered in the international literature about natural sciences education, ranging from the school to post-school level. Next, was to create a detailed multi-perspective description of the challenges, in order to inform practice and further research. Below, we will begin by placing the research focus in context, before elaborating upon the focus.

Background Information

Practical work has been defined in broad terms, as classroom, laboratory, or field activities, that offer learners opportunities to directly interact with natural phenomena or with data about the phenomena, that have been gathered beforehand by other people (National Research Council, 2005a, 2006). The science education literature (Hodson, 2014; Jagodziński & Wolski, 2015; Kidman, 2012; Millar, 2009; National Research Council, 2006), identifies a number of primary learning goals relating to practical work. The goals include learning about science concepts; the characteristics of scientific inquiry, and the nature of science; coupled with developing the practices that are needed in scientific inquiry.

✉ f.v.akuma@gmail.com **(*Correspondence)** ✉ estelle.gaigher@up.ac.za

Contribution to the literature

- We have described contextual teaching challenges relating to Inquiry-Based Practical Work (IBPW) in school and post-school natural sciences education settings, from three new perspectives.
- The perspectives are geographical location, coupled with the level, and the field of natural sciences education.
- The challenges occur mostly in the northern hemisphere, with the highest proportion in the Upper- and Post-secondary education levels, and more than half in integrated natural sciences education settings.
- From an education framework perspective, seven new categories of the challenges such as quality of school texts, assessment practices, and developmental age, have emerged.

While scientific inquiry has been considered as a varied set of practices that scientists regularly use to address the questions they ask about the natural world (Bartos & Lederman, 2014; Maeng & Bell, 2013; National Science Teaching Association, 2018), the current research is associated with practical work that is orientated towards the development of these practices. The practices include asking questions, planning investigations, constructing explanations, coupled with acquiring, evaluating, and communicating information (Bell et al., 2010; National Research Council, 2012; Rönnebeck et al., 2016).

In educational contexts, the word "inquiry" does not have a unique meaning. In the literature (Bybee, 2000; Lunetta, 1998; National Research Council, 2000, 2007), one finds meanings that include 1) an instructional strategy aimed at increasing learner understandings of science concepts, coupled with 2) a learning outcome consisting of the acquisition of a) epistemological understandings of science, and b) scientific practices. The meaning of the term "inquiry" in 2b), is the meaning used in the research presented in this paper, as it coincides with the development of scientific practices primary learning goal in practical work.

In terms of the selected learning outcome and goal in practical work, classroom inquiry implementation strategies are not equally suitable. The strategies have been widely considered to consist, in principle, of verification, structured, guided, and open inquiry (Blanchard et al., 2010; Herron, 1971; Schwab, 1962). While these strategies are in order of increasing learner autonomy in the inquiry activity, open inquiry best allows a learner to develop scientific practices, whereas verification inquiry least supports learner development of the practices. The latter strategy is also referred to as the confirmatory, teacher-centred, and traditional strategy in practical work. Although Sadeh and Zion (2012) acknowledge that this strategy is effective in the development of observation, data gathering, inference generation and other basic science skills, some researchers (Nedungadi et al., 2015; Sadeh & Zion, 2012; Zion & Mendelovici, 2012) exclude verification inquiry when discussing classroom inquiry implementation strategies. Since verification inquiry involves a science question, data collection methods, and the interpretation of results all from the teacher (Abrams et al., 2007; Schwab, 1962), this strategy is actually not in line with the earlier noted meanings of the term "inquiry" in educational settings. In this light, and with reference to practical work, Bowen et al. (2018), argue that verification-based practical work does not involve inquiry. Thus, we consider the term verification-based practical work to mean classroom, laboratory, or field activities, in which learners interact with natural phenomena, or with data about such phenomena, with a focus on basic science skills such as observation and data collection, coupled with the verification of science concepts, in a teacher-driven manner.

The current research rather focused on practical work involving the critical engagement of learners, in line with the view presented by Bowen et al. (2018), and the description given by Sesen and Tarhan (2013) to an inquiry-based laboratory activity. This is a learning experience which not only engages learners in activities such as observing events and objects, but also asking questions, designing investigations, suggesting explanations, gathering and analyzing data, coupled with comparing suggested explanations with fresh evidence. Terms that some authors have used for such activities include science inquiry work (So, 2013), inquiry-based learning activities (Chairam et al., 2015), practical enquiry activities (Toplis & Allen, 2012), and Inquiry-Based Practical Work (IBPW) (Kim & Tan, 2010). We have used the term IBPW in the current research, to mean classroom, laboratory, or field activities, in which learners interact with natural phenomena, or with data about such phenomena, with emphasis on the development of scientific practices, based on a strategy that goes beyond verification inquiry and towards open inquiry. Thus, IBPW excludes verification-based practical work.

There is evidence of the learning benefits of IBPW in the literature. For example, Lavonen and Laaksonen (2009) found that the drawing of conclusions is a predictor of high learning outcomes in Finland. In the context of Israel, secondary school science students who took part in IBPW, were found to ask better questions, to better plan when dealing with variables in an experiment, in addition to making suggestions regarding more reliable and valid equipment (Hofstein & Lunetta, 2004).

Research Focus

Verification-based practical work, is predominant in many countries as evidenced by the natural sciences education literature (Abrahams & Millar, 2008; Childs et al., 2012; Di Fuccia et al., 2012; Ramnarain & Schuster, 2014; Sandoval et al., 2016). Although there is value in this type of practical work, its predominance is at the expense of IBPW, and may be obscuring challenges associated with IBPW.

Many teaching challenges associated with IBPW can be found in a scattered manner, in the international school and post-school natural sciences education research literature (Crawford, 2016; Duangpummet et al., 2019; Lederman & Lederman, 2012; Ramnarain, 2016). Although some of the challenges are teacher-based (Duangpummet et al., 2019; Ramnarain, 2016), the focus in the presented research was on the contextual challenges. We consider contextual teaching challenges relating to IBPW as factors in the educational environment (for example, an inadequacy in classroom space and managerial support), that hinder the efforts of any teacher, when implementing IBPW in that environment.

Limited research has been conducted to yield a detailed description of the challenges. Akuma and Callaghan (2019) provide a description based on a case study of physical science classrooms in two schools, and from the education framework perspective. In many countries, the framework consists of a national, regional, and school level. The case study yielded a description of the challenges that is a function of the specific challenges that were found in the research context. Although a description incorporating the many challenges that have been found in other contexts would enhance knowledge about the challenges, such a description is currently lacking. There is also the lack of a description incorporating other perspectives that researchers have used in the description of educational phenomena. An example is the level of education perspective, with levels ranging from early childhood education to the doctoral or an equivalent level (Minner et al., 2010). Another perspective is the field of education perspective (Park & Liu, 2016), involving for example, the physical sciences, environment, coupled with the biological and related sciences.

Given the discussion in the preceding paragraphs, the goal of the systematic review presented in this paper, was to gather the contextual teaching challenges relating to IBPW that are scattered in the international school and post-school natural sciences education research literature, and then to create a detailed multi-perspective description of the challenges. The description is an aggregation of the accumulated and dispersed international evidence about contextual teaching challenges relating to IBPW. As seen later in section *Discussion and Conclusions*, the description expands knowledge regarding the challenges, allows for both a sector-wise and systemic approach in addressing the challenges, while suggesting lines in future research.

CONCEPTUAL FRAMEWORK

Elaborating a Definition of Contextual Teaching Challenges for the Current Research

First of all, Schoepp (2005) defined a teaching challenge as a situation that hinders a teacher when working towards an outcome. In the current research, the 'outcome' is the successful implementation of IBPW. Regarding 'a situation that hinders a teacher' from reaching this outcome, Akuma and Callaghan (2019) considered hindrances associated with the physical, cultural, and social characteristics of an educational environment. An example of a cultural hindrance is found in Toplis and Allen (2012), who note that due to the high stakes assessment culture, IBPW is being limited to a few verified investigative activities that are disconnected from routine science instruction. Regarding a physical hindrance, we see in Kidman (2012), that some teachers cited limitations in classroom space as a key hindrance associated with the enactment of IBPW. In terms of the social characteristics of the educational environment, inadequate managerial support is a hindrance regarding the enactment of IBPW (Huziak-Clark et al., 2007; Ramnarain, 2011). Although space limitations and inadequate managerial support may occur only in some classrooms and schools, respectively, the same is not true of a high-stakes assessment culture. The environment in which teachers work, goes beyond a specific school (Clarke & Hollingsworth, 2002), to include the regional and national levels of the education framework, as seen later within section *Education framework perspective*. Contextual teaching challenges linked to IBPW can emanate from many aspects of this extensive professional environment.

