



# Framework for reducing teaching challenges relating to improvisation of science education equipment and materials in schools

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The science education budget of many secondary schools has decreased, while shortages and environmental concerns linked to conventional Science Education Equipment and Materials (SEEMs) have emerged. Thus, in some schools, resourceful educators produce low-cost equipment from basic materials and use these so-called improvised SEEMs in practical work. However, scattered in the literature are diverse challenges linked to the production and/or use of improvised SEEMs. Thus, the purpose of the literature review presented here was to design a framework useful in the reduction of these challenges. In this regard, we systematically gathered, characterised and clarified the challenges, in addition to collecting and reflecting on ways of reducing them. This enabled us to design the framework which focuses on educator learning and practice in the improvisation of SEEMs under specified conditions. Regarding the implementation of the framework, we have discussed the role that stakeholders including professional development providers and researchers may play.

*Keywords:* educator learning, framework, improvisation challenges, low-cost equipment, practical work

## INTRODUCTION

In this paper, we present a literature review whose primary purpose was to design a framework to guide the reduction of teaching challenges relating to the production and use of improvised Science Education Equipment and Materials (SEEMs) in practical work in secondary schools. We use the term 'improvised SEEMs' to refer to low-cost equipment, self-created models as well as equipment and materials for conducting small-scale experiments which need smaller quantities of chemicals. Improvised SEEMs may be produced by resourceful educators from basic materials (e.g., plastic bottles and straws). The equipment and such materials may then be used

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in practical work in their classrooms. It is in relation to the challenges that educators may encounter in this regard that we set out to design the framework. However, in view of providing context, we begin with a brief discussion of practical work and ways of producing and/or supplying SEEMs in secondary schools.

### Overview of practical work

Around the world, practical work is considered an essential aspect of science education by researchers, scientists, educators and learners (e.g., Abrahamsa & Millar, 2008; Lee, Guo, & Ho, 2008; Nivalainen, Asikainen, Sormunen, & Hirvonen, 2010). This is in line with the rationale for practical work provided by many people involved in science education (e.g., Kerr, 1963; Wilkinson & Ward, 1997 cited in Kidman, 2012; Lynch, 1986; Tamir, 1991). The rationale includes 1) enhancing learners' interest in science, 2) allowing learners to develop practical, thinking and problem-solving skills, 3) enabling the misconceptions of learners to be identified and addressed, 4) assisting in nurturing scientific values and attitudes in learners, and 5) giving learners the opportunity to develop their procedural knowledge and to investigate the physical world.

Millar (2011) considers practical work as consisting of activities in which learners individually or collaboratively engage in manipulating and/or observing real materials and objects as opposed to simulated ones (e.g., interactive computer simulations). However, some researchers (e.g., Eilks, Prins, & Lazarowitz, 2013; Hodson, 1998) hold that practical work may not be limited to traditional laboratory activities, given that in many situations, computer-based learning (e.g., using data-logging and simulated equipment) may be more effective. In actual fact, real (hands-on) and simulated SEEMs have their respective merits and thus complement each other in practical work (e.g., De Jong, Linn, & Zacharia, 2013; Urban-Woldron, 2009).

### Science education equipment and materials

Many classrooms in industrialised and less developed countries lack essential conventional hands-on SEEMs (e.g., Childs, Tenzin, Johnson, & Ramachandran, 2012; Ens, Olson, Dudley, Ross, Siddiqi, Umoh et al., 2012; Nivalainen et al., 2010; Singh & Singh, 2012). This may be explained by the fact that even in industrialised countries such as Germany and Japan, conventional SEEMs are costly, coupled with the fact that in many industrialised and less developed countries science education budgets have decreased (Poppe, Markic, & Eilks, 2011; Schaffer & Pfeifer, 2011; Set & Kita, 2014). This is also the case in the former Soviet Union countries of Georgia and Moldova (Kapanadze & Eilks, 2014). In many less developed countries, including Kenya and Nigeria, conventional hands-on science education equipment and materials tend to

### State of the literature

- Although there is a decrease in many science education budgets, coupled with shortages and adverse environmental effects of conventional Science Education Equipment and Materials (SEEMs), improvised SEEMs are playing a significant and increasing role in practical work in many secondary schools.
- However, some science educators even in ill-equipped classrooms seldom produce and/or use improvised SEEMs (e.g., self-created models, small-scale experiments and low-cost equipment).
- At the same time, diverse teaching challenges linked to the production and/or use of improvised SEEMs, as well as ways of reducing these challenges are scattered in the literature.

### Contribution of this paper to the literature

- The literature may be extended by gathering, characterising and clarifying the diverse challenges educators are exposed to in terms of the production and/or use of improvised SEEMs.
- Also, it is helpful to collect in a systematic manner and reflect on the adequacy of certain recommended ways through which the challenges may be reduced.
- It is also useful to focus on the above contributions to address the lack of a framework for providing guidance in the reduction of the challenges linked to the production and/or use of improvised SEEMs in many science classrooms.

be imported, difficult to obtain and expensive (Bhukuvhani, Kusure, Munodawafa, Sana, & Gwizangwe, 2010; Ezeliora, 1998; Ndirangu, Kathuri, & Mungai, 2003).

Against the above background, various alternative methods have been used around the world to gain access to conventional SEEMs. These methods include borrowing from or using facilities outside individual schools (e.g., mobile laboratories, local museums and science centres), using a micro-scale (small-scale) approach in carrying out conventional experiments, as well as improvisation at school level or at a central production unit (Bradley, 1999; Di Fuccia, Witteck, Markic, & Eilks, 2012; Musar, 1993; Singh & Singh, 2012; Sussman, 2000; Tran, Scherpbier, Van Dalen, & Wright, 2012). Though all the above ways of producing or gaining access to science education equipment are useful, this paper focuses on equipment improvisation in schools. This is because, as observed by Ndirangu et al. (2003), many schools function as islands.

