DEVELOPING AN INSTRUCTIONAL MODEL TO SUPPORT TEACHING OF INVESTIGATIVE PRACTICAL WORK IN SECONDARY SCHOOL CHEMISTRY

Authors: Monica Gakii Ituma
PhD student in Science Education
Kenyatta University- Kenya

Nicholas Wanjala Twoli
Professor of Science Education
Department of Educational communication and technology
Kenyatta University- Kenya.
P. O. BOX 43844 – 00100.
Nairobi-Kenya

Corresponding author,
Monica Gakii Ituma
P.O. Box  5166-00200,
Nairobi- Kenya.
Abstract

Many teachers in developing countries including Kenyan schools use practical work in chemistry as perhaps the closest method to teaching by inquiry. Performance in chemistry at the end of course in Kenya has, however, been consistently low, implying the ineffectiveness of the conventional practical work. This realization led to an interest in the study, which aimed at determining the practices that could develop scientific thinking in learners. A Design Based Research (DBR) approach was used to develop a design process for incorporating instructional features intended to promote use of investigative practical work in secondary school chemistry. Model materials that support teaching of investigative practical work were developed in a cyclic approach of design that includes formative evaluation. They were used in chemistry classrooms and they proved to be effective in supporting teachers’ use of investigative activities. This process led to the development of Secondary Chemistry Investigative Practical Work (SCIPW) model aimed at providing guiding principles and processes in the organization and development of such instructional materials.

Key Words

Instructional materials, chemistry teaching, investigative practical work model, Instructional Design;

1. Introduction

Inquiry-based teaching has been proposed and encouraged by a number of science educators as a significant tool in the development of students’ scientific skills, knowledge and cognitive acceleration. While chemistry subject is taught using theory and practical approaches, this research focuses on the practical work. Practical work in science in its prime functions is defined as ‘hands-on’ activities that support the development of practical skills, and help to shape students’ understanding of scientific concepts and phenomena (SCORE, 2009). Most chemistry teachers believe that practical work is important and leads to meaningful learning of Chemistry. Some science educators have, however, raised questions about the effectiveness of conventional practical work as a teaching and learning strategy (Abrahams & Millar, 2008). They argue that practical work should involve learner-centered learning environment which engage students in knowledge construction, as opposed to teacher-centered environment which involves information absorption. Current Science Education reforms are geared towards investigative approaches of science learning which involves practical work (SCORE, 2007; Trowbridge et al, 2004).

Though many teachers spend a lot of time in practical work, the process may not necessarily be investigative in nature. In the conventional practical work, the learners follow laid down procedures to arrive at a predetermined outcome and do not use scientific ideas to guide their actions during the practical activity and hence to reflect upon the data they collected (Motswiri 2004). Many of the instructional materials used in schools, do not also support the teachers in the use of investigative practical activities.

2. Research problem

There has been consistently low performance in chemistry subject in Kenya and possibly other developing countries over the years. Studies which have been carried out to establish the causes of the low performance seem to point at the low contribution and quality of practical work (Orado, 2009; Nyang’ai, 2010; Achimugu, 2009; Kamau, 2004; Inzahuli, 2007; Bekele & Melesse 2010; Sunzuma et al, 2012). Evaluation reports have constantly advised teachers to expose learners to more practical work that involves investigations (KNEC, 2008; KNEC, 2011; KNEC, 2012). It is also imperative that the low performance in the practical work examination does affect the overall performance in chemistry.
While many teachers spend a lot of time in practical work, the process might not be investigative enough to impact on the overall learning of chemistry. Traditional laboratory experiments where procedures are provided to guide learners in a step by step manner, do not seem to provide enough opportunities for students to use their minds to solve problems posed in the laboratory (Chiapetta & Koballa, 2010; Trowbridge et al, 2004). Hubber & Moore (2001) argue that ‘hands on’ activities in science practical work do not necessarily guarantee scientific investigation. When learners follow laid down procedures to arrive at a predetermined outcome, they do not use scientific ideas to guide their actions during the practical activity and to reflect upon the data they collected (Motswiri 2004). Trowbridge et al (2004), who advocated for action oriented process argue that, learners should instead be guided to identify problems and potential solutions, design their own procedures, analyse and discuss assumptions, procedures, predictions, products and solutions and link their experiences to activities, concepts and principles.