Contextual teaching challenges can also be thought of, as challenges that emanate from outside what Clarke and Hollingsworth (2002) refer to as the personal domain of teachers. The personal domain, consists of intrinsic teacher attributes such as professional knowledge, beliefs and attitudes. For some teachers, there may be challenges linked to IBPW that are associated to these attributes. These would be teacher-based, and not contextual challenges, one of which Ramnarain (2016) identified as inadequate pedagogical content knowledge. In contrast to such challenges, a contextual challenge affects all teachers working in the context in which the challenge occurs. This makes limitations in classroom space, inadequate managerial support, a high-stakes assessment culture, examples of

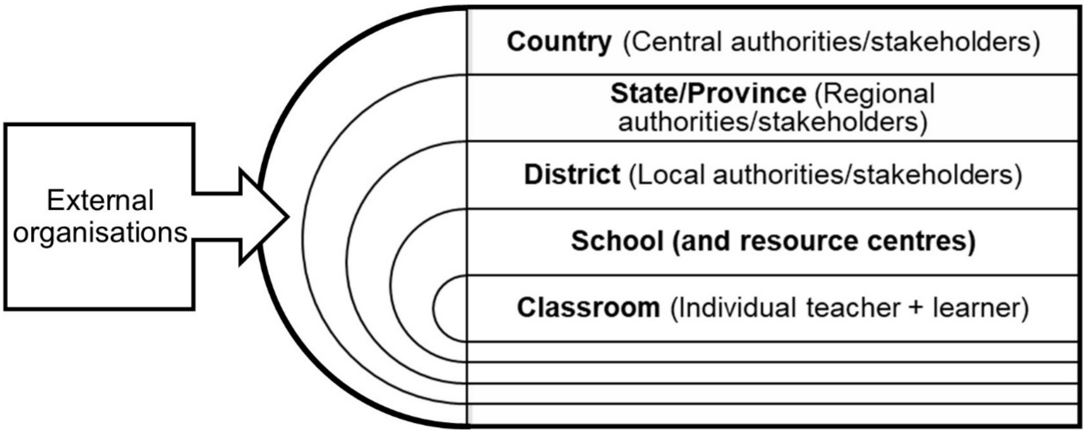

Figure 1. An education framework as occurs in many countries

contextual teaching challenges associated with IBPW at the classroom, school, and regional/national levels, respectively. Thus, we define a contextual teaching challenge relating to IBPW, as a context-based factor (for example, an inadequacy in classroom space and managerial support), that hinders the efforts of a teacher, in relation to the implementation of IBPW.

Perspectives Useful in Describing Contextual Teaching Challenges Relating to IBPW

Firstly, it has been noted that education is a complex endeavour, with multiple facets (Elmore, 1996). It is thus natural that educational phenomena have been described from different perspectives. The question here is that of the perspectives that may be used in creating a detailed description of contextual teaching challenges associated with IBPW. In this regard, we discuss the geographical location, education framework, level of education, and field of education perspectives.

Geographical location perspective

The country of origin of the research, has been used by some researchers when describing educational phenomena (Abelha et al., 2020; Heradio et al., 2018; Plomp & Nieveen, 2013). However, as Plomp and Nieveen (2013) note, the geographical location of the research must not be mistaken for the country where the researchers live. Also worthy of note, is the fact that some researchers rather specify the applicable continent when reporting the geographical location of the research. An example is Khan (2011), who reports the geographical location as North America. Different contextual challenges may be found in the same geographical location, such as Europe (Kennedy, 2013; Toplis & Allen, 2012), while similar challenges may be found in very different locations such as Africa and Asia (Childs et al., 2012; Kriek & Grayson, 2009).

Education framework perspective

Figure 1 illustrates the education framework in the context of many countries around the world, as reported in a number of literature sources (ET 2020 Working Group on Schools, 2018; Makoelle, 2012; National Research Council, 2015; Tichnor-Wagner et al., 2019).

In the framework in Figure 1, there are multiple interacting levels, a shared vision, the setting of expectations in the higher levels, and efforts to shape the system from lower levels (ET 2020 Working Group on Schools, 2018). The organisations mentioned in the left of the figure, include non-governmental educational institutions that create instructional materials (e.g., curriculum units and textbooks), or provide professional development.

Associated with the framework in Figure 1, are specific levels, as seen in the literature (Akuma & Callaghan, 2019; Jones, 2004). The levels consist of the system-level (national, state, or district), coupled with the school level. The scarcity of inquiry-based practical activities in some school science textbooks (Abd-El-Khalick et al., 2004; Crawford, 2016), is a system-level contextual teaching challenge associated with IBPW. The lack of valuing of classroom inquiry by some staff leaders (Huziak-Clark et al., 2007), is a school-level contextual teaching challenge.

System-level and school-level teaching challenges have been found to be material-related and/or non-material-related (Akuma & Callaghan, 2019; Pelgrum, 2001). The preceding examples are, material-related and non-material-related challenges, respectively.

Level of education perspective

Researchers have also described educational phenomena from the perspective of the level of education (Minner et al., 2010; Plomp & Nieveen, 2013). This perspective is reflected in the term "education sector" used by Plomp and Nieveen (2013). The International Standard Classification of Education (ISCED) offers a harmonised framework of levels, coupled with fields of education and training. The nine levels of education in ISCED 2011, are contained in the first two columns in Table 1 (UNESCO Institute of Statistics, 2020). The table also shows the mapping of the

Table 1. Mapping ISCED 2011 levels of education to two countries (UNESCO Institute of Statistics, 2020)

ISCED 2011 Level	South African equivalent		United States equivalent	
	Name	Theoretical starting age	Name	Theoretical starting age
0 Early childhood education	Grade R	5	Preschool or pre-kindergarten/ Kindergarten	2 – 4 4 – 6
1 Primary education	Primary education (Grades 1 – 7)	7	Primary education	5 – 7
2 Lower secondary education	Lower secondary education (Grades 8 – 9)	14	Middle education (Grades 7 – 9)	11 – 13
3 Upper secondary education	e.g., Further education training band (Grades 10 – 12)	16	H.S. Equivalency Programme / Secondary education (Grades 10 – 12)	16+ / 14 – 17
4 Post-secondary non-tertiary education	e.g., National Higher certificate	19	Certificate Program	18 – 30
5 Short-cycle tertiary education	National Diploma	20	e.g., Academic Associate's Degree Programme	18 – 30
6 Bachelor level education and equivalent	e.g., Bachelor's and Advanced diploma	19	e.g., Post-bachelor's certificate programme (e.g. teaching)	22 – 30
7 Master's or equivalent level	Master's	24	e.g., First Professional Degree Programme	22 – 30
8 Doctoral or equivalent level	Doctorate degree/Laureatus in Technology (Technikon)	26	Doctorate (Ph.D. – Research)	24 – 32

break down, in the case of two countries used as examples.

Table 1 can serve as a basis for describing contextual teaching challenges associated with IBPW in relation of the level of education in which the challenges were reported. For example, consider the case of the increased time needed for course completion and revision resulting from the integration of inquiry in practical work in the Junior Certificate science programme in Ireland (Higgins, 2009). This is a lower secondary education level (ISCED level 2) challenge linked to IBPW, in the given context. This is because the programme spans the first three years of post-primary education, and is commenced at an age of at least 12 years (National Council for Curriculum and Assessment, 2008). As a second example, Ramnarain and Schuster (2014) found in their research in high school physical sciences classrooms, that the lack of science education equipment is a challenge when attempting to implement IBPW. This challenge lies in the Upper secondary education level (ISCED level 3 in Table 1), since as seen in Department of Basic Education (2011), physical science is taught in grades 10 to 12.

Field of education perspective

This is another perspective that has been used by many researchers when describing educational phenomena (Park & Liu, 2016; Rutten et al., 2012). The ISCED for fields of education and training, identifies broad, narrow, and detailed fields of education and training (UNESCO, 2014). One of the broad fields is natural sciences, mathematics and statistics (Table 2).

We can use Table 2 when describing challenges associated with IBPW from the field of education perspective. From this perspective, the examples of

Table 2. Broad, narrow, and detailed fields of education involving the natural sciences (UNESCO, 2014)

Broad field	Narrow field	Detailed field
05 Natural sciences, mathematics and statistics	051 Biological and related sciences	0511 Biology 0512 Biochemistry
	052 Environment	0521 Environmental sciences 0522 Natural environments and wildlife
	053 Physical sciences	0531 Chemistry 0532 Earth sciences 0533 Physics
	054 Mathematics and statistics	0541 Mathematics 0542 Statistics

contextual challenges linked to IBPW from Higgins (2009), and Ramnarain and Schuster (2014), as seen in the end of the preceding section, can be considered to lie in the natural sciences broad field (Field 05) and the physical sciences narrow field (Field 053), respectively. Although this is obvious in the case of the example from Ramnarain and Schuster (2014), further information may be needed in relation to the Junior Certificate science programme in Ireland. The programme combines biology, chemistry and physics (National Council for Curriculum and Assessment, 2008), as a result of which the said challenge falls under Field 05 in Table 2.