The improvisation of SEEMs is a strategy that has been used in science education for many years, as evidenced by the literature (e.g., Barbara & Sam, 1957; Fagle, 1958; Set & Kita, 2014). Based on this strategy, resourceful science educators produce equipment, including physical models from basic materials and use this equipment and materials in practical work in their classrooms (Gilbert, Justice, & Arsela, 2003; Ndirangu et al., 2003; Ogoh, 2014). Basic materials that have been used in industrialised and developing countries in the production of science education equipment include syringes, plastic bottles, scrap timber from the school workshop, aluminium foil, tin cans, food colouring, baking soda, cabbage juice used as a chemical indicator, glycerine, and plastic bags and straws (Ens et al., 2012; Gilbert et al., 2003; Nyaumwe & Mavhunga, 2005; Sussman, 2000; Tran et al., 2012; Wilke & Tronicke, 2007, 2008). However, improvised equipment includes both equipment initially meant for other purposes (as evidenced by the above list) and equipment that is modified for use in practical work (Alonge, 1979; Di Fuccia et al., 2012; Kapanadze & Eilks, 2014; Von Borstel, 2009). Such materials are readily available to science educators (Stephen, 2015; Wood, 1990).

Educators may produce and/or use improvised science education equipment for a number of reasons. Normally, improvised science education equipment has been considered as equipment that may be used when the ideal (conventional) ones are lacking (Eniajeyu, 1983; Ogoh, 2014). However, educators may also produce and use their own SEEMs when commercially available SEEMs are less environmentally friendly, too hazardous to use in classroom, or suitable only in educator demonstrations (Di Fuccia et al., 2012 on Germany; Ens et al., 2012 on the United States; Poppe et al., 2011 on Germany; Rettich & Battino, 1989). An example of a hazardous conventional material (reagent) is Syto13 or ethidium bromide, needed for staining during gel electrophoresis, which is an important technique in molecular biology taught in some high schools (Ens et al., 2012). However, Ens et al. further state that these hazardous reagents can be replaced satisfactorily using methylene blue available in pet supply stores. Educators have also produced improvised equipment to respond to learning difficulties. An example is Rogerson and Cheney Jr (1989), who developed a physical model for use in teaching the dynamics of protein synthesis. The improvisation of SEEMs also provides a means of linking science education to the real-life experiences of learners (Kyle, 2006; Stephen, 2015).

Improvised science education equipment (e.g., small-scale experiments) has been found by educators and researchers on different continents to be useful in various areas of science education in secondary schools. This includes measuring conductivity and understanding ion interactions in water (Seng, Kita, & Sugihara, 2007; Set & Kita, 2014 on Japan and Cambodia), as well as in studying DNA molecules, visualising the electrolysis of water and investigating energy transfer using a generator (Davis, Athey, Vandevender, Carihfield, Kolanko, Shao et al., 2014; Ens et al., 2012; Fletcher,

Rommel-Esham, Farthing, & Sheldon, 2011 in United States). In one hundred schools studied by Ndirangu et al. (2003) in Kenya, departmental heads judged improvised science education equipment as largely adequate in modelling concepts, satisfactory in visual appeal as well as being usable over a reasonable duration, in addition to contributing significantly to science education equipment stocks.

### **Purpose and rationale of this paper**

Against the above background, it is not surprising that researchers, curriculum designers, teacher educators, policy documents and organisations involved in science education have urged educators in ill-equipped classrooms to be resourceful in terms of producing and using improvised Science Education Equipment and Materials (SEEMs, e.g., Department of Basic Education, 2011; Ezeasor, Opara, Nnajiolor, & Chukwukere, 2012; KIE, 1992; Ndirangu et al., 2003; Nyaumwe & Mavhunga, 2005; Ogoh, 2014; Sussman, 2000; United Nations Educational Scientific and Cultural Organisation, 1979). In line with such calls, the use of improvised SEEMs (e.g., small-scale experiments) is an increasing trend in practical work in science classrooms in Germany (Di Fuccia et al., 2012). However, despite the willingness of some educators to improvise equipment for practical work (Childs et al., 2012), improvised SEEMs are seldom used in many ill-equipped science classrooms in secondary schools (Ezeasor et al., 2012; Sedibe, 2011; Singh & Singh, 2012). This result shows, first of all, that the improvisation of SEEMs is a strategy that can be better implemented in these classrooms. At the same time, it indicates that many science educators probably face challenges relating to the production and/or use of improvised SEEMs. A challenge, according to Schoepp (2005), is a condition that poses a difficulty in terms of progressing toward or attaining an objective. The objective in this case is the production and/or use of improvised SEEMs in practical work in science classrooms in secondary schools.

A number of researchers (e.g., Bhukuvhani et al., 2010; Ezeasor et al., 2012; Stephen, 2015) have mentioned certain challenges that educators are exposed to relating to the production and/or use of improvised SEEMs. However, these teaching challenges are scattered in the literature and have so far been considered in a manner that is largely descriptive and not systemic. Also, though relevant ways of reducing individual challenges have been suggested by various researchers (e.g., Collard & Looney, 2014; Ndirangu et al., 2003), the field of science education lacks a framework for guiding the reduction of the challenges in a systematic manner. Thus, the primary purpose of the literature review presented here is to design a framework useful in guiding the reduction of teaching challenges relating to the production and/or use of improvised SEEMs in practical work in science classrooms in secondary schools.

In view of achieving the above purpose, we consider it useful, first of all, to gather, characterise and clarify teaching challenges relating to the production and/or use of improvised SEEMs. Also useful is the gathering of relevant ways in the literature (e.g., Oladejo, Olosunde, Ojebisi, & Isola, 2011; Singh & Singh, 2012) for reducing specific challenges. Thus, in order to achieve the above purpose, we focus on answers to the following three research questions:

1. What are the different teaching challenges that educators are exposed to in relation to the production and/or use of improvised SEEMs?
2. How can the challenges be characterised and clarified?
3. What are relevant ways of reducing specific challenges?

