Chemistry Teachers' Role in Changing Practical Work from Simple 'Hands On' Activities to More of 'Minds on' Activities

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Abstract

Practical work is important for effective learning of Chemistry. In most secondary schools especially in Kenya, practical work in Chemistry mainly involves 'hands on' activities where learners follow laid down procedures to arrive at a predetermined outcome. This may lead to working on practical activities without much thought of the actions and thus low conceptualization resulting in poor performance in Chemistry at the end of the course. This study aims at providing alternative approach on how to engage the learners' mind more in practical activities. The process started by collecting data through observations of convectional practical lessons, followed by analysis of instructional materials used by Chemistry teachers and questionnaires for the Chemistry teachers. The findings showed that the strategies used to teach practical work did not adequately focus on the learners' 'minds on' activity. There was need, therefore for the re-design of the activities to support the implementation of learner-centred investigative practical work in secondary school Chemistry. The study suggests a model for organising instructional activities for Chemistry practical work at secondary school level.

Keywords: Instructional materials, 'minds on' practical activities, investigative practical work, secondary Chemistry practical work model

1. Introduction

Despite the many advantages associated with practical work and great attempts by teachers to use practical work in the teaching of Chemistry, many science educators have expressed significant doubts about the effectiveness of practical work in teaching science knowledge and skills (Abrahams & Millar, 2008; CERG, 2009; Dikmenli, 2009; Kennedy, 2011). This could be mainly due to the nature of practical activities carried out in schools. Conventional methods of teaching practical work used in most Kenyan secondary schools mainly focuses on developing students' knowledge in Chemistry, rather than on developing understanding of scientific investigative procedures. The practice in practical work has been a cookbook trend where the instructions are carried out like a recipe which reduces meaningful learning. The learners therefore, do not use scientific ideas to guide their actions during the practical activity and to reflect upon the data they collect. In this regard, Kim & Chin (2011) argue that such recipe-based practical work is not sufficient to develop students 'habits of mind' because they involve simply doing but do not require thinking through doing.

Effective practical activities should enable students to build a bridge between what they can see and handle (hands-on), and the scientific ideas that account for their observations (minds-on). In order for Chemistry practical work to be effective in producing meaningful learning, the teachers should develop activities that engage the learners in scientific investigations which focus their minds on the activity and its outcome. Motswiri (2004) observed that classroom practices in most secondary school Chemistry lessons are characterised by chalk-and-talk and little practical work. Some science educators 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 (Gravoso et al, 2008).

1.1. Need to support investigative practical work

There has been continued poor performance in Chemistry at the end of course examination in most developing countries including Kenya. This indicates that the learning of Chemistry may not be as effective as required. Motswiri's (2004) argument that classroom practices in most secondary school Chemistry lessons are characterised by chalk-and-talk and little practical work raises some questions on the quality of science learning in schools. It is further noted that in cases where practical work is implemented, it only requires students to follow instructions developed by the teacher or from textbooks where the learners are supposed to strictly carry out the activities as per the instructions; sometimes without much interest or thought on what they are doing. Learners tend to follow the teacher's guidance to the letter. It is therefore of paramount importance to change the teachers' practice in order to achieve meaningful learning of practical Chemistry. Studies indicate that use of investigative approaches of science learning through practical work is one means of improving learning in Chemistry (SCORE, 2007). Investigative inquiry approaches to learning the content and process of science has been central in the recent years yet the challenges to investigative teaching are still evident and the shift from traditional expository methods has been slow (Krajcik et al 2003). Hubber & Moore (2001) argue that 'hands on' activities in science practical work do not necessarily guarantee scientific investigation. These points to a need to support teachers in the use of learner centred investigations.

Changing practical activities from 'hands on' to 'minds on' type requires proper management of all stages of the activity. Practical work is usually carried out in four main stages (Twoli, 2006; Omosewo, 2006); planning, implementation/activity, discussions and conclusions (Figure 1). When these stages are well managed they can lead to conceptualization of scientific knowledge and acquisition of skills.