The discussion in this section, illustrates how it is possible to create a description of contextual teaching challenges associated to IBPW, from four perpectives that have been used before, to describe educational phenomena. It may be worth noting that these perspectives are mutually exclusive, since given sufficient information, each contextual teaching challenge linked to IBPW, can be positioned in each of the different perspectives. As an example, consider the

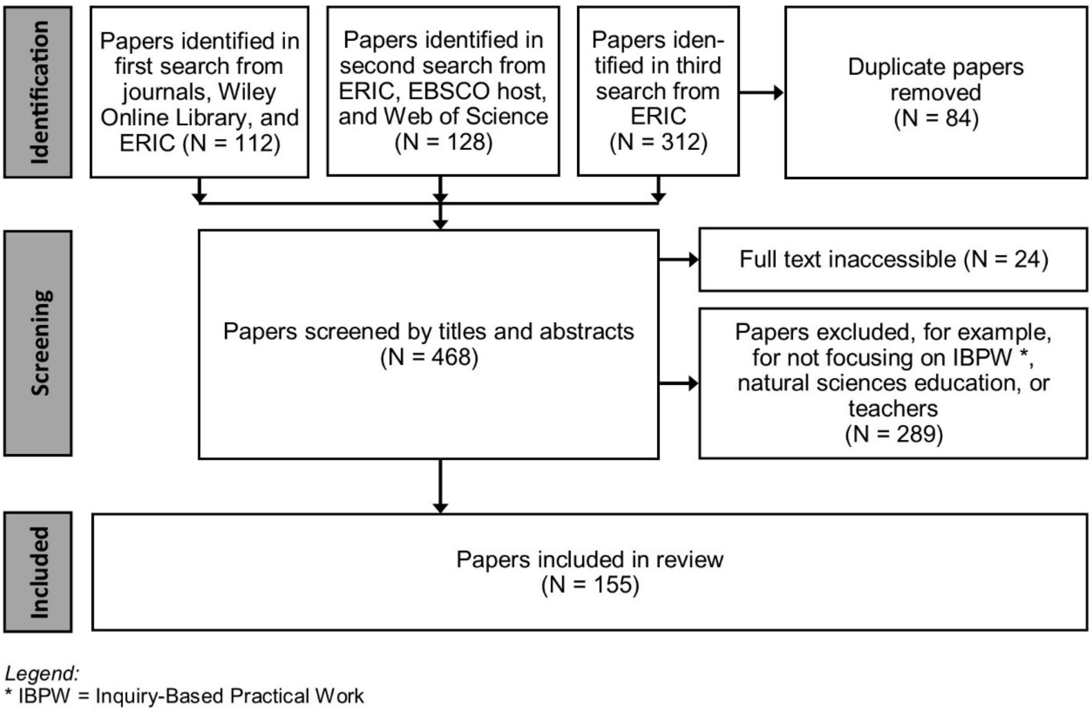

Figure 2. Summary of paper identification and screening (Adapted from the PRISMA 2020 flow diagram in Page et al., 2021)

challenge found by Ramnarain and Schuster (2014) in their research in high school physical sciences classrooms, that the lack of science education equipment is a challenge when attempting to implement IBPW. This challenge is identified in Africa (geographical location), in the physical sciences (field of education), in the Upper secondary education level (level of education), and is a school-level challenge (level of education framework).

Considering the purpose of the current research, we will next describe how we gathered the contextual challenges as defined in section *Elaborating a Definition of Contextual Teaching Challenges for the Current Research*, and then analysed them as illustrated throughout section *Perspectives Useful in Describing Contextual Teaching Challenges Relating to IBPW*, to create the desired detailed multi-perspective description of these challenges.

METHODOLOGY: A SYSTEMATIC REVIEW

A systematic review has been described as a review of the literature, that closely adheres to a set of techniques aiming to reduce bias in the identification, evaluation, and synthesis of all related research, in an effort to respond to one or more given questions (Petticrew & Roberts, 2006). In the presented research, the literature is the international school and post-school natural sciences education research literature regarding IBPW, while the question is that of a detailed multi-perspective description of the contextual teaching challenges linked to IBPW, that are found in this literature.

We carried out the systematic review, with reference to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 checklist (Page et al., 2021). We incorporated the guidelines in relation to reviews in the field of education that reflect the guidelines (Abelha et al., 2020; Henderson et al., 2011; Martin et al., 2019). In this regard, the first step was to state the goal of the literature review, which is to gather the contextual teaching challenges relating to IBPW that are scattered in the international school and post-school natural sciences education research literature, and then to create a detailed multi-perspective description of the challenges (section *Research focus*). The other steps which follow, go from searching for related research papers, to extracting and analysing the data.

Searching for Related Research Papers

To identify suitable papers, we conducted three searches, with the second and third searches meant to expand upon, and update the initial search. The searches are summarized in the first row in Figure 2. The total return from the three searches, was 552 papers including 84 duplicates. A detailed description of the three searches follows.

The first search was in 2017 and involved six online databases, of which three were journal databases. To the journal databases, we added Wiley Online Library and ERIC, to diversify the databases we used. The search terms were 'secondary school' AND 'science education' AND 'laboratory work' OR 'practical work' AND 'inquiry-based' AND 'investigative'. Thus, although this first search was restrictive in relation to the level of education (a weakness we addressed in subsequent searches), it was open in relation to the fields of natural science, geographical location, and education framework. While applying the search terms in the full text of the papers, we retained only papers with publication dates going back to 2007, as we desired at the time, to include only research that was within a ten-year period prior to the search date, in line with Rutten et al. (2012). The resulting search list contained 112 papers.

We carried out the second search for research papers in March 2019, in ERIC, EBSCO host, and Web of Science. This was based on the search terms we used before. However, to expand the data collection, this time, we did not restrict the search to the secondary school level, while also lowering the lower limit of the publication date range to 2000. Taking the case of EBSCO host as an example, the search settings we used were English (Language), January 2000 to February 2019 (publication date range), Full pdf-text available, Peer-reviewed journals, and Find all my search terms (Method). The search results from this second search consisted of 128 papers.

We conducted a third search for research papers to update and further expand the data collection in October 2019. The search was carried out in ERIC, in line with the criteria used in the second search. The result of the third search, was a list of 312 papers. This brings the total number of papers in the three search lists to 552. However, there were 84 duplicates, leaving 468 unique papers in the three search lists combined.

Screening the Search List for Papers to Include

This step which is summarised in the middle and bottom of Figure 2, started with a check of the availability of the full text of the 468 unique papers from the search for papers. After excluding 24 papers whose full text was not readily available, we screened the titles and abstracts of each of the remaining 444 papers, with reference to the search criteria noted earlier. In the process, we excluded many papers for not focussing on IBPW (e.g., Talanquer et al., 2015). We also excluded papers such as Corlu and Aydin (2016), which rather focussed on student self and peer assessment in mathematics and engineering education. We also found that many of the papers were not specifically on natural sciences education. Examples are papers focusing on vocational education (Boldrini et al., 2019), and active learning in general (Di Biase, 2019). In the end, the number of papers we could include from the three searches were 71, 54, and 30, respectively, bringing the total to 155 papers included in the current systematic review.

Coding the Included Papers

In order to identify the characteristics of the set of included papers, we used the following four mutually exclusive perspectives, according to the theoretical frame in section *Perspectives Useful in Describing Contextual Teaching Challenges Relating to IBPW*, to code the papers: geographical location (section *Geographical location perspective*), education framework (section *Education framework perspective*, Figure 1), level of education (section *Level of education perspective*, Table 1), and field of education (section *Field of education perspective*, Table 2). Since review papers involve research conducted in many different geographical locations, we did not code these papers in relation to geographical location. In general, we coded the 155 included papers to yield a coding sheet that is illustrated in Figure 3. The coding sheet shows, for example, that

Paper	Perspective			
	Geographical location [a]	Education framework [b]	Level of education (ISCED 2011 level) [c]	Field of natural sciences [d]
1. Abrahams and Reis (2012)	EU	I, C	1 – 2	05
2. Afra, Osta, and Zoubeir (2009)	AS	II	3	0533
3. Aksela and Boström (2012)	EU	II	2	0531
4. Alexakos (2010)	NA	II	N/A [e]	05
. . .				
155. Zuiker and Whitaker (2014)	NA	II	1	0533

Legend:

a
AF = Africa
AS = Asia
EU = Europe
NA = North America
OC = Oceania/ Australia
SA = South America

b
I = System-Level
C = Country-Level
S/P = State-/Province-Level
D = District-Level
II = School-Level

c
1 = Primary education
2 = Lower secondary education
3 = Upper secondary education
4 – 6 = Post-secondary non-tertiary education to Bachelor level education and equivalent

d
0511 = Biology
0512 = Biochemistry
0521 = Environmental sciences
0522 = Natural environments and wildlife
0531 = Chemistry
0532 = Earth sciences
0533 = Physics
05 = Natural sciences (General science, primary science, and combinations of specific natural sciences)