Most instructional materials used in schools do not fully support the teachers in the use of investigative practical activities. In 1981 the National Science Teachers Association (NSTA)- United States sought for exemplary programs in secondary school science teaching that focused on inquiry and investigative methods of teaching (recorded in Trowbridge et al, 2004). It was found that textbooks and commercially published supplementary activity guides are non-inquiry approaches to science teaching. Other studies have also indicated curriculum materials as failing to support investigative practical work (Krajick et al, 2003; Kesidou & Roseman, 2002, Krajcik et al, 2007). The teachers can be guided to use the existing instructional materials to develop instructional strategies that support the implementation of learner-centred investigative practical work in secondary school chemistry learning.

Trowbridge et al (2004), notes that the challenges to investigative teaching are still evident and the shift from traditional expository methods has been very slow. In support, Krajcik et al (2003) claim that the approaches of pedagogical reforms to bring inquiry into classrooms present core challenges for the field of science education. They, therefore, pointed out that research-based curriculum materials can address these challenges and provide improved tools for learning for teachers and students through development of appropriate instructional designs. Efforts to reform science education, therefore, call for specifically designed instructional materials for the improvement of chemistry and science teaching and learning. The main objective of this study was to develop an instructional model for constructing instructional materials that support teachers in the use of investigative practical work in secondary school chemistry.

### 3. Research Methodology

The study employed a Design-Based Research (DBR) design. Design based research is a systematic but flexible methodology aimed at improving educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories (Wang & Hannafin, 2005; DBRC, 2003). DBR design was appropriate because it helped to create and extend knowledge about developing, enacting, and sustaining innovative learning environments (DBRC, 2003). The five basic phases of an Instructional Design Model (IDM) made up the five stages this study. These were: (1) Assessment of the practices and needs of Chemistry practical work in schools (2) Design and development of Chemistry practical work instructional materials prototype (3) Try out of the prototypes (4) Evaluation of the instructional strategies (5) Refinement of the materials. The research process involving the five stages is summarised in figure 1.
Needs analysis for Chemistry practical work is the theoretical problem analysis which involved literature review on characteristics of appropriate materials for learner-centred investigative activities. It also involved context analysis of current practice and needs for learner-centred Chemistry practical work. This stage involved empirical analysis of: (a) the teaching needs of chemistry practical work (b) Instructional materials available for chemistry practical work (material needs analysis) (c) Worksheets and textbooks to identify skills emphasized by practical work in the curriculum materials as well as presentation of practical activities in the materials (content needs analysis).

The study at this stage was carried out using questionnaires for teachers, teacher interviews, document analysis schedule and lesson observation of chemistry practical lessons. Document analysis schedule was used for analysis of the textbooks commonly used by teachers for Chemistry practical work. Using data gathered in stage one, design specifications were formulated. These are design standards against which the final materials were evaluated. Some design specifications found in Ottevanger (2001), CDC-HKEAA (2007), Ottevanger (2013) and Motswiri (2004) were adapted to suit the requirements of this study.

Instructional materials were then designed and developed based on the design specifications with complete guidelines on how to introduce, perform and conclude the lesson. These materials consisted of both teacher support materials and learner’s work sheet. To make them more relevant, the activities were based on the objectives of the local secondary school chemistry syllabus the process also adapted a lot from available materials by changing the practical activities into investigative practical work problems to encourage learner-centred classroom practice through presenting scenarios and asking students to develop experimental plans to
solve the problems. From the content in the topic *acids, bases and indicators*, six lessons were constructed for the practical work.

Experts in the science discipline conducted content reviews on the practical work materials developed (first level prototype) to ensure scientific accuracy. Forty seven teachers Chemistry trained teachers were involved in the study to evaluate materials with the view of determining the appropriate methods of teaching chemistry and provide feedback on important characteristics for investigative practical work. Other three teachers who had a long experience in the teaching of chemistry were given a specific role to appraise the materials. At the same period two science education experts from a university were also requested to appraise the materials and the study instruments mainly as a verification measure. The feedback was used to redesign and improve the materials to develop the second level prototype that was used by teachers.

The chemistry practical work learning materials developed in stage two were used by three teachers and their students in a laboratory and provided feedback and assessment on different aspects of their practicality and effectiveness. Feedback from these trials was used to review and redesigned the instructional materials producing a third level of materials (third prototype). The third prototype was used in the laboratory by five teachers. This stage involved formative evaluation of the practicality and effectiveness of the instructional strategies in the materials in Chemistry laboratory settings. The last stage of the development of the exemplary instructional materials design involved refining the materials based on the feedback from the outcomes to produce the best model of instructional materials that can be used in learner-centred investigative practical chemistry.