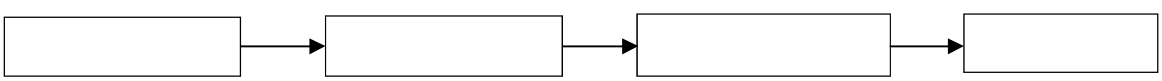

Figure 1: Process of practical work for the development of understanding of scientific principles

Krajcik et al (2003) noted that research-based curriculum materials can address these challenges and provide improved tools for learning among teachers and students through development of appropriate instructional designs. Instructional materials can serve as learning materials for both students and teachers. Materials can also serve as a primary influence on how teachers should teach science (Krajcik et al 2003). Yandila et al (2003) quoted teachers as facing difficulties in implementation of learner-centred approach due to, among other factors, lack of exemplary teaching materials and inappropriate textbooks.

2. Aim of the study

The main aim of this study was to develop insights into the characteristics of instructional strategies that would support teachers to engage learners in use of learner centred investigative practical work in the secondary school Chemistry. This was done by working with Chemistry teachers in redesigning instructional materials to make them support more learner centred strategies.

3. Study location and population

The study was carried out in Kajiado County in Kenya. The forty two (42) public schools managed by the government were taken as the study population. From a sample of 19 schools, 42 teachers responded to a questionnaire and lesson observations were carried out schools. Instructional materials were developed and appraised by teacchers.

4. Conceptualization of the study

Considering that this study aimed at defining the characteristics of learner centred instructional strategies and how they can be developed and used, the study focused on instructional design strategy that involves designing, developing and evaluating instructional material prototypes. Such developmental research characterizes the situation with all its complexity instead of identifying a few variables to hold constant (Aksela, 2005; DBRC, 2003). The study considered the content of instructional materials for practical work and teaching strategies (including student engagement in designing practical work) as the conditions that affect understanding of concepts and acquisition of skills (learning outcome). Instructional strategies were designed in the instructional materials and developed through various stages to produce refined model of instructional materials that contain strategies for investigative practical work. The study was also based on constructivism theory of learning which propose meaningful learning for students. Constructivism is a philosophy of learning founded on the premise that, by reflecting on their experiences, the learners construct their own understanding of the world they live in. adjusting their mental models to accommodate new experiences (Smith & Ragan, 1999). It is considered to be a learner-centered theory that focuses on the knowledge of interpretation and experience-based activities (Brooks & Brooks, 1993).

5. Methodology

This study employed a Design-Based Research (DBR) design. Design-Based Research is one terminology used to describe a research methodology that is used to design/develop an intervention (such as programs, teaching-learning strategies and materials, products and systems) with the aim to solve a complex educational problem and to advance knowledge about the characteristics of these interventions and the processes to design and develop them (Plomp & Nieveen 2007). Some scholars also refer to this research design as developmental research design (Wang & Hannafin, 2005; Motswiri, 2004). DBR design was appropriate for this study because it helped create and extend knowledge about developing, enacting, and sustaining innovative learning environments (DBRC, 2003). DBR has an advantage of offering solutions to real life problems because the research is carried out in real life setting where learning is done, it has multiple dependent variables, it characterizes the situation with all its complexity and involves different participants in the design who bring in differing expertise instead of being subjects of study. It is a flexible design for revision in which tentative initial set is revised depending on success (Krajcik et al, 2007; DBRC, 2003). DBR emphasizes the participatory role of practitioners and in this case, teachers and students who can become re-designers by collaborating with researchers (Aksela, 2005). Based on constructivist theory of teaching and learning, practical work instructional materials that support investigative learner-centred teaching strategies were developed.

A construct referring to step by step prescriptive procedure for creating instructional materials in a consistent and reliable fashion in order to facilitate learning is often referred to as an instructional design model. The five basic phases of Instructional Design Model were used in the study (Gustafson and Branch 2002). The first stage involved assessment of the practices and needs of Chemistry practical work in schools. This was done through use of questionnaires for teachers, lesson observations and analysis of content in the books commonly used by teachers in Chemistry teaching. Stage two involved design and development of Chemistry practical work instructional materials prototype. Design specifications were developed based on the outcome of stage one analysis, constructivism theories and state-of-the-art knowledge about teaching of science. From the specifications, the first prototype of the materials was then developed. These were appraised by teachers. After the appraisals, the materials were refined and developed into a second prototype. The third stage was the try-out of the second prototypes with Chemistry teachers in the form one classes. The feedback from these try-outs were used to refine the materials further thus development of the third prototype. The fourth stage involved evaluation of the instructional strategies. This was carried out in the laboratories as chemistry teachers used the materials to support their implementation of learner centred investigations. The evaluation was done using lesson observation, teacher logbook, teacher’s interview and student questionnaire. The feedback obtained was used for the refinement of the materials leading to a model of instructional materials that support learner centred investigative work.