[e] N/A = Not Applicable (e.g., in the case of review papers) or Not Available

Figure 3. Excerpt of coding sheet for the included papers

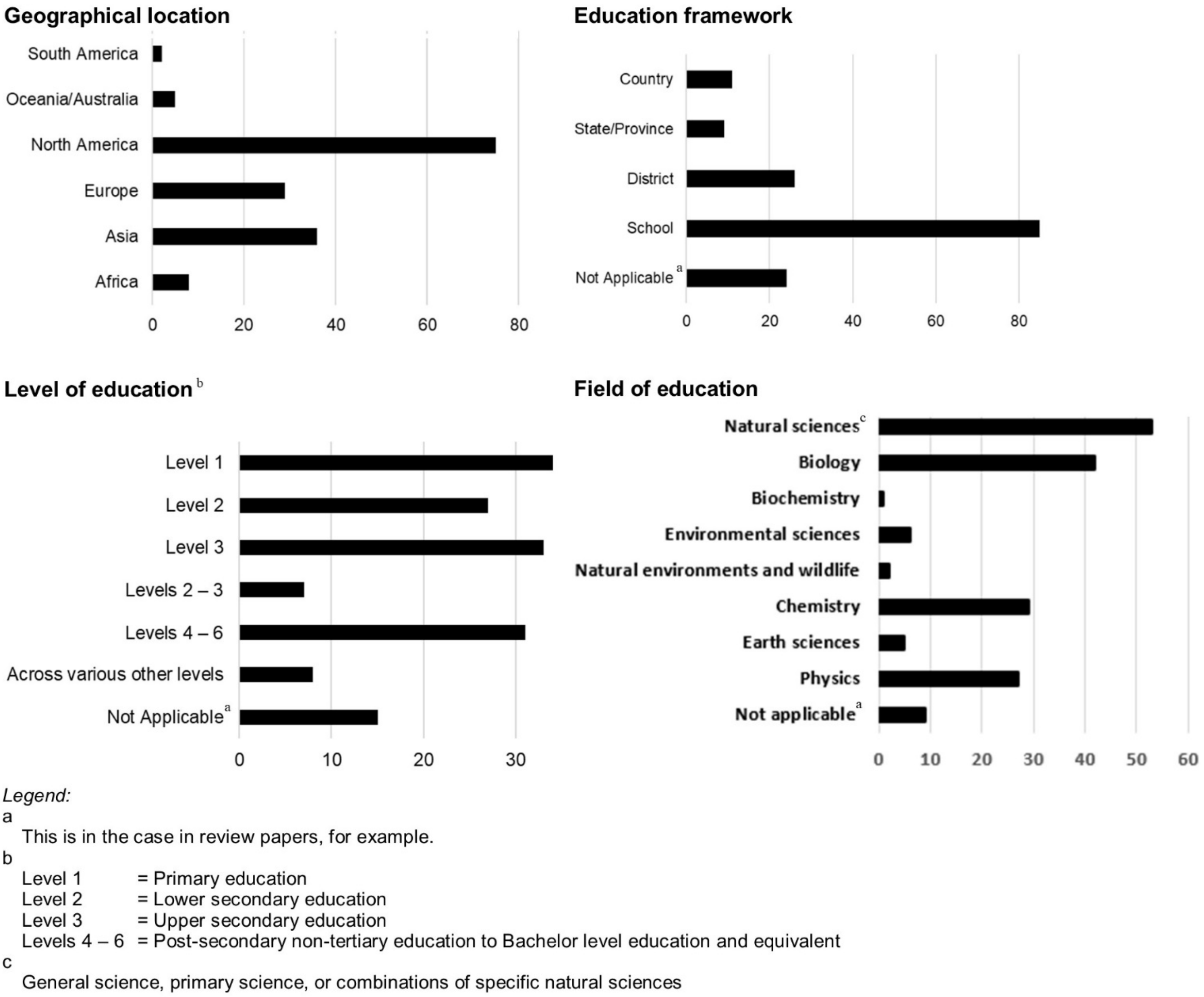

Figure 4. Characteristics of the included papers, from four perspectives

the first paper involves research carried out in Europe, at the system level country wide. Also, the research is at the primary to lower secondary education level, and in integrated natural sciences education settings.

By analysing the data in the coding sheet, we obtained the characteristics in Figure 4, for the 155 papers included in this systematic review.

In the top left of Figure 4, we see that although a relatively large proportion of the included papers come from North America, and also from Europe and Asia, a few come from the southern hemisphere. Overall, the figure shows that the included papers are diverse, in terms of falling in several categories, in each of the four perspectives covered. Thus, the coding of the set of 155 included papers, largely confirms the comprehensiveness, and thus the suitability of the set of papers, for use in this systematic review.

Extracting and Analysing the Data

First, we note that in this systematic review, data consisted of contextual teaching challenges associated with IBPW, with the challenges being factors in the educational environment (for example, an inadequacy in classroom space and managerial support), that hampers the efforts of any teacher, when implementing IBPW in that environment (section *Elaborating a Definition of Contextual Teaching Challenges for the Current Research*). Considering IBPW as practical work involving a strategy that goes beyond verification inquiry and towards open inquiry, contextual teaching challenges associated with verification-based practical work were not included as data in the current research.

To extract the contextual challenges linked to IBPW, we first read each of the 155 papers in detail. Only 66 articles yielded one or more challenges. We coded each challenge in the form CXx, where "C" stands for the word "Challenge", uppercase X is a serial number (1, 2, 3, and so on), and lowercase x, is a lowercase letter (a, b, c, and so on), used in cases where the same challenge is reported in different studies. The coding of the challenges in this way, is found in the first two columns in Appendix, which shows the challenge that each code

Table 3. An illustration of the categorization of the contextual challenges

Perspective	Examples of deductively-generated categories		Examples of inductively-generated categories
	Primary	Secondary	Tertiary
Education framework	School-level	Material related	Physical resources
		Non-material related	Learner-related difficulties
	System-level	Material related	Quality of school texts
		Non-material related	Curriculum design Assessment practices
Geographical location	Africa Europe		
Field of education	Physical science Biology		
Level of education	Lower secondary education Upper secondary education		

represents. In addition to serving as an inventory of the challenges, with a description of each, Appendix plays an important role in the data analyses and in the presentation of the results of the analyses.

The analyses of the coded challenges, involved both descriptive statistics and qualitative analysis, in line with Minner et al. (2010). In the qualitative analysis, we used the two strategies in thematic analysis, beginning with the *a priori* template of codes strategy (Crabtree & Miller, 1999), which proceeds from a theory to a phenomenon and is thus deductive. The second strategy, being inductive and data-driven (Boyatzis, 1998), proceeds from a phenomenon to a theory.

With reference to the deductive strategy, we first defined *a priori* categories of contextual teaching challenges. In the field of education perspective, the categories were from Table 1, in terms of the natural sciences, while in the level of education perspective, the categories were those in the first two columns in Table 2. This was coupled with the system-level and school-level categories from the education framework perspective (section *Education framework perspective*). In the system-level and school-level primary categories, material-related and non-material-related challenges were the secondary *a priori* categories.

In continuation of the data analyses, we assigned each identified contextual teaching challenge to the applicable category in each of the four perspectives as seen in the last four columns in Appendix. It is worth bearing in mind as explained in the end of section *Conceptual Framework*, that the four perspectives are mutually exclusive, as a result of which every challenge was assigned to a category under each perspective.

After assigning all the identified challenges as noted, the data analyses could proceed inductively, to yield emergent categories of the challenges. However, we found that this aspect of the data analysis was meaningful in the case of the education framework perspective only. Table 1 and Table 2, already provide the basis for a detailed description of the challenges from the level of education, and field of natural sciences education perspectives, respectively. Regarding the geographical location perspective, the information in this regard in most research papers is usually rather broad, to protect the identity of participating institutions and respondents. As a result, the challenges could not be inductively analysed from this perspective as well.

The deductive coding is illustrated in the first three columns in Table 3, while inductive coding is illustrated in the fourth column, which contains examples of inductively-generated categories of the challenges.

To yield the inductively-generated categories of challenges that are exemplified in the last column in Table 3, we utilised the method of constant comparison due to Strauss and Corbin (1990), with the specific challenges in each secondary category of the challenges. In the process, we found some challenges to be identical, although reported in different research contexts. For example, see C1a, and C1b in Appendix. We also found similarities in some of the challenges, allowing the inductively-generated tertiary categories of the challenges to emerge from the data.

After the deductive and inductive qualitative data analyses, we generated descriptive statistics in line, for example, with Rutten et al. (2012). The statistical analysis involved counting the challenges in each deductively- and inductively-generated category.

RESULTS

The detailed multi-perspective description of contextual teaching challenges relating to IBPW from our systematic literature review, involves 47 unique challenges. With 13 of the challenges occurring in more than one geographical location, there are 66 occurrences of the challenges. The description of these challenges that we present in this section, is based on Appendix, as noted in the preceding section. We first present the deductively-generated aspect of the description of the challenges. The inductively-generated aspect, which is from the education framework perspective only, as explained within section *Extracting and Analysing the Data*, then follows.

In both aspects of the description, we have used the codes of specific challenges, described in section