### **CONCEPTUAL FRAMEWORK**

The teaching challenges that science educators are exposed to relating to the improvisation of SEEMs may be characterised with reference to relevant extant categorisations of teaching challenges. Based on these categorisations, a framework

of teaching challenges may be compiled. This framework may then be used to gather systematically, the teaching challenges relating to the production and/or use of improvised SEEMs, as well as relevant ways through which the different challenges may be reduced. In terms of being able to clarify the teaching challenges, it is useful to consider the competences required of science educators.

### **Categorisation of teaching challenges**

Relevant categorisations of teaching challenges exist in the context of constructivist teaching in general and problem- and inquiry-based teaching in particular. This is also the case in the context of information and communication technology (ICT) integration in teaching and learning. In the context of constructivist teaching, Windschilt (1999) grouped the inherent challenges into three categories: political challenges (e.g., getting learners to attain standardised outcomes), logistical challenges (e.g., lack of time) and pedagogical challenges (e.g., inadequate knowledge of ways of exploring content). In terms of enacting inquiry- and problem-based learning, some researchers (Chin, Goh, Chia, Lee, & Soh, 1994; Lee, Tan, Coh, Chia, & Chin, 2000) have categorised the challenges as internal (e.g., attitude and lack of knowledge) and external (e.g., classroom structure and time constraints). Similar categorisations are available in the context of the integration of ICTs (e.g., interactive computer simulations) in classroom. One of these categorisations consists of educator-level challenges (such as resistance to change) and institutional- (school-) level challenges (e.g., shortage of equipment) (British Educational Communications and Technology Agency, 2004; Sherry & Gibson, 2002). Another categorisation of teaching challenges in the context of ICT integration in classroom consists of intrinsic challenges (linked to an individual in this case an educator) and extrinsic challenges, which are teaching challenges relating to an organisation (Hendren, 2000 cited in Al-Alwani, 2005; Ertmer, 1999). The last two categorisations of teaching challenges become identical if the term 'organisation' is considered to mean an institution (a school).

Though the above categorisations of teaching challenges originate in different pedagogical contexts, they have one commonality. This is the fact that teaching challenges consist of those relating to the characteristics of particular educators and those that are not linked to these characteristics. We may refer to these categories of teaching challenges simply as intrinsic and extrinsic challenges respectively.

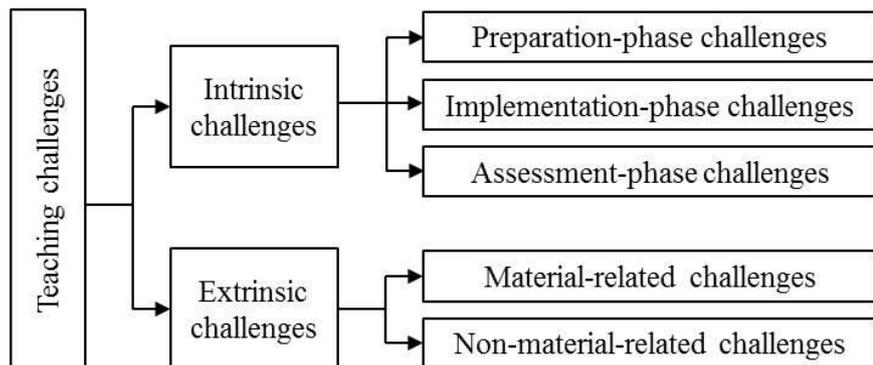
With reference to the primary purpose of the literature review presented here, we consider it useful to further categorise intrinsic teaching challenges in terms of the phases of the teaching process. Phases of the teaching process may be derived from models of Instructional Design (ID). ID deals with systematic planning aimed at making instruction more relevant and effective (Merril, 1996; Reiser & Dempsey, 2007). Many ID models exist. However, the Analysis, Design, Development, Implementation and Evaluation model (Peterson, 2003) has been widely used (Balta, 2015; Magliaro & Shambaugh, 2006; McGurr, 2008). If we consider that the first three phases of this ID model are aspects of preparation, then according to the model, the ID process consists essentially of preparation, implementation and evaluation phases. These phases of ID are applicable to teaching, given that teachers are instructional designers. In fact, many people involved in education (e.g., Airasian & Russell, 2008; Wells, 1999) consider teaching to consist of three major interdependent phases which are preparation, implementation and assessment (evaluation).

In the preparation phase of teaching, the educator sets learning goals, prepares learning experiences, prepares learning materials (e.g., self-created models) and plans assessment (Airasian & Russell, 2008; Wiggins & McTighe, 1998). The implementation phase of teaching is where the planned lesson is implemented in classroom. The third phase of teaching includes an evaluation of the degree to which

learners have reached specified outcomes (Airasian & Russell, 2008). Thus, in principle, intrinsic teaching challenges may be categorised simply as preparation-phase, implementation-phase and assessment-phase challenges.

On the other hand, we can further categorise extrinsic challenges by borrowing from research into the integration of ICTs (e.g., interactive computer simulations) in the classroom. In this context, Pelgrum (2001) identified two categories of teaching challenges: those relating to a material condition and those that are linked to a non-material condition. Examples of these categories of teaching challenges from above are respectively the shortage of equipment (e.g., tools) and the lack of time.

The discussion in this section indicates that by borrowing from extant categorisations of teaching challenges, those linked to the production and/use of improvised SEEMs may be characterised with reference to Figure 1.



**Figure 1.** Conceptual framework of teaching challenges

In addition to being useful in characterising teaching challenges relating to the production and/or use of improvised SEEMs, Figure 1 also allows relevant ways of reducing specific challenges to be juxtaposed systematically with the related challenges. It remains to consider how the challenges may be clarified. We consider this as most useful in relation to intrinsic teaching challenges.