4. **Data Analysis and Results**

The Development of Secondary Chemistry Investigative Practical Work (SCIPW) Model

The results of each stage of the study were used in the construction of a linked procedure in the form of a model for the development of instructional materials for teaching secondary school chemistry practical work through investigations. I label this model as *Secondary Chemistry Investigative Practical Work (SCIPW)* model. The SCIPW provides a guide through the process of developing instructional strategies that support teachers in the implementation of learner centred investigative practical work in Secondary School Chemistry. Secondary Chemistry Investigative Practical Work (SCIPW) model was basically constructed through some key stages identified by the study. The first stage is the ‘mainstream’ which is regarded as the *backbone* of the overall model.

4.1. **Stage one of SCIPW model: The Mainstream**

The first stage involves a close analysis of the content of chemistry practical work currently used in secondary schools. In most cases this would be contained in the national syllabus. This guides in the design of instructional strategies and activities for investigative practical work. The designed activities went through various, appraisals, trials, evaluation and refining as well as redesigning through an iterative process to produce a final prototype of practical chemistry materials (Dick & Carey 2005). This was guided by the mainstream model (figure 2)
4.2. Stage two of SCIPW Model: Identifying Chemistry Practical Work Content

The content of the instructional materials should reflect facilitation of activities that would stimulate the learners’ cognitive mode and in a way allow them to construct their minds and activities. The content of instructional materials (mainly textbooks) that teachers were using in schools to guide learners through chemistry practical work were analysed with an aim of finding out the nature of content as well as support for investigative practical work available in the materials. The syllabus usually provides a guide on appropriate content for the level of learners. The content recommended by the syllabus which was also reflected in the textbooks was analysed using document analysis schedule. The utilization of such materials was also sought through lesson observations of teacher practices as informed by the instructional materials they used. Essentials for teaching practical work through investigative methods were also identified through teacher questionnaires in which the teachers provided their views of what they considered as the best and improved way of carrying out practical activities. Figure 3 shows processes of the second stage of SCIPW model.
Five different textbooks commonly used by teachers and approved by the national curriculum centre which is Kenya Institute of Curriculum Development (KICD) for the teaching of Form One chemistry topic of acids, bases and indicators were analysed. The textbooks were found to contain practical work content presented largely in a cookbook style where most of the procedures were provided and the expected outcome outlined. Such designs in instructional materials are likely not to support learners thinking skills (Kidman, 2012; Krajcik et al, 2003). Instead, such materials tend to encourage learners to simply perform instructions in a mechanical form. Similar observations were made by Abrahams & Millar (2008) who argued that practical work was generally effective in getting students to do what is intended with physical objects, but much less effective in getting them to use the intended scientific ideas to guide their actions and reflect upon the data they collect.

Each of the six lesson areas in the books were analysed to determine the support they provide for investigative practical work. Interestingly textbooks were found to contain little support for investigative activities. The only support found in most textbooks was provision of objectives observed in 73.3% of the materials. Other support features for investigative practical work were found in low percentages such as; providing relevant phenomena (23.3%), reference to prior knowledge (30%) and provision of background information related to the practical activity (30%). Opportunities such as guiding on learner participation in formulation of procedures to use in the activity, guide on pooling of results together and probable learner questions were lacking. Similar weaknesses concerning instructional materials have been noted by other researchers (Thijs, 1999; Stoffelsma, & Kwetu, 2004; Ottevanger, 2001; Motswiri, 2004; Krajcik et al, 2003). Such weaknesses in instructional materials could hinder the use of constructivism that supports ‘cognitive acceleration’ in the learning set up. Lesson observations showed that teachers were not conducting lessons using learner-centred strategies. The teachers provided step by step guide on the activities they carried out which the learners followed without question or reflection. In most cases the results were not consolidated and learners were not given opportunities for scientific reasoning and arguments. Most teachers were found to follow the practical work as outlined in the textbook without alterations.

This practice indicates the importance of constructing instructional materials based on the current teacher practice with a change in the approach to instruction. This nature of ‘recipe-based’ practical work is not sufficient to develop students scientific thinking referred to by Kim & Chin (2011) as ‘habits of mind’. It was observed that learners were restricted to the use of procedures given and did not even question them. During class activities involving practical work, learners were keen on following procedures and could be heard asking each other to read out the next ‘step’ in the procedure provided. When finished with the activity, they would sit and wait for the teacher to tell them what they should do next. They were found to be reluctant to discuss their findings among themselves, thus giving a docile mood for what is otherwise expected to be a vibrant session.

This analysis of content and teacher practice provided the researcher with an important base of identifying content needs in the learning of investigative practical work. The content of the books gave a useful lead to develop activities that were modified towards investigative activities.