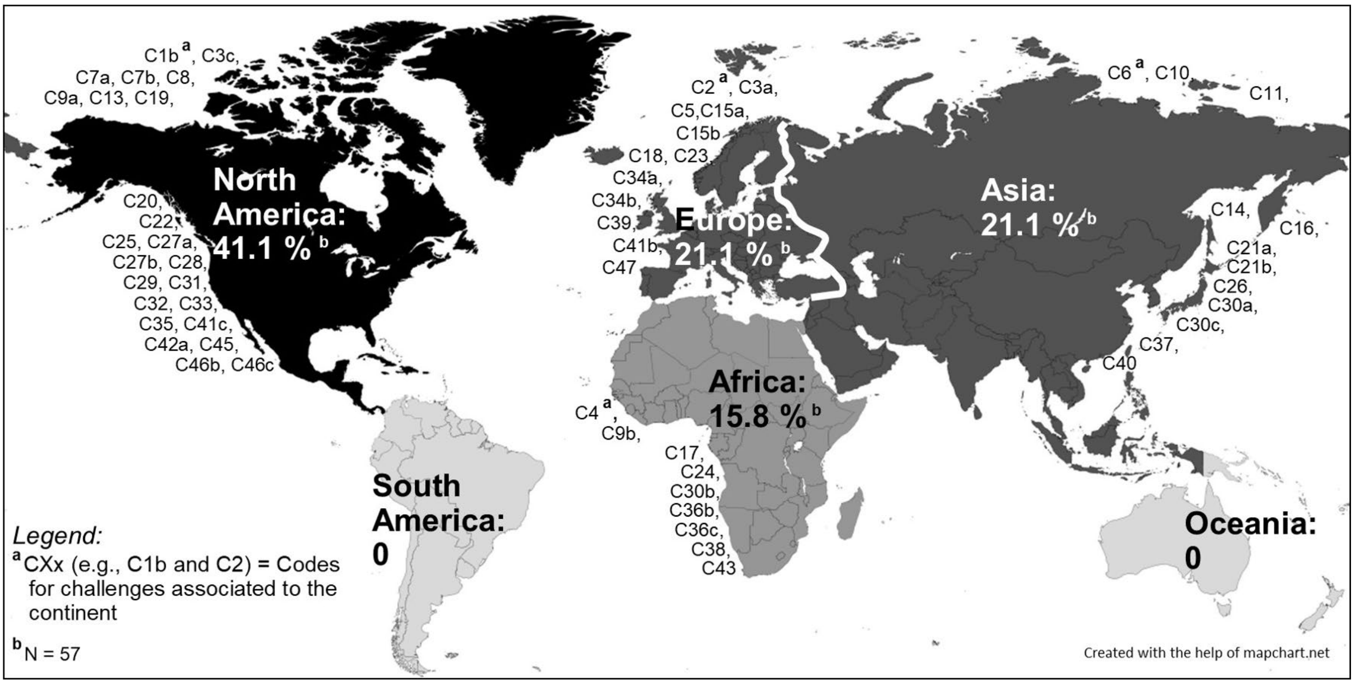

Figure 5. Distribution of the contextual teaching challenges linked to IBPW by geographical location

Extracting and Analysing the Data, and in relation to Appendix. Specifically, much of the description may need to be read in conjunction with the first two columns in Appendix.

Deductively-Generated Description of the Challenges

Geographical location perspective

In this regard, although the 47 challenges have 66 reported occurrences, we could not find the geographical location of nine of the occurrences, with the available information. The geographical locations for the remaining 57 occurrences are widely distributed across much of the globe, although mostly in the northern hemisphere (Figure 5). The largest proportion of the identified locations occur in North America, which accounts for about 41 % of the challenges, while Europe and Asia harbour nearly 21 % of the challenges each. While almost 16 % of the located challenges occur in Africa, we did not locate any of the challenges in South America and Australia/Oceania. Although we didn't find the geographical location for nine of the challenges and didn't locate any of the remaining challenges in South America and Oceania, the located challenges are nevertheless widely distributed by being spread over four continents, especially in the northern hemisphere.

Read in conjunction with the first two columns in Appendix, Figure 5 shows the continent where particular challenges have been reported. For example, C26, which says the activities in manuals for practical work are usually restricted to structured inquiry, is one of the twelve challenges reported in Asia, as can be seen in the top right of Figure 5.

Level of education perspective

We could not determine the level of education in which more than a fifth of the 47 challenges fall, as seen at the bottom of Table 4. However, we found that the remaining challenges are diverse in terms of the level of education in which they fall. This is as they span the Primary to Post-secondary education levels, with many identified in research that cuts across levels of education, as seen towards the top and the lower middle, in Table 4. The specific levels with the highest proportion of the challenges are the Upper- and Post-secondary education levels with about 18 % of the challenges each, while the specific level with the lowest proportion of the challenges is the Primary education level, with about 8 % of the challenges.

In each of the different levels and range of levels of education, the codes for the specific challenges occurring in the level, are listed in the last column on the right, in Table 4. Based on the codes and Appendix, the challenges in the different levels of natural sciences education can be identified. For example, C45 which is reported in the primary education level, says the unavailability of equipment (e.g., hot plate) limits the investigations that teachers can allow their learners to perform.

Field of education perspective

We could not identify the field of natural sciences education for about a fifth of the 66 occurrences of the 47 contextual teaching challenges, based on the available information. Regarding the remaining occurrences of the challenges, more than half are in integrated natural sciences education settings, as seen on the left, in the last row in Table 5. A relatively much smaller proportion of

Table 4. Description of contextual challenges regarding IBPW [a] from the level of education perspective

Category	Proportion of challenges (%)	Specific challenges [b]
Primary education	7.6	C1b, C20, C41b, C45 and C46
Lower secondary education	10.6	C5, C9b, C15a, C18, C34b, C39, and C47
Upper secondary education	18.2	C4, C6, C11, C13, C17, C19, C22, C24, C26, C37, C38, and C43
Post-secondary education	18.2	C3c, C9a, C14, C25, C27a, C27b, C30b, C32, C33, C36c, C40, and C41c
Across several levels	18.2	C2, C3a, C7b, C10, C16, C21a, C21b, C23, C30a, C31, C34a, C35, C36b, and C42a
Unknown level (s) [c]	24.2	C1a, C3b, C7a, C8, C12, C15b, C28, C29, C30c, C34c, C36a, C41a, C42b, C44, C46a, and C46b

[a] IBPW = Inquiry-Based Practical Work

[b] Note: The codes in the column, represent specific challenges described in Appendix

[c] The case of challenges picked up, for example, from review papers, while the cited paper is not accessible.

Table 5. Description of contextual challenges regarding IBPW [a] from field of education perspective

Category	Proportion (%)	Specific challenges [b]
Physics	1.5	C36b
Physical sciences	9.1	C4, C17, C24, C30b, C38, and C43
Biology	12.1	C3c, C6, C11, C20, C26, C37, C41b, and C41c
Unknown field (s) [c]	19.7	C1a, C3b, C10, C12, C21b, C30c, C34c, C36a, C41a, C42b, C44, C46a, and C46b
Integrated natural sciences [d]	57.6	C1b, C2, C3a, C5, C7a, C7b, C8, C9a, C9b, C13, C14, C15a, C15b, C16, C18, C19, C21a, C22, C23, C25, C27a, C27b, C28, C29, C30a, C31, C32, C33, C34a, C34b, C35, C36c, C39, C40, C42a, C45, C46c, and C47

[a] IBPW = Inquiry-Based Practical Work

[b] Note: The codes in the column (for example C33 and C46c) represent specific challenges described in Appendix.

[c] The case of challenges picked up, for example, from review papers, while the cited paper is not accessible

[d] Examples are general science, primary science, and combinations of specific natural sciences

Table 6. Description of the contextual challenges regarding IBPW [a], from the education framework perspective

Category		Proportion (%)		Specific challenges [b]
Primary	Secondary			
School-level	Non-material-related	19.7	45.5	C9a, C9b, C11, C13, C18, C22, C24, C25, C27a, C27b, C32, C37, and C38
	Material-related	25.8		C4, C7a, C7b, C14, C15a, C15b, C19, C30a, C30b, C30c, C31, C36a, C36b, C36c, C40, C43, and C45
System-level	Material-related	6.1	54.6	C26, C42a, C42b, and C47
	Non-material-related	48.5		C1a, C1b, C2, C3a, C3b, C3c, C5, C6, C8, C10, C12, C16, C17, C20, C21a, C21b, C23, C28, C29, C33, C34a, C34b, C34c, C35, C39, C41a, C41b, C41c, C44, C46a, C46b, and C46c

[a] IBPW = Inquiry-Based Practical Work

[b] Note: The codes (for example C12 and C34a) in the column, represent specific challenges as seen in Appendix.

the occurrences are in physical sciences and biology education, respectively, with a negligible proportion in physics education settings, as seen towards the top left of the table.

Down the third column in Table 5, we see the codes for the specific challenges associated with each field of natural sciences education. For example, using Appendix, we see that C6, which is reported in research focusing on biology education, says that many teachers did not have the opportunity to experience scientific inquiry, during their prior and teacher education.

Education framework perspective

The description of the 66 occurrences of the 47 contextual teaching challenges in relation the level of the education framework in which each occurs, is found in Table 6.

As seen in the first two columns in Table 6, the contextual teaching challenges linked to IBPW, occur at the system and school levels. In the system level, the non-material-related challenges are predominant, unlike the case at the school level. We see this in the proportions of the challenges in the third column in the table. The proportions in the fourth column show that the challenges are deeply divided between the system- and the school-level of the framework. In general, the challenges are diverse, from the educational framework perspective.

The codes in last column in Table 6, show which specific challenges lie in the corresponding primary and/or secondary category of the challenges. Reading this column in conjunction with Appendix, allows one to find the specific challenges in each category. Consider, for example, C21a and C21b, in the non-material-related system-level category. The challenge as seen in

Appendix says that curricula often emphasise learner mastery of content, rather than the enhancement of their investigative skills.

Overall, considering Figure 5, coupled with Tables 4, 5 and 6, the 47 contextual teaching challenges linked to IBPW that are reported in 66 instances, are considerably diverse, given that they are spread over a number of categories from the perspectives of the geographical location, field of education, level of education, and education framework. The preceding results are all linked to the deductive component in the data analysis. This is unlike the subsequent results, which are the outcomes of the inductive component of the analysis. As explained within the sixth paragraph in section *Extracting and Analysing the Data*, the subsequent results are solely from the education framework perspective.

Inductively-Generated Description of the Challenges: Education Framework Perspective

It may be worth recalling that the description of the challenges from the education framework perspective resulting from the deductive data analysis, involved primary and secondary categories of the challenges. Due to the inductive data analysis, we found twelve tertiary categories of the challenges across the different primary and secondary categories. The tertiary categories are listed in the first column in Table 7. The proportion of challenges in each tertiary category is found in the second column in the table.