**Clarifying intrinsic teaching challenges**

The intrinsic teaching challenges that educators may face in the different phases of teaching in relation to improvised SEEMs, may be clarified with reference to frameworks of educator competence. Here, we consider a national framework of educator competence (Chong & Cheah, 2009) and the educator competence framework of the United Nations Educational, Scientific and Cultural Organisation (United Nations Educational Scientific and Cultural Organisation, 2011). These frameworks have knowledge, understanding, skills and values as categories of educator competences. Constituents of the values and skills needed by educators are outlined in Chong and Cheah (2009). Included in the skills category are pedagogical, reflective, personal and management skills. The values educators need to be equipped with include concern and care for learners, commitment and dedication to their practice, collaboration and team spirit, as well as the desire for innovation, continuous learning and excellence. Regarding the knowledge base of educators, its major components include knowledge of educational context, content knowledge, pedagogical knowledge and technological knowledge (Chong & Cheah, 2009; Mishra & Koehler, 2006; Shulman, 1986).

In order to be effective in their teaching, science educators need to be sufficiently knowledgeable and skilled (McComas, 2005; Onwu & Stoffels, 2005), in addition to possessing the above values. This is evidenced, for example, by the fact that science educators have been observed to encounter teaching challenges stemming from the lack of sufficient professional knowledge and skills (Newton, 2000; Windschitl, 1999).

Educator competences thus provide a basis for clarifying the intrinsic challenges that science educators may face in relation to the production and/use of improvised SEEMs, in the different phases of teaching.

## DATA COLLECTION AND ANALYSIS

In order to expand the data collection, we used relevant terms (e.g., improvised instructional materials, handmade science equipment, low-cost science equipment and inexpensive science equipment) in the full text of papers, to search the databases of several Web of Science journals as well as ERIC. The search was not restricted to specific countries, or to a particular methodological approach or theoretical perspective. However, we focused only on literature regarding secondary school classrooms, as we considered learners in these classrooms to be close to or to lie in the range of 12 to 20 years that Rutten, van Joolingen, and van der Veen (2011) consider as the age range within which learners acquire the most essential part of their basic knowledge of science. That said, observing the fairly scarce nature of relevant research-based evidence, we took into consideration the fact noted by Di Fuccia et al. (2012) that the experiences of science educators covered in journals for educators and in conferences constitute a useful body of knowledge. This knowledge, which covers the other half of the knowledge spectrum, is useful for more fully understanding science teaching practices (McIntyre, 2005). In addition to conference papers, we located a few relevant documents from institutions or organisations involved in science education. In this way, we found 40 papers mostly from research-based journals and also from journals for educators. In addition, we obtained four publications from the other sources. This adds up to 44 sources that we initially considered in the literature review presented in this paper.

Following a preliminary review of the above sources, we found that 13 of them, although dealing with the subject of improvisation, were concerned with curriculum areas other than science or were not concerned with the improvisation of SEEMs. These sources were thus excluded from the literature review presented here. We also excluded one article for having limited data in terms of involving only two educators. Thus, we used 30 sources on the subject of the production and/or use of improvised SEEMs as well as relevant ways of reducing the inherent challenges in school. This includes a conference paper and documents from institutions or organisations involved in science education (3), papers as well as laboratory experiments and exercises from peer-reviewed journals for educators (10), and papers from peer-reviewed academic journals (17). This last category of papers covered a range of research methods consisting of survey, observation, document analysis, interview as well as quasi-experimental and experimental research.

Based on the retained sources and using the afore-mentioned definition of a challenge from Schoepp (2005), we gathered teaching challenges educators face in their teaching in relation to improvised SEEMs (e.g., low-cost equipment, self-created models and small-scale experiments). For each challenge, we searched the literature in terms of relevant ways of reducing the challenge. We then juxtaposed each teaching challenge with the corresponding recommended way/s of reducing the challenge. Finally, we individually assigned each challenge and its associated recommended way/s of reducing it to the appropriate category based on the framework in Figure 1. The results are presented and discussed below.

## TEACHING CHALLENGES RELATING TO THE PRODUCTION AND/OR USE OF SEEMs

### Intrinsic challenges

In this category, some educators face preparation-phase teaching challenges relating to motivation and skills as well as an implementation-phase challenge linked to their pedagogical knowledge.

*Lack of motivation.* Educators often lack the motivation to put additional effort into the preparation of practical work (Musar, 1993). Here, the preparation includes the production of self-created models, low-cost equipment or small-scale experiments. Many science educators have been noted for lacking the willingness or motivation to improvise science education equipment for their lessons (Ezeasor et al., 2012; Hakansson, 1983; Stephen, 2015; Tsuma, 1998). Thus, educators may need to be provided with incentives to motivate them as well as compensate them for the additional time they employ in the production of their own science education equipment (Holman, 1986; Ndirangu et al., 2003; Ogoh, 2014). This is because motivated educators put effort into improving learning activities, use creative ways of achieving learning goals and persist in carrying out tasks (Pintrick & Schunk, 1996). In this case, the task is that of producing small-scale experiments, self-created models or low-cost equipment for practical work in their classrooms. Though improved output is an effective intrinsic incentive, motivation is hard to sustain in the absence of extrinsic incentives (Gaible & Burns, 2005).

The lack of motivation in the above regard in many established science educators is in stark contrast to the fact noted in DomNwachukwu and DomNwachukwu (2006) that many candidate educators are motivated by the desire to make a difference and the love for children. These sources of motivation are consistent with such educator values as the concern and care for learners, as well as the desire for innovation and excellence. Thus, the lack of motivation to produce and/or use improvised equipment in the classroom may be due to a deficiency in such values. At the same time, the lack of motivation may be an indication of the existence of underlying challenges. For example, science educators may be unable to improvise science education equipment because they either lack an appreciation of the need to do so or lack the required skills (Tsuma, 1998).