6. The findings

6.1. The role of practical work in chemistry

The information regarding the role of practical work in Chemistry was obtained from teachers using a questionnaire. All the teachers involved indicated that they used some form of practical work in teaching Chemistry. This implies that teachers attach a lot of value to the practical work in Chemistry instruction. When asked about the method they used to teach Chemistry practical work, the highest percentage of the teachers (64.3%) indicated that they commonly used demonstration method despite acknowledging that class experiments would produce better learning of chemistry concepts. A small percentage (21.4%) of teachers indicated that they commonly used class experiments. Project work was rarely used by the teachers (2.4%) (Figure 2)

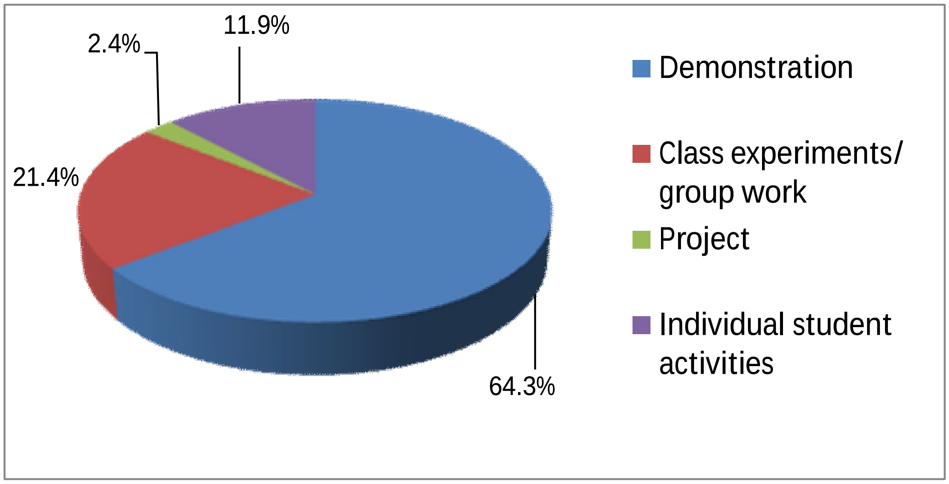

Figure 2: Methods used to manage instruction in school Chemistry practical work

Teachers organized practical work by placing learners into groups and providing them with detailed procedures to follow. Responses to questionnaire items showed that most teachers (80.9%) believed that providing learners with detailed procedures to follow leads to their engagement in learning. It is however important to note that merely placing learners in groups does not lead to practice of inquiry as some can be in a dormant stage (Wachanga & Mwangi; 2004). Educationists argue that following strictly set procedures to arrive at a predetermined outcome is limiting and does not lead to meaningful learning in science (Hubber & Moore, 2001; Trowbridge et al, 2004; Motswiri 2004; Chiapetta & Koballa, 2010). There are some common practices observed during chemistry practical lessons in secondary school chemistry. The frequencies with which these practices are carried out depend on how the teacher organizes the learning activities. For the practical lessons observed, frequencies of the common practices were as shown in figure 3. Many teachers (71.4%) were unwilling to allow the learners to develop their own procedures, or carry out procedures that interested them. Some teachers did not even allow learners to question the procedures they were given. This indicates that the learners may not actively engage their minds during the practical activity as their activities were completely closed. This method of conditioning learners has been referred to as providing 'hands on' and not 'minds on' activities (Chiapetta & Koballa, 2010).