### 4.3. Stage three of SCIPW model: Design and Development of Instructional Activities

Design and development of practical activities in the instructional materials started with the development of design specifications. Design specifications for the instructional materials were informed by theoretical orientation (what literature presents as best practice for learner-centred investigative practical work) and feedback from empirical analysis (textbook content, teachers’ views and actual teacher practice in the
classroom). Theoretical orientation provided the designer with what is considered as best practice in constructivist learning environment (Smith & Ragan, 1999; Brooks & Brooks 1993; Hidir & Gultekin, 2007; Kirschner et al, 2006; Jonassen, 1999) and design specifications for developing materials used in similar studies (Ottevanger, 2001; Thijs, 1999; Motswiri, 2004; Davis & Krajcik, 2005; CDC-HKEAA, 2007; Ottevanger, 2013; Davis et al, 2014). Designing the instructional materials also involved a consideration of the challenges identified in the books used by teachers to support teaching of practical work (obtained from document analysis schedule and teachers’ views in teacher questionnaires) as well as observed classroom practices during practical work lessons. Availability of resources in the local set-up was considered in the design and suggestions for improvisations provided in the instructional materials. Activities were designed such that available resources could be used to enhance Chemistry and science learning in general (figure 4). New teaching approaches were infused in the design of the practical work activities.

Figure 4: Stage 3 of SCIPW Model: Design and development of instructional activities

Five areas of science practical work designed to emphasize instructional materials were identified as science content, scientific practices, literacy practices, participation structures and assessment modes (Davis, et al 2014). Design specifications were formulated with detailed characterization of each of the five areas of learning. The first prototype of instructional materials was then designed. These materials included the teachers’ guide (which was the main document) and a brief student guide. The main focus of the teacher guide was to support the teacher in guiding learners through conducting practical activities in an investigative way.
The role of the teacher was presented as to design meaningful experiences in learning environments while that of the learner was to join discussions and collaboration activities. Designed meaningful experiences were to motivate students to construct new knowledge in their long term memory (Isman, 2011).

To play its functional role, the quality of instructional materials at this stage should be carefully checked. Three sets of criteria for judging appropriateness of instructional materials used were; pedagogical appropriateness, science content and presentation format (The National Academy of Sciences, 1998; Rubdy, 2003). It was also considered necessary to have the instructional materials appraised by the teachers who are the users of such materials in the classroom. The process was iterative, with the outcome of one appraisal leading to the refinement of the materials. A good number of teachers on pre-service training in chemistry teaching were found important in the appraisal of the materials. This was boosted by the fact that a high percentage (91.5%) of the teachers indicated that the materials reflected the national syllabus and were usable in chemistry laboratory. Most of the teachers (68.1%) agreed that learners could cope with the approach of teaching suggested in the materials. They suggested various adjustments on time allocation for laboratory activities, provision of suggestions for improvisations and alternative designs and inclusion of safety precautions. These suggestions were used in the review and re-organisation of the instructional materials.

To reinforce this important stage, three teachers with long experience in the teaching of chemistry at secondary school level were given an opportunity to appraise the materials. From their recommendations, more adjustments were made on the timings of the practical activities and more guidance on teacher activities especially on assessment provided. To cap it all, two science education experts lecturing at the university appraised the materials and research instruments that were used in the study. These appraisals also offered quality check on relevance and consistency of the instructional materials. The instructional materials were redesigned leading to the development of the third prototype.

4.4. Stage Four of SCIPW Model: Trials of Materials

The third prototype was tried out in a laboratory set-up. This was a key stage and it aimed at testing the practicality of the materials in a laboratory set-up. Ottevanger (2013) describes practicality as the usability of the intervention in the settings for which it has been designed. Isman (2011) supports this process when he argues that problems in instructional design are identified during testing of prototypes. Three teachers and their form one learners participated in this section of the study. During the tryout, a consideration of resources available for use in schools was made. Some adjustments for improvisation and grouping learners for practical activities were made. The teachers used teacher guide to assist in the lesson preparation and implementation. Time available for teaching was a major consideration at this stage as it seemed it would take longer than the conventional approach (figure 5).
During the lesson activities lesson observation was done by the researcher. It was observed that teachers were able to understand and utilize the instructional materials appropriately. Analysis of lesson observations showed that 81.06% of expected teacher actions in an investigative practical work set-up were observed. Grouping of learners was, however, affected by lack of sufficient resources and time for improvisation as well as large class sizes considering the intense guidance required from the teacher. To boost on information uptake, a logbook was introduced to gather detailed information regarding teacher experiences during planning and implementation of the lessons. Teacher interview at the end of the lesson series provided clarification on areas they mentioned in the logbook and their experiences in the laboratory. Student interviews were used to gather information about effectiveness as perceived by the learners. The observations and views were used in the redesign of the materials producing another prototype for evaluation in stage five.