*Lack of creativity.* Creativity, which involves doing something in new ways (NCERT, 2006; Tan, 2000), is considered important in science teaching by a number of authors (e.g., Shanahan & Nieswandt, 2009; Singh & Singh, 2012). In particular, this skill is required in the designing of improvised science education equipment (Ezeasor et al., 2012; Nyaumwe & Mavhunga, 2005). However, creativity is lacking among many science educators (Ezeasor et al., 2012; Kadzera, 2006; Stephen, 2015). This is in line with the fact that some science educators find it difficult to think as designers (Penuel & Gallagher, 2009). The creativity of educators may in general be enhanced in a collaborative manner by way of partnerships between creative professionals and educators (Collard & Looney, 2014). With specific reference to the improvisation of SEEMs, the creativity of educators may be developed through training programmes (Ezeasor et al., 2012).

*Insufficient practical skills.* In the preparation phase of teaching, educators have, among other activities, to prepare learning resources (Airasian & Russell, 2008; Wiggins & McTighe, 1998). In this case, the resources include improvised SEEMs (e.g., self-created models). According to Cribb and Gewirtz (2001), practical attributes are as important in teaching as intellectual capabilities. However, many educators lack the practical skills needed for producing improvised science education equipment (Bhukuvhani et al., 2010). This challenge can however be reduced. As noted by a number of authors (e.g., Munby, Cunningham, & Lock, 2000; Schön, 1991), practical

competences (practical skills in this case) may be learned by doing tasks in educational contexts that are informal and based on problems encountered in real-life situations.

*Inadequate pedagogical knowledge.* Many educators are uncertain about how to use improvised SEEMs in practical work (Pimpro, 2005 cited in Bhukuvhani et al., 2010). Unlike the last three, this is an implementation-phase teaching challenge. In this context and based on Mishra and Koehler (2006), pedagogical knowledge includes knowledge of processes and methods or practices useful in motivating learners and implementing practical work.

Due to the degree of learner engagement involved, inquiry-based (IB) learning enhances the motivation and the attitude of learners towards science (Fairbrother, 2000; Osborne & Dillon, 2008; Rocard, 2007). In view of promoting such learning, the educator creates situations in which learners are challenged to observe phenomena; raise questions regarding the phenomena; formulate relevant hypotheses; design and carryout experiments from which they collect and analyse data in order to either contradict or support their hypotheses in addition to drawing conclusions (Hattie, 2009). For providing learners with such IB experiences, improvised equipment (e.g., self-created models) are useful (Schmidt, 2003). Thus, a number of authors (Ezeasor et al., 2012; Musar, 1993) have recommended the training of pre-service and established science educators in the use of improvised SEEMs. In order to enhance such training, the European Union project, Student Active Learning in Science (SALiS), provided educators access to low-cost experimental techniques (Poppe et al., 2011) that are useful in the context of inquiry-based practical work in school classrooms (Kapanadze & Eilks, 2014).

In view of implementing low-cost experimental techniques in IB practical work, science educators may use an Instructional Model (IM) as a guide. The National Research Council (2000) provides five phases common to IMs and useful for guiding IB teaching. The phases correspond to those of the 5E IM of Bybee (1997) which has been widely successful in educational contexts (Bybee, Taylor, Gardner, Van Scotter, Powell, Westbrook et al., 2006; Zuiker & Whitaker, 2014). The phases of this IM consist of Engagement, Exploration, Explanation, Elaboration and Evaluation. The first phase includes short activities which are based on an object (e.g., a self-created model), a situation, a real problem or an event and which are useful in puzzling learners, promoting curiosity among them, creating cognitive disequilibrium (Bybee, 2009; Bybee et al., 2006; Palmer, 2009) and thus motivating them. The Exploration phase includes activities that provide learners concrete experiences as they investigate situations, materials and objects (Bybee, 2009). The remaining phases of the 5E IM are described for example in Bybee (2009) and Bybee et al. (2006).

In view of using improvised SEEMs (low-cost experimental techniques) in practical work based on the 5E IM, science educators need to be able to support collaboration and to guide inquiry (Schneider, Krajcik, & Blumenfeld, 2005). In this regard, we find it useful for the educator to possess knowledge on how to support learners in the formulation of questions that can be investigated, how to elicit these questions, ways of assisting learners in ensuring that their claims are data-based, ways of providing guidance or responding to the questions of their learners, as well as getting learners to work effectively in groups. Data to this effect is available in the literature (e.g., Chin, 2004; Chin & Osborne, 2008; Cuccio-Schirripa & Steiner, 2000; Davis, 1999; Dillon, 1988; Piaget, 1985; Schneider et al., 2005). However, pedagogical knowledge on practical work is insufficient, as educators need opportunities to put this knowledge into practice (Nivalainen et al., 2010). In this regard, many educators face additional challenges.

## Extrinsic challenges

Many science educators face material-related and/or non-material-related extrinsic teaching challenges linked to the production and/or use of ISEEMs.

*Lack of training.* The lack of professional training is a non-material-related teaching challenge educators may experience in relation to the effective use of improvised resources in science classrooms (Oladejo et al., 2011 citing Maduabunni, 2003). Some pre-service science educators studied by Singh and Singh (2012) claimed that their inability to improvise science education equipment stems from the lack of training. Thus, some researchers (Oladejo et al., 2011; Stephen, 2015) have recommended regular seminars and workshops in terms of strengthening established science educators on the improvisation of science education equipment through exposing them to local materials, as well as enabling these educators to acquire useful skills and strategies. On the other hand, some pre-service educators recommend the infusion of improvisation into science method modules in educator preparation programmes and the designing of an entire module on innovation and improvisation in science (Singh & Singh, 2012). They also consider the module useful for established science educators who may use the module as a short course. This is actually the case in Georgia and Moldova for example, where such modules have been accredited and where established science educators take part in Continuous Professional Development involving the incorporation of low-cost SEEMs in inquiry-based practical work (Kapanadze & Eilks, 2014).