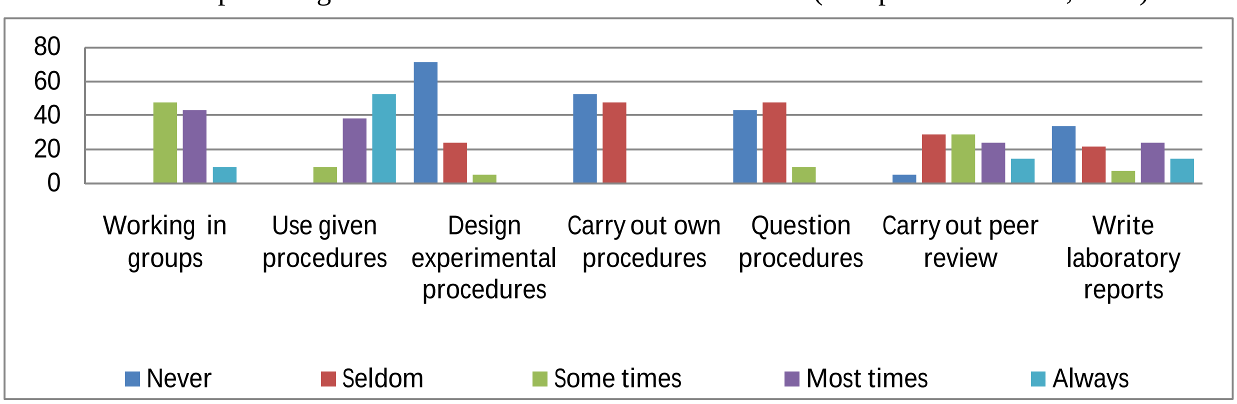

Figure 3: Common practices carried out in secondary school chemistry practical work

The study further showed that teachers did not have laboratory manuals that they could use for practical work. They used Chemistry text books that are approved by the National curriculum centre (Kenya Institute of Curriculum Development, KICD). Most of the practical activities in these materials appeared to be geared towards confirmation of facts and ideas and therefore provide detailed step by step experimental procedures. Most of the teachers (81.0%) indicated that the expected results of the practical activity were clearly outlined and most learners work towards getting the results indicated in the book. The books were found to emphasize mainly on manipulative skills and observation but lacking emphasis of important skills of predicting/hypothesizing, creativity and imagination, as well as application of scientific facts. Such materials do not provide learners with an opportunity to develop their own procedures for practical activity or look for alternatives to procedures given and do not encourage thoughtful reflection on experience. This indicates the need for special instructional material support for practical work in Chemistry teaching and learning. The lessons observed indicated that teachers used the textbook as guide for structuring their lessons. Learners were not accorded opportunities to engage in scientific arguments and support the outcome of their experiments. Similar weaknesses concerning instructional materials have been noted by other researchers (Motswiri, 2004; Krajcik et al, 2003).

6.2. Design and development of the investigative practical work instructional materials

Having established the convectional materials and practices by teachers the researcher set out to develop an initial prototype of the instructional materials that would support teachers in implementing investigative practical activities in Chemistry. These were designed as a set of six lessons from the topic; *Acids, Bases and Indicators*. This is a topic in Form One (Year 1 at secondary school level) syllabus. The design specifications for the materials were informed by needs for Chemistry teaching and learning of practical work as identified from stage one of study, constructivism theory of learning, and literature by other researches (Reiser, et al 2003; Motswiri, 2004; Ottevanger, 2013, Davis et al, 2014). The design specifications emphasized a focus on: science content, scientific practices, scientific literacy practices, participation structures and assessment opportunities:

The features of appropriate instructional materials were adapted. These included pedagogical appropriateness, appropriate science content, presentation and format (National Science Resources Center, 1997; National Academy of Sciences, 1998). A number of evaluation processes (Nieveen, 1997; Motswiri, 2004; Ottevanger, 2013) were carried out at this stage. The first was expert appraisal in which experienced teachers evaluated the materials and identified areas that required review and improvement. The appraisal was guided by a structured questionnaire that mainly comprised open-ended questions and an informal interview. The results indicated that the materials reflected the secondary school syllabus and could be used in the classroom. Suggestions were made for adjustments of materials that were to be used for practical experiments. There was a general agreement that the materials would be instrumental in guiding the teacher through discussions during the lesson and in helping learners build information on their prior knowledge.

Science education lecturers from a university also appraised the materials with the purpose of enhancing consistency of the materials and research instruments. Their views were used to review and redesign the materials producing a second prototype. This prototype was tried out by three teachers with their students in their classrooms. This focused on the practical usability of the materials in the chemistry classes. The results were used to review the materials producing the third prototype. This prototype was taken for a field test where evaluation of practicality and effectiveness were carried out. The instructional materials for a series of six lessons were used by five teachers in their classrooms. The results of the evaluation were used to refine the materials further producing the final version. These evaluation activities in the study were embedded in a cyclic approach of design and formative evaluation for the development and refinement of the instructional strategies for learner centred investigative practical work.