In Table 7, the proportion of challenges in some tertiary categories is considerably higher. Examples are the Time constraints, Developmental age, and Physical resources tertiary categories. Compared especially to these categories, the proportion of challenges in the Large classes tertiary category is relatively low.

Next, is a presentation of the challenges in each tertiary category in Table 7. This is within the framework of the different primary and secondary categories. It is worth bearing in mind that only the abridged version of most of the challenges are used, with the full version available in Appendix. To link the two versions, we have used superscripts consisting of the codes for each challenge (for example, [C26] and [C42a]), following the statement of the challenge.

System-level: Material-related tertiary categories

Quality of school texts. While inquiry-based activities are scarce in some school science textbooks (Abd-El-Khalick et al., 2004; Crawford, 2016) [C42a, C42b], the activities in manuals for practical work, are usually restricted to structured inquiry (Zion, Cohen, & Amir, 2007) [C26]. It has been claimed that finding genuinely open-ended problems that can be investigated in the classroom is difficult (Kind et al., 2011) [C47].

Table 7. Further description of contextual challenges regarding IBPW [a] from the education framework perspective

Tertiary category [b]	Proportion of challenges (%)
Large classes [II, A]	2.1
School culture [II, B]	6.4
Quality of school texts [I, A]	6.4
Curriculum design [I, B]	6.4
Assessment practices [I, B]	6.4
Teacher education [I, B]	6.4
Classroom and laboratory facilities [II, A]	8.5
Learner-related difficulties [II, B]	8.5
Teacher support [II, B]	8.5
Physical resources [II, A]	12.8
Developmental age [I, B]	12.8
Time constraints [I, B]	14.9

[a] IBPW = Inquiry-Based Practical Work
[b] Note: The superscripts in this column, indicate, first, the associated primary category (I or II), then the secondary category (A or B):
I = System-level
II = School-level
A = Material-related
B = Non-material-related

System-level: Non-material-related tertiary categories

Curriculum design. A curriculum was found to have only a few broad ideas linked to experiments and process skills (BouJaoude cited in Abd-El-Khalick et al., 2004) [C16], while another curriculum requires that only two practical activities be assessed per grade (Dudu & Vhurumuku, 2012) [C17]. In addition, curricula often lack emphasis on the enhancement of the investigative skills of learners (Childs et al., 2012; Dai et al., 2011) [C21a and C21b].

Assessment practices. While the skills developed by some learners from carrying out open-ended inquiry are either not assessed or inadequately recognized (Abrahams & Reis, 2012; Higgins, 2009; Lederman & Lederman, 2012) [C34a, C34b and C34c], due to a high stakes assessment culture, IBPW is being limited to a few verified activities (Toplis & Allen, 2012) [C2]. In addition, standardised-assessments often require strategies based on more passive techniques, at the expense of IBPW (Minner et al., 2010) [C35].

Time constraints. There is evidence that IBPW requires more time than verification-based practical work (Abrahams & Reis, 2012; Anderson, 2007; Carlin, 2010) [C3a, C3b, and C3c]. Allowing students with the time they need to develop their inquiry plans can be difficult (Jordan et al., 2011) [C33], with inquiry needing time, for example, to design experiments and communicate the findings (Keen-Rocha, 2005) [C8]. As a result, instructors occasionally avoid inquiry-based activities (Keen-Rocha, 2005) [C28], and limit practical work to a small number of verified investigations (Toplis & Allen, 2012) [C23]. Also, some teachers implement the minimum of 'full inquiry' that is required towards the assessment of practical investigations (Dai et al., 2011) [C10]. It has also been found that the integration of inquiry in practical work, affected the duration of the learning programme (Higgins, 2009) [C39].

Developmental age. It has been found that reading literature on scientific inquiry, can be difficult for young learners (Baker et al., 2002) [C29], and that science questions do not freely arise from learners (Chin & Osborne, 2008) [C12]. Also noted is the fact that asking relevant and productive science-related questions is rather difficult, especially for children of preschool age (Bell et al., 2010; Ergazaki & Zogza, 2013; Marbach-Ad & Sokolove, 2000) [C41a, C41b and C41c], while hypothesis testing is very hard for young people (Klahr, 2000; Kuhn & Dean, 2005) [C1a and C1b]. Young children may not have the cognitive resources that adults possess, in relation to designing controlled experiments and evaluating their models (Klahr, 2000; Kuhn & Dean, 2004; Masnick & Klahr, 2003) [C46a, C46b and C46c]. Investigations have been found to often lead to new lines of learner questions that teachers are not ready to pursue, given the young age of the learners (Samarapungavan et al., 2008) [C20].

Teacher education. While many teachers did not experience scientific inquiry during their prior and teacher education (Zion et al., 2007) [C6], the successful enactment of inquiry-based science projects, tends to require extended professional support (Lederman & Lederman, 2012) [C44]. A critical hindrance that some teachers are confronted with in relation to IBPW, is the lack of nationwide teacher professional development (Higgins, 2009) [C5].

School-level: Material-related tertiary categories

Classroom and laboratory facilities. The facilities needed has been noted as an obstacle to classroom inquiry (Baker et al., 2002; Jackson & Boboc, 2008) [C7a and C7b], with some teachers citing limitations in classroom space as a key hindrance associated with IBPW (Kidman, 2012) [C14]. Also, researchers have found that science laboratories are absent or have limitations, especially in schools in rural settings (Childs et al., 2012; Kriek & Grayson, 2009; VanBalkom & Sherman, 2010) [C30a, C30b and C30c], as a result of which it is not easy for teachers to have access to science laboratories (Higgins, 2009; Kennedy, 2013) [C15a and C15b].

Large classes. Teachers of a township school interviewed about learners doing inquiry, cited the large classes they teach as a challenge (Ramnarain, 2014) [C43]. Such classes cause teachers to resort to didactic pedagogy.

Physical resources. Barriers to student inquiry include the materials needed (Jackson & Boboc, 2008) [C31]. For example, an attempt to engage several groups of students in the investigation of a lake ecosystem, met with difficulties given the need for multiple sets of technologies (including a digital titrator and veneer sensors) (Ebenezer et al., 2011) [C19]. There is a short supply of conventional natural sciences education materials and equipment in many schools (Kapanadze & Eilks, 2014; Qhobela & Moru, 2014; Singh & Singh, 2012) [C36a, C36b and C36c], with teachers foreseeing that the lack of physical resources would be a key hindrance when implementing the inquiry component of a new science curriculum (Kidman, 2012) [C40]. Actually, the unavailability of equipment (e.g., hot plate), limits the investigations that teachers can allow their learners to perform (Capobianco & Thiel, 2006) [C45], in addition to limiting the use of IBPW by some teachers (Ramnarain & Schuster, 2014) [C4].

School-level: Non-material-related tertiary categories

Learner-related difficulties. In some classrooms, IBPW is seriously constrained by the lack of prior learner experience (Ramnarain & Schuster, 2014) [C38]. Although the participation of learners in the formulation of a researchable question is crucial in open inquiry, this type of inquiry depends on the cognitive abilities of learners (Zion & Mendelovici, 2012) [C37], with some learners struggling, for example, to link an inquiry question to the associated phenomenon, design an experiment, handle equipment, and select suitable methods (Zion et al., 2007) [C11]. Inadequacies in their competencies, constrained some high school learners when conducting full inquiry (Gengarelly & Abrams, 2009) [C13].

Teacher support. In some schools, teachers suffer from inadequate managerial support in relation to IBPW (Huziak-Clark et al., 2007; Ramnarain, 2011) [C9a and C9b], or from the absence of laboratory assistants (Higgins, 2009) [C18]. The lack of valuing and pressure from parents could hinder the use of inquiry-based activities in classroom (Crawford, 2007; Huziak-Clark et al., 2007) [C27a and C27b]. Also, some teachers have been found to face the lack of valuing of inquiry-based activities, by their colleagues (Huziak-Clark et al., 2007) [C25].

School culture. School context is another factor that could inhibit success in teaching science as inquiry (Crawford, 2007) [C32]. School ethos which is significantly constraining the use of IBPW by some teachers (Ramnarain & Schuster, 2014) [C24], can take the form of the lack of learner motivation and inadequate prior experience (Gengarelly & Abrams, 2009) [C22].

DISCUSSION AND CONCLUSIONS

Recall that the goal of the systematic review presented in this paper, was to gather the contextual teaching challenges relating to IBPW, that occur in a dispersed manner, in the international school and post-school natural sciences education research literature, and to then create a detailed multi-perspective description of challenges. The 47 challenges with 66 reported occurrences that we found, fall in multiple categories from the perspective of the geographical location, level of education, field of natural sciences education, and educational framework level (Figure 5, and Tables 4 – 6, respectively). Thus, the challenges are many in number and occurrences, in addition to being diverse considering the four different perspectives.