*Time constraints.* Another non-material-related extrinsic challenge regarding the improvisation of science education equipment is the lack of time for educators to design and produce their own equipment (Ezeasor et al., 2012; Stephen, 2015). This challenge may be understood in terms of the fact that improvisation demands some patience and persistence on the part of especially educators new to its practice (Daramola, 1987; Fletcher et al., 2011; Sussman, 2000). However, science educators do not have to produce the science education equipment they need all by themselves. This is because they may be assisted in this regard by learners (Steward, 1983; Tobon, 1988). According to Ezeliora (1998), the involvement of learners is often minimal and limited to the provision of the raw materials needed by the educator for the improvisation of science education equipment. However, using suitable safety guidelines and equipment, learners have been involved in working collaboratively while developing their thinking and problem-solving skills as they participate in the production of science education equipment (Fletcher et al., 2011; Ndirangu et al., 2003; Sussman, 2000).

*Lack of tools and critical parts.* This is a material-related extrinsic teaching challenge regarding which Musar (1993) notes that some critical parts like lenses or small devices such as ammeters needed in the production of improvised science education equipment may not be locally available. On the other hand, Stephen (2015) observed that some science educators lack tools for use in the production of improvised science education equipment. Financial resources are thus needed for acquiring the above items. However, many science educators lack the financial support they need from their managers towards producing improvised science education equipment (Ezeasor et al., 2012; Stephen, 2015). At the same time, Ndirangu et al. (2003), in their study involving 50 schools, found that a relatively small percentage (19.2 %) of managers experience difficulties relating to funding the production of improvised science education equipment in school. There is thus the need for greater educator engagement with management in terms of the provision of tools and critical parts for the production of improvised SEEMs.

The discussion in this section may be summarised as in Table 1.

Table 1 shows that the teaching challenges that many science educators face in relation to the production and/or use of improvised SEEMs though numerous and

**Table 1.** Challenges linked to production and/or use of improvised science education equipment and materials and ways of reducing them

Major category	Secondary category	Teaching challenge	Way (s) of reducing challenge
Intrinsic	Preparation-phase	Lack of motivation Lack of creativity	- Use of intrinsic and extrinsic incentives - Partnerships with creative professionals - Training - Learning by doing
	Implementation-phase	Inadequate pedagogical knowledge	- Training - Access to low-cost experimental techniques
Extrinsic	Non-material related	Lack of training  Time constraints	- Pre-service training modules - In-service workshops and seminars - Involvement of learners
	Material related	Lack of tools and critical parts	- Greater educator engagement with managers

diverse in nature, are surmountable. Thus, the table may serve as a starting point towards designing a framework for guiding the reduction of the challenges.

### FRAMEWORK FOR REDUCING CHALLENGES TO PRODUCTION AND/OR USE OF IMPROVISED SEEMs IN SCHOOLS

The third column of Table 1 shows that the intrinsic challenges that many science educators face relating to the production and/or use of improvised SEEMs stem from a shortfall in their competences. Specifically, the educators possess inadequate relevant values, knowledge and skills. Thus, a framework for reducing teaching challenges relating to the production and/or use of improvised SEEMs needs to have as one of its goals, to prepare or enhance educators in the above areas of competence. In line with this goal, the ways of reducing intrinsic teaching challenges focus on educator learning as seen in the fourth column of Table 1. Among them is training, the availability of which is in itself an extrinsic teaching challenge.

Training (in this case through modules, workshops and seminars), is useful in enabling educators to gain new ideas, skills and strategies (Gaible & Burns, 2005; Grant, 1996). However, training often occurs outside the school setting and context, in addition to using resources (in this case tools and basic materials) unfamiliar to educators (Fullan & Steigelbauer, 1991). This is unlikely to be the case in partnerships with creative professionals which allow for continuous learning in school settings. The continuous deepening of knowledge and skills is necessary for effective practice in any profession (Garet, Porter, Desimone, Birman, & Yoon, 2001). Thus, educator learning in the production and/or use of improvised SEEMs (e.g., self-created models and small-scale experiments) may consist of the training of mostly pre-service educators and mainly Continuous Professional Development of established educators.

The general goal in professional development of educators is to effect a change in their knowledge, skills, understanding, attitude and practice (Griffin, 1983). In line with the framework of educator competences discussed above, we may add a change in the professional values of educators. Professional development is a continuous process including not only training, but also practice, feedback and follow-up support (Organisation for Economic Cooperation and Development, 2009). Thus the term 'Continuous Professional Development' (CPD) is often used to describe such professional development. The CPD of science educators requires, amongst others, collective participation in professional learning communities, content focus, methods similar to those needed in the classroom, an adequate duration as well as active learning (e.g., through learning by doing) and coherence (Desimone, Porter, Garet, Yoon, & Birman, 2002; Ingvarson, Meiers, & Beavis, 2005; Marx & Harris, 2006;

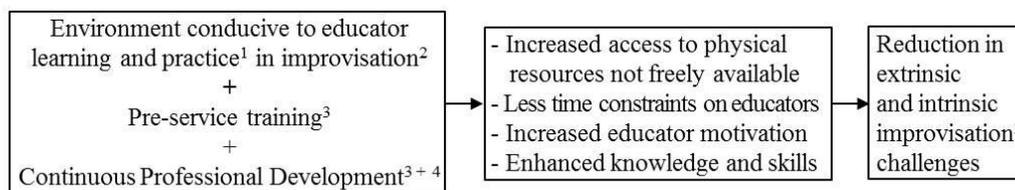
National Science Teachers Association, 2006). Also, Capps, Crawford, and Conostas (2012), based on a synthesis of the literature (e.g., Desimone, 2009; Penuel, Fishman, Yamaguchi, & Gallagher, 2007), identified other characteristics of CPD. These characteristics consist of opportunities for educator participation in authentic and modelled IB experiences and the planning of inquiry experiences for their lessons during workshops.