4.5. Stage Five: The SCIPW model

The materials were further refined after the first try-out and used by five teachers in their Form One classes. This was the evaluation of the materials in laboratory use. Evaluation of instructional materials was based on practicality and effectiveness (Nieveen, 1999), which Huitt et al (2009) identified as effectiveness, efficiency, and appeal. Practicality (efficiency) was based on: the ability of the instructional materials to support teachers in the teaching of investigative practical work; relevance of the materials in the teaching of secondary school
chemistry; clarity of instructions in the materials; complexity of the teaching approach, congruence with current teacher practice and cost associated with use of the approach (Ottevanger, 2013; Nieveen, 1999).

Effectiveness was based on achievement of desired objectives and student response to instruction. Evaluation involved observing the teacher activities during the practical lesson and recording the observations as guided by the observation schedule. Learner participation as they interacted with available resources pointed to the effectiveness of the lesson. Data on Practicality and effectiveness of the materials as gathered through lesson observation, logbook recordings, interviews, student questionnaires and concept maps. These informed the refinement and development of the final model of instructional materials for secondary school chemistry practical work (figure 6).

Figure 6: The SCIPW model for developing investigative practical work materials

Teachers’ views indicated in the logbook as well as expressed during teacher interviews indicated that they found the instructional materials to be providing them with necessary support for learner-centred investigative practical work. The instructions were clear and easy to follow and the complexity level was within the ability of both the teachers and the learners. Teachers, however, found the approach incongruent with their conventional practical lessons. They pointed to the challenge of large classes with the amount of coordination required in the approach of teaching. They also felt that learners were challenged in involving themselves through the thinking and planning of the processes of investigation. The indication with continued use of the
approach in the six lesson series was that learners tended to adapt and also liked the new approach. It was realized that the cost of resources was higher than usual and the demand on teachers’ time and participation was also high. The teachers, however, indicated that the outcome of learning would be higher and thus worthwhile, as one teacher after the lessons expressed “I have never thought of asking learners to formulate their procedures, it however would involve learners more and make them understand the concepts.”

Effectiveness of an investigation is achieved when using the intervention results in desired outcomes (Ottevanger, 2013). Analysis of lesson observation schedule indicated that 80.92% of expected teacher actions during the investigative practical lessons were observed. The high percentage was taken as a positive indication of practicality and effectiveness of the instructional materials. Learners were also required to give some feedback by completing concept maps linking the concepts and skills learnt through the use of the instructional materials. Use of concept mapping in the learning of chemistry is important in summarizing important concepts learnt, thus aiding conceptualization (Trowbridge & Wandersee, 1998; Kilic & Cakmak, 2013). The mean score from the concept maps was 80.55% which was also taken as an indication that meaningful learning had been achieved. Learners were requested to complete a questionnaire indicating their perception concerning the lessons taught using the instructional materials. Most learners indicated that they were able to participate in the lesson activities (95.6%), enjoyed the taking part in the lesson (90.7%), were able to understand more (88.2%) and felt motivated to learn chemistry (83.3%). Going by these indicators, one can conclude that learners found it quite an academically enriching experience.

5. Conclusion

The main goal of Secondary School Chemistry Investigative Practical Work (SCIPW) Model is to give a route map to organize the development of instructional materials for use in chemistry learning of practical work which ensures the learners are intellectually and physically involved in the Chemistry learning activities. A learner is active during the learning activities, which can lead to better understanding of science concepts and development of both manipulative and process skills.

SCIPW model can be used to develop instructional activities of practical work not only in the chemistry subject but also in other science subjects. The iterative nature of DBR used in the study ensured feedback at each stage in the design which then enriched the next stage. The materials to be used to generate such a model should go through various evaluation activities (Ottevanger, 2013; Nieveen, 1999; Motswiri, 2004). These included appraisals by chemistry teachers who used the instructional materials and expert appraisal to enhance consistency.

SCIPW is based on instructional systems design that covered five stages; analysis, design, development, implementation, and evaluation of instructional materials. Such a design should ensure that it closely conforms to the larger educational policy and structure of education in a given country to be acceptable by users. In this study the model closely relates to the Kenya Certificate of Secondary Education (KCSE) syllabus and Kenya National Examinations Council (KNEC) regulations. For chemistry and science teachers in general, this is a process to try out, either partially or in full for it brings lots of benefits to the learners.
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