Contribution

Descriptions of contextual teaching challenges linked to IBPW such as the current study, are rare in the international research literature about school and post-school natural sciences education. The only readily available description appears to be one from a case study of physical science classrooms in two non-fee-paying South African schools (Akuma & Callaghan, 2019). The case study describes the contextual teaching challenges linked to IBPW from the education framework perspective only. From this perspective, however, there are differences between the existing description (Akuma & Callaghan) and the current one. For example, there are eight tertiary categories of the challenges in the existing description, unlike in the current results where there are twelve. The number of newly identified tertiary categories is seven and consist of Quality of school texts, Assessment practices, Developmental age, Teacher education, Large classes, Teacher support, and School culture. Although this is a significant addition to our knowledge about the teaching challenges, even more striking, is the fact that the current results provide a description of the contextual teaching challenges associated with IBPW, from three perspectives that have not been used before in describing the challenges. The new perspectives which significantly improve the existing description of these challenges, are the level of education, field of natural sciences education, and geographical location (section *Deductively-Generated Description of the Challenges*).

Overall, the current description of contextual teaching challenges associated with IBPW adds new perspectives and detail to the existing description of the challenges. When a phenomenon is described in detail, this helps in uncovering the complex nature of the phenomenon (Rozenszajn & Yarden, 2014). The description of contextual teaching challenges associated with IBPW achieved in this study, presents our response to calls for a detailed picture of teaching challenges. Although the calls are, for example, in relation to practical work (Nivalainen et al., 2010) and the incorporation of inquiry-based strategies in natural sciences education (Crawford, 2007), we address the intersection of these two domains in the current research, and in terms of contextual teaching challenges linked to IBPW. In this regard, the results also show that contextual teaching challenges relating to IBPW, cut across levels of the education framework, levels of education, and fields of natural sciences education, while being scattered in locations across continents.

At a broader level, the current results make another contribution. This is in the sense that they complement existing descriptions of teacher-based teaching challenges associated with IBPW (Akuma & Callaghan, 2018), allowing for a more holistic understanding of the teaching challenges associated with IBPW.

Implications

The presented results have research-, and practice-based implications. Regarding the practice-based implications, it has been noted that the successful implementation of science education reforms in general, and in inquiry-based science education, requires extended teacher support, even in the case of experienced teachers (Lederman & Lederman, 2012; National Research Council, 2015). It has been noted that to provide teachers the support they need, it is necessary to have an understanding of the difficulties that they face (Harris & Rooks, 2010). The presented results inform understanding regarding challenges relating to IBPW, along four perspectives: level of education, field of natural sciences education, geographical location, and education framework.

Independent of the perspective, the results seem to suggest that there is the need for more teacher support in relation to specific categories, considering the relative proportions of the challenges. The most attention appears to be needed, for example, in North America (Figure 5), in the Upper secondary education and Post-secondary education levels (Table 4); and in Integrated natural sciences education settings (Table 5). From the education framework perspective, the system-level non-material related category, appears to need the most attention (Table 6). In this secondary category, the specific tertiary categories seeming to need more attention are the Time constraints category and the Developmental age categories (Table 7). While suggesting categories that may need more attention when providing teachers support, the results allow for a focus on specific challenges, as a function of the given geographical location, level of education, field of natural sciences education, and education framework level. In this regard, Figure 5, and Tables 4 – 6, respectively, provide codes for the specific applicable challenges, as decoded in the first two columns in Appendix. In the specific case of the education framework perspective (Tables 6 and 7), the applicable challenges can also be found using section *Inductively-Generated Description of the Challenges: Education Framework Perspective*, where the codes appear as superscripts in the end of statements of the corresponding challenges.

For actually providing teachers support in relation to each of the many and diverse challenges identified, there may be the need for a systematic search of the research literature in terms of identifying possible strategies. Taking the Time constraints category as an example, a possible strategy seen in National Research Council (2005b), is block-scheduling, wherein time could be freed in the school timetable for inquiry. On this basis, instead of classes taking place every day for 40 or 45 minutes, they come together after each other day, during longer periods of about 90–100 minutes. However, this strategy is not necessarily applicable everywhere, thus the need to identify other possible strategies. Another research-related implication lies in the relatively large differences in the proportion of challenges in the different categories under each of the four perspectives used in the analyses. Examples are Africa and North America (Figure 5); Primary and Upper secondary education (Table 4); coupled with Biology and Integrated natural sciences (Table 5). In this regard, one question that arises is whether some categories of the challenges are under researched. A third research-related implication of the current results, is linked to the fact noted by Rozenszajn and Yarden (2014), that a detailed description of any phenomenon (in this case the contextual teaching challenges associated with IBPW), assists in tracking the evolution of the phenomenon. This suggests that the description of the challenges reflected in Figure 5, and in Tables 4 – 7, could be used in longitudinal studies on the evolution of contextual teaching challenges linked to IBPW. It has been noted that by identifying the discrete categories of a concept, researchers can better create data collection instruments to arrive at knowledge about specific categories (Abell, 2008). Thus, as the fourth research-related implication this systematic review, researchers are encouraged to zoom into, for example, the different tertiary categories of the challenges shown in Table 7.

CONCLUSION

The presented systematic review, significantly increases knowledge about the complexity of the contextual teaching challenges relating to IBPW, that occur in school and post-school natural sciences education settings. This is with the introduction of three new perspectives in the description of the challenges, coupled with more and new categories, considering the previously reported description from the education framework perspective. The challenges occur mostly in the northern hemisphere, with the highest proportion occurring in the Upper secondary and Post-secondary education levels. In addition, more than half of the challenges occur in integrated natural sciences education settings, while being deeply divided between the system- and the school-levels of the education framework.

The existence of these challenges, which appear systemic from the different perspectives, coincides with the predominance of verification-based practical work in natural sciences education settings in many countries around the world. While there is value in this type of practical work, its dominance is not surprising, given the many and diverse contextual challenges associated with IBPW as seen in this systematic review. Contextual challenges relating to IBPW, are definitely limiting the implementation of practical work that critically engages learners towards the development of scientific practices.

The research results allow for a systemic and a sector-wise approach, when supporting teachers in the implementation of IBPW. The results also suggest possible lines in future research towards better supporting teachers and further unravelling the contextual challenges associated with IBPW. The thus informed future efforts of researchers and teacher support providers, should contribute towards greater use of practical work that focuses on critical learner engagement in the development of scientific practices and the understanding of scientific inquiry.

Author contributions: All authors have sufficiently contributed to the study, and agreed with the results and conclusions.

Funding: No funding source is reported for this study.

Declaration of interest: No conflict of interest is declared by authors.

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APPENDIX

Inventory and Coding Sheet for the Contextual Challenges

Challenge		Description perspective			
Code	Statement of challenge, with citation to associated paper	Geographical location [a]	Education framework [b]	Level of education [c]	Field of education [d]
C1a	Developmental research has suggested that hypothesis testing is a concept that is	N/A [e]	I, B, e	N/A	N/A
C1b	very hard for young people to acquire (Klahr, 2000; Kuhn & Dean, 2005) [C1a, C1b].	NA [f]	I, B, e	1	05
C2	Due to a high stakes assessment culture, IBPW is being limited to a few verified investigative activities that are disconnected from routine science instruction (Toplis & Allen, 2012).	EU	I, B, b	2 – 3	05
C3a	There are concerns, claims and findings to the effect that the enactment of IBPW	EU	I, B, d	1 – 2	05
C3b	requires more time in relation to traditional practical work (Abrahams & Reis, 2012;	N/A	I, B, d	N/A	N/A
C3c	Anderson, 2007; Carlin, 2010) [C3a, C3b, C3c].	NA	I, B, d	4 – 6	0511
C4	The lack of science education equipment is also constraining some teachers from using an inquiry-based strategy in practical work (Ramnarain & Schuster, 2014).	AF	II, A, i	3	053
C5	A critical hindrance some teachers are confronted with in relation to IBPW, is the lack of nationwide teacher professional development to assist them implement an inquiry-based strategy in practical work (Higgins, 2009).	EU	I, B, f	2	05
C6	Many teachers did not have the opportunity to experience scientific inquiry, during their prior and teacher education (Zion, Cohen, & Amir, 2007).	AS	I, B, f	3	0511
C7a	It has been noted that the obstacles to classroom inquiry include the facilities	NA	II, A, g	N/A	05
C7b	needed (Baker, Lang, & Lawson, 2002; Jackson & Boboc, 2008) [C7a, C7b].	NA	II, A, g	2 – 3	05
C8	Inquiry needs time for students to, for example, design experiments, acquire materials, collect data, coupled with communicating their findings (Keen-Rocha, 2005).	NA	I, B, d	N/A	05
C9a	In some schools, inadequate managerial support is a constraining factor regarding	NA	II, B, k	4 – 6	05
C9b	the enactment of IBPW (Huziak-Clark et al., 2007; Ramnarain, 2011) [C9a, C9b].	AF	II, B, k	2	05
C10	Time constraints may lead teachers to implement the minimum of 'full inquiry' that is required to satisfy the curriculum requirement on the assessment of practical investigations (Dai, Gerbino, & Daley, 2011).	AS	I, B, d	2 – 3	N/A
C11	Learners with an inadequate knowledge infrastructure, find it a challenge to link an inquiry question to the associated phenomenon, have difficulties when designing an experiment, in addition to exhibiting difficulties when handling equipment, selecting suitable methods, and resolving the technical difficulties arising during their work (Zion et al., 2007).	AS	II, B, j	3	0511
C12	Science questions, although rooted in the curiosity of learners, do not freely arise from them (Chin & Osborne, 2008).	N/A	I, B, e	N/A	N/A
C13	Inadequacies in prior knowledge and skills, constrained some high school learners when conducting full inquiry (Gengarelly & Abrams, 2009).	NA	II, B, j	3	05
C14	Some teachers cited limitations in classroom space, as a key hindrance associated with the enactment of IBPW (Kidman, 2012).	AS	II, A, g	4 – 6	05
C15a	As a result of limitations in laboratory facilities, it is not easy for teachers to have	EU	II, A, g	2	05
C15b	access to science laboratories for enacting practical work (Higgins, 2009; Kennedy, 2013) [C15a, C15b].	EU	II, A, g	N/A	05
C16	It was found that the new Lebanese science curriculum lacked 'a coherent and well-thought-out framework regarding inquiry' (BouJaoude cited in Abd-El-Khalick et al., 2004, p. 400). This was in terms of having only a few broad ideas linked, for example, to experiments, and process skills, dispersed in the introduction and objectives for each level of education.	AS	I, B, a	1 – 3	05
C17	Dudu and Vhurumuku (2012) noted in South Africa, that by requiring that only two practical activities be assessed per grade, the curriculum could be sending a wrong signal to teachers, who may be misinterpreting this guideline as ''Do only two practicals''.	AF	I, B, a	3	053
C18	The implementation of IBPW is a challenge in some schools due to the absence of laboratory assistants (Higgins, 2009).	EU	II, B, k	2	05
C19	When the teachers attempted to engage several groups of students in the investigation of a lake ecosystem, they experienced difficulties because they needed multiple sets of technologies (including a digital titrator, graphing calculators, and veneer sensors) (Ebenezer, Kaya, & Ebenezer, 2011).	NA	II, A, i	3	05
C20	Investigations have also been found to often lead to new lines of learner questions that teachers are unwilling or unable to pursue, as the concepts involved were considered to be inappropriate for the age (Samarapungavan, Mantzicopoulos, & Patrick, 2008).	NA	I, B, e	1	0511
C21a	Curricula often emphasise learner mastery of content, rather than the enhancement	AS	I, B, a	1 – 3	05
C21b	of their investigative skills (Childs, Tenzin, Johnson, & Ramachandran, 2012; Dai et al., 2011) [C21a, C21b].	AS	I, B, a	2 – 3	N/A
C22	Aspects of school culture that have been found to serve as a barrier in the enactment of inquiry in the classroom, include the lack of learner motivation and inadequate prior experience of inquiry (Gengarelly & Abrams, 2009).	NA	II, B, l	3	05