In addition to the above requirements, other aspects that appear to be critical in educator learning are motivation and the involvement of professional values. Fraser and Saunders (1998) highlighted the importance of professional values as an aspect in educator learning. These values, as noted earlier, include concern and care for learners, commitment and dedication to practice as well as the desire for innovation, continuous learning and excellence. Thus, CPD that enhances these values may enable educators to better pursue learning and practice in relation to the production and/or use of improvised SEEMs. However, Boyd, Banilower, Pasley, and Weiss (2003) note that a primary challenge relating to professional development is that of attracting educators and sustaining their interest. Thus, a framework for reducing teaching challenges relating to the production and/or use of improvised SEEMs needs to incorporate incentives, the enhancement of professional competences (values, skills and knowledge), as well as offer training and CPD.

The framework needs to also provide for the reduction of the other extrinsic teaching challenges than the lack of educator learning opportunities. These challenges are reflected in Table 1 which also shows possible ways through which the challenges may be reduced. Against the above background, we have designed the framework in Figure 2 to serve as guide in the reduction of challenges relating to the production and/or use of improvised SEEMs in schools, across the different categories in Table 1.

The requirements of the framework in Figure 2 are based on the preceding discussion in this and earlier sections. In Table 2, we have summarised the literature on which these requirements are based.

We see from Table 2, that the framework in Figure 1 is backed by a significant segment of the literature. However, it is useful to note that this framework is generic.



Legend:

<sup>1</sup> availability of intrinsic and/or extrinsic incentives, provision of tools and critical parts, as well as the involvement of learners in equipment production

<sup>2</sup> relating to production and/or use of low-cost science education equipment and materials (e.g., self-made models)

<sup>3</sup> including:

- instilment of professional values (e.g., care for learners, desire for innovation and desire for excellence)
- pedagogical knowledge enhancement: experiencing, planning and facilitating inquiry-based practical work based on 5E instructional model and incorporating low-cost experimental techniques
- skills development: creativity, designing and practical skills needed for producing low-cost science education equipment

<sup>4</sup> involving: collective participation in professional learning communities, content focus, adequate duration, active learning (e.g., through learning by doing), coherence and use of methods similar to those needed in classroom (e.g., inquiry-based learning)

**Figure 2.** Framework for reducing teaching challenges relating to production and/use of improvised science education equipment and materials in schools

**Table 2.** Theoretical justification of requirements of framework in Figure 2

<b>Requirement</b>	<b>Theoretical backing</b>
Intrinsic and extrinsic incentives	Boyd, Banilower, Pasley, and Weiss (2003), Gaible and Burns (2005), Stephen (2015)
Provision of tools and critical parts	Musar (1993), Stephen (2015)
Learner involvement in equipment production	Steward (1983), Tobon (1988), Ezeliora (1998), Fletcher et al. (2011), Ndirangu et al. (2003), Sussman (2000)
Training	Gaible and Burns (2005), Stephen (2015), Grant (1996), Oladejo et al. (2011 citing Maduabunni, 2003), Singh and Singh (2012)
Instilment of professional values	Fraser and Saunders (1998), Chong and Cheah (2009)
Pedagogical knowledge enhancement	Chong and Cheah (2009), Mishra and Koehler (2006), Newton (2000), Windschitl (1999), Shulman (1986)
Skills development	e.g., McComas (2005), Onwu and Stoffels (2005), Newton (2000), Shanahan and Nieswandt (2009), Singh and Singh (2012), Ezeasor et al.(2012), Nyaumwe and Mavhunga (2005)
Continuous Professional Development	Garet, Porter, Desimone, Birman, and Yoon (2001), Organisation for Economic Cooperation and Development (2009), Capps, Crawford, and Constas (2012)

Thus, there may be opportunities available locally for fulfilling the requirements of the framework, and there may also be context-specific constraints on certain requirements. As examples, we consider variations in the context under which different science educators work and learn, as well as the needs of in-service and established educators.

School culture is a factor in terms of educator motivation and the likelihood of their engagement in tasks that demand effort (Hayes, 1997). This includes the designing and production of low-cost science education equipment. Thus, the nature and magnitude of the incentives needed for attracting and sustaining the interest of educators in this regard is context-specific. In relation to the availability of assistance in the production and/or use of improvised SEEMs, some pressured science educators may be able to obtain help from other staff in addition to learners. This is because in order to support pressured science educators, some schools deploy Science Technicians, Laboratory Technicians or Teacher Aids, some of whom take part in practical work (Higgins, 2009; Kidman, 2012; Moor, Jones, Johnson, Martin, Cowell, & Bojke, 2006; Royal Society (The) & Association For Science Education, 2001). Though it may be possible for these professionals to assist science educators in designing and producing improvised science education equipment (e.g., self-created models), this option is not available in all schools, countries or parts of the world where schools cannot afford such staff. For example, only 11 % of junior secondary schools in Ireland use Laboratory Technicians (Higgins, 2009).

Context may also affect the CPD component of the framework in Figure 2. The need to carry out CPD in professional learning communities may be fulfilled using Lesson Study (LS) for example. LS brings educators together to discuss lessons they have jointly prepared and observed in actual classrooms (Lewis, Perry, Hurd, & O Connell, 2006; Lewis, Perry, & Murata, 2006; Perry & Lewis, 2009). However, though common in Japan, China and increasingly in Canada, the United States, Europe and Australia (Gaible & Burns, 2005), LS is still an emerging innovation (Lewis, Perry, & Murata, 2006; Perry & Lewis, 2009). Thus, in some other countries and parts of the world such as Africa, where Lesson Study is not common, educators may need more external support when using LS to fulfil the CPD component of the framework in Figure 2. However, where required, such support is normally provided by LS Advisors. These are typically "instructional superintendents" assigned to schools (Fernandez, 2002) and university professors, though they could also be specialists from a regional education agency or district curriculum specialists (Richardson, 2004).

Also, there may be a variation in the learning needs of educators in terms of their competences. For example, established educators naturally have more practical knowledge than pre-service educators, considering as noted by Van Driel, Beijaard, and Verloop (2001) that such knowledge results from teaching experience. Thus, the

design of the CPD of science educators needs to be consistent with both their specific needs and the existing knowledge (e.g., Garet et al., 2001; National Science Teachers Association, 2006), within the context in which they work (Mansour, EL-Deghaidy, Alshamrani, & Aldahmash, 2014). It may be worth noting that in terms of varying the knowledge and skills that in-service educators may need to enhance in the context of the framework in Figure 2, as opposed to established educators, the literature may not provide clear direction. For example, Nivalainen et al. (2010) observed that though possessing more practical and theoretical knowledge of instructional approaches than their pre-service counterparts, some established science educators did not portray this in the planning of practical work. On the other hand, established educators studied science through more traditional approaches than today's pre-service educators (Anderson, 2007). Thus, the competences to be enhanced in these two groups of educators have not been differentiated in the context of the framework in Figure 2. However, in terms of in-service educators, the competences highlighted in Figure 2 may be considered against a given teacher education programme.

## DISCUSSION AND CONCLUSION

The literature review presented here had as its primary purpose to design a framework useful in guiding the reduction of the diverse teaching challenges linked to the production and/or use of such improvised SEEMs as self-created models and small-scale experiments in practical work in schools. In order to design the framework (Figure 2), we gathered in a systematic manner, the challenges and relevant ways of reducing them with the help of the conceptual framework of teaching challenges in Figure 1. In the process, and as reflected in Table 1, we identified two primary categories of challenges: intrinsic and extrinsic challenges. The intrinsic teaching challenges stem from a shortfall in the associated professional competences of educators in the domains of values, skills and knowledge. While being specific to practical work involving improvised SEEMs, this finding is consistent with prior research. For example, science educators have been observed to face (intrinsic) teaching challenges stemming from the lack of sufficient professional knowledge and skills (Newton, 2000; Windschitl, 1999). However, the literature presented in this paper goes further by highlighting the importance of professional values as well. In view of enhancing the competences (skills, knowledge and values) of science educators in relation to the preparation and implementation of practical work involving improvised equipment and materials, the framework in Figure 2 has thus been designed to serve as a guide.

In designing the framework, we augmented training which is a key recommended way of reducing specific challenges, based on the professional development research output. This research is included in Table 2 which illustrates the literature on which the framework is based. Basically, the framework in Figure 2 provides for broad-based educator learning as a way of reducing the intrinsic challenges linked to the production and/or use of improvised SEEMs. On the other hand, the framework responds to the inherent extrinsic challenges through the creation of an environment that is conducive to practice and educator learning. This is through the incorporation of a way of reducing each specific extrinsic challenge.

In line with the framework and following their empirical study in Kenya, Ndirangu et al. (2003) recommended the exposure of pre-service science educators to the improvisation of science education equipment. Also aligned to the framework in Figure 2, is the fact that in countries including Germany and the former Soviet countries of Georgia and Moldova, the use of inexpensive (low-cost) alternatives to traditional materials is becoming part of educator preparation programmes (Di Fuccia et al., 2012; Kapanadze & Eilks, 2014). In fact, many voices in the field of science education (e.g., Bhukuvhani et al., 2010; Ezeasor et al., 2012; Musar, 1993;

Singh & Singh, 2012) have recommended that not only pre-service but also practising educators be provided with training workshops or courses on the production, use and even maintenance of improvised science education equipment. However, the framework we have designed goes further in terms of specifying the enabling conditions for practice and educator learning in this regard. Thus, school managers, teacher educators and professional development providers may consider the implementation of this framework in their programmes. In doing so, the context under which the framework is being implemented may have to be considered, as illustrated by the discussion at the end of the last section.

Alongside the implementation of the framework in Figure 2 by practitioners, professional development researchers may evaluate it in view of providing empirical data towards its enhancement. Also useful in this regard is data as to why teaching challenges relating to the production and/or use of improvised SEEMs appear not to be present in industrialised countries. In addition, though the requirements of CPD are more or less well known to the science education community and are thus a part of the framework in Figure 2, this is not the case concerning a mechanism for educator learning in this context. In specific terms, there is need for data regarding the means, ways and processes that may be employed in view of arriving at CPD outcomes (Hewson, 2007). In this case, the immediate outcome is the enhancement of the competences of educators in relation to the preparation and implementation of inquiry-based practical work involving improvised SEEMs (e.g., self-created models, low-cost equipment and small-scale experiments). Data regarding the mechanism through which this outcome may be attained should facilitate the translation of the framework in Figure 2 into practice.

The discussion in the preceding paragraphs shows that the implementation of the framework in Figure 2 requires the efforts of many actors including science educators and learners as well as school managers, teacher educators, professional development providers and professional development researchers. Though the efforts of many role players are needed, their collective efforts can lead to significant educational and environmental benefits linked to SEEMs. The educational benefits include the fostering of science inquiry through increased availability of SEEMs at a lower cost, reduced dependence of classrooms on hazardous conventional equipment and materials (e.g., ethidium bromide), increased educator ability to address learning difficulties (e.g., using self-created models) as well as reduced dependence of schools on external sources of SEEMs (e.g., mobile laboratories). The environmental benefits include a reduction in household waste through recycling (e.g., plastic bottles) and a reduction in the use of environmentally unfriendly conventional SEEMs.

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