C23	Time constraints contribute in investigative practical work being limited to only a small number of verified investigations, unconnected to everyday science teaching (Toplis & Allen, 2012).	EU	I, B, d	2 – 3	05
C24	School ethos significantly constrains some teachers when using an inquiry-based strategy in practical work (Ramnarain & Schuster, 2014).	AF	II, B, l	3	053
C25	It has been found that some teachers face the lack of valuing of inquiry-based activities, by their colleagues (Huziak-Clark et al., 2007).	NA	II, B, k	4 – 6	05
C26	The activities in manuals for practical work are usually restricted to structured inquiry (Zion et al., 2007).	AS	I, A, c	3	0511
C27a	The lack of valuing and pressure from parents could hinder the use of inquiry-based activities in classroom (Crawford, 2007; Huziak-Clark et al., 2007) [C27a, C27b].	NA	II, B, k	4 – 6	05
C27b		NA	II, B, k	4 – 6	05
C28	Instructors occasionally avoid inquiry-based activities as a result of limitations in classroom time (Keen-Rocha, 2005).	NA	I, B, d	N/A	05
C29	It has been found that reading literature on scientific inquiry, which is based on reflective or hypothetical-deductive reasoning, can be difficult for young learners (Baker et al., 2002).	NA	I, B, e	N/A	05
C30a	Researchers have found that science laboratories are absent or have limitations, especially in schools in rural settings (Childs et al., 2012; Kriek & Grayson, 2009; VanBalkom & Sherman, 2010) [C30a, C30b, C30c].	AS	II, A, g	1 – 3	05
C30b		AF	II, A, g	4 – 6	053
C30c		AS	II, A, g	N/A	N/A
C31	Barriers to student inquiry include the materials needed for the inquiry (Jackson & Boboc, 2008).	NA	II, A, i	2 – 3	05
C32	School context is another factor that could inhibit success in teaching science as inquiry (Crawford, 2007).	NA	II, B, l	4 – 6	05
C33	Allowing students with as much time as they need to create and modify their inquiry plans can be difficult (Jordan et al., 2011).	NA	I, B, d	4 – 6	05
C34a	Some teachers are constrained by the fact that the skills developed by their learners from carrying out open-ended inquiry are either not assessed, or lack adequate recognition in assessment criteria (Abrahams & Reis, 2012; Higgins, 2009; Lederman & Lederman, 2012) [C34a, C34b, C34c].	EU	I, B, b	1 – 2	05
C34b		EU	I, B, b	2	05
C34c		N/A	I, B, b	N/A	N/A
C35	The current standardised-assessment laden educational environment, often requires strategies based on more passive techniques, at the expense of IBPW (Minner, Levy, & Century, 2010).	NA	I, B, b	1 – 3	05
C36a	There is a short supply of conventional science education materials and equipment in many schools in industrialised and developing countries (Kapanadze & Eilks, 2014; Qhobela & Moru, 2014; Singh & Singh, 2012) [C36a, C36b, C36c].	N/A	II, A, i	N/A	N/A
C36b		AF	II, A, i	2 – 3	0533
C36c		AF	II, A, i	4 – 6	05
C37	Although the participation of learners in the formulation of a researchable question is crucial in open inquiry, this type of inquiry depends on the cognitive abilities of learners (Zion & Mendelovici, 2012).	AS	II, B, j	3	0511
C38	In some classrooms, the enactment of IBPW is being seriously constrained by the lack of prior experience, wherein some learners are easily distracted away from the intended conceptual understanding by apparatus and chemicals (Ramnarain & Schuster, 2014).	AF	II, B, j	3	053
C39	A very high percentage (95.7%) of surveyed teachers were found to be of the opinion that the integration of inquiry in practical work in the Junior Certificate science programme in Ireland, affected the time needed for course completion and revision (Higgins, 2009).	EU	I, B, d	2	05
C40	Teachers noted that the lack of physical resources would be a key hindrance when implementing the inquiry component of Australia's new science curriculum with emphasis on practical work (Kidman, 2012).	AS	II, A, i	4 – 6	05
C41a	It has noted that asking relevant and productive science-related questions is rather difficult for learners, especially children of preschool age (Bell, Urhahne, Schanze, & Ploetzner, 2010; Ergazaki & Zogza, 2013; Marbach-Ad & Sokolove, 2000) [C41a, C41b, C41c].	N/A	I, B, e	N/A	N/A
C41b		EU	I, B, e	1	0511
C41c		NA	I, B, e	4 – 6	0511
C42a	There is the scarcity of inquiry-based activities in some school science textbooks (Abd-El-Khalick et al., 2004; Crawford, 2016) [C42a and C42b].	NA	I, A, c	1 – 3	05
C42b		N/A	I, A, c	N/A	N/A
C43	Teachers of a township school interviewed about learners doing inquiry, cited the large classes they teach as a challenge when interacting with individual learners to scaffold them to conceptual understanding (Ramnarain, 2014). Such classes cause teachers to resort to didactic pedagogy.	AF	II, A, h	3	053
C44	The successful enactment of inquiry-based science projects, tends to require extended professional support, even in the case of experienced educators (Lederman & Lederman, 2012).	N/A	I, B, f	N/A	N/A
C45	The unavailability of equipment (e.g., hot plate), limits the investigations that teachers can allow their learners to perform (Capobianco & Thiel, 2006).	NA	II, A, i	1	05
C46a	Young children may not have the cognitive resources that adults or scientists possess, in relation to designing controlled experiments and evaluating how their models fit the associated data (Klahr, 2000; Kuhn & Dean, 2004; Masnick & Klahr, 2003) [C46a, C46b, C46c].	N/A	I, B, e	N/A	N/A
C46b		NA	I, B, e	N/A	N/A
C46c		NA	I, B, e	1	05
C47	It has been claimed that finding genuinely open-ended problems that can be investigated in the classroom is difficult (Kind et al., 2011).	EU	I, A, c	2	05

Legend:

[a]	[b]	[e]	[d]
AF = Africa	I = System-Level	1 = Primary education	0511 = Biology
AS = Asia	II = School-Level	2 = Lower secondary education	0512 = Biochemistry
EU = Europe	A = Material-Related	3 = Upper secondary education	0521 = Environmental sciences
NA = North America	B = Non-Material-Related	4-6 = Post-secondary non-tertiary education to Bachelor level education and equivalent	0522 = Natural environments and wildlife
OC = Oceania/Australia	a = Curriculum design		0531 = Chemistry
SA = South America	b = Assessment practices		0532 = Earth sciences
	c = Quality of school texts		0533 = Physics
	d = Time constraints		053 = Physical sciences
	e = Developmental age		05 = General science, primary science, or integrated science
	f = Teacher education		
	g = Classroom and laboratory facilities		
	h = Large classes		
	i = Physical resources		
	j = Learner-related difficulties		
	k = Teacher support		
	l = School culture		

[e] N/A = Not Applicable (e.g., in the case of a review paper) or Not Available

[f] NA is not to be mistaken for N/A