6.3. Evaluation of the materials

The instructional materials consisted of the teacher guide and student materials that composed six practical lessons covering the topic: *acids, bases and indicators*. The teacher‘s guide provided detailed procedures on how to guide the learners through each step of the investigative process including predicting/ hypothesizing and formulation of procedures to use for the activity. The evaluation involved use of the materials with five teachers in their Chemistry classes. This involved a total of 144 learners. A total of 30 lessons were carried out. The evaluation of the materials was carried out to determine the instructional support the materials provided in achieving learner centred investigative practical work.

The key criteria for this evaluation were guided by determination of practicality and effectiveness of the materials in actual classrooms (Krajcik et al, 2003; Nieveen, 1999; Otteavenger, 2013). Practicality was evaluated as a measure of the materials' quality, which was indicated by support, clarity, congruence, complexity, and cost as perceived by the teacher using it in the context of his or her practice.

Lesson observation schedule was used to guide the recording of observations made during the practical activity. The teacher was provided with a logbook to record the happenings in each lesson carried out. This contained a structured guide with open-ended questions to guide the teacher. The teachers were interviewed at the end of the lesson series while the learners responded to the student's questionnaire. The Lesson observation guide was outlined as teacher expected actions in an investigative lesson set-up in which the researcher recorded whether the expected action was observed or not. Teacher interview and logbook records provided information regarding their perception on how the materials supported them in implementing learner centred investigative practical activities. They also provided the researcher with teachers' perception on the effectiveness of the materials. Lesson observations provided data on practicality and effectiveness as observed by the researcher while questionnaire for students provided feedback from the learners. The average percentage of expected teacher actions observed during investigative practical work in each of the Chemistry practical lessons were computed (Table 1).

Table 1: Observed teacher actions during investigative practical work

	Lesson number						
Lesson Phase	1	2	3	4	5	6	**Average %**
Introduction	60.16	79.98	91.42	79.98	88.56	91.42	**81.92**
Development	71.22	86.30	86.32	85.04	78.80	78.80	**81.08**
Conclusion	63.36	74.28	93.32	84.26	89.98	76.66	**79.75**

From table 1, it can be observed that an average of 81.92% of expected teacher actions were observed in the introduction phase of the lessons, 81.08% expected teacher actions were observed in the lesson development phase and 79.75% actions were observed in the conclusion stage. These high percentages were taken to be an indication that the materials were used as intended by the developer and were able to facilitate teaching of practical work.

From the logbook and the interviews, the teachers indicated that the objectives for all the lessons were achieved. This implies that the materials were effective in their classes and were able to offer support for the implementation of investigative practical work. Concerning congruence, the teachers indicated that the practice was very different from what they commonly used in the laboratory but also indicated that the investigations would be easier to carry out when supported by such materials. All the teachers indicated that they experienced a problem with learners adjusting to the practice of developing their own procedures while they were used to being provided with step by step procedures for all their practical activities. The teachers indicated that the method had high demand on resources but also agreed that the materials were available and all it required was change in teaching approach as well as innovativeness.

The responses from students also showed that most students (83.3%) perceived the structure of the practical activities as motivating and helpful to them in carrying out the investigations. The responses that agreed to the statement 'doing practical work by setting our own procedures makes practical work easier and more satisfying' was quite high (88.2%). A high percentage (90.7%) of the learners indicated that they enjoyed the activities. Students perceived the exemplary materials helpful to their learning and understanding (88.2%). They perceived that they were able to learn the concepts easily because the development of their own procedures made them think about what they were doing. These responses gave indications that if chemistry teachers could be supported by appropriate instructional materials they can make practical work a 'minds on' investigative activity. After the evaluation, the materials were refined to produce a model of materials that would support teachers in implementing learner centred practical work. The materials were meant to guide the teacher in carrying out a practical activity that would engage the learners both mentally and physically. The instructional materials model can be considered as a sample lesson planning and implementation guide. The basic structure of the practical activity resembles the common outline of a practical lesson involving planning, introduction of the lesson, lesson development and conclusion.

7. Secondary school Chemistry investigative practical work lesson model

The model guides through sequencing of instructional activities which starts with identification of content to be taught to a particular group of learners based on their learning level. Content is identified from the curriculum guiding the particular learning group as per the subject syllabus. For this study, text books that are approved by the national curriculum, Kenya Curriculum Development Institute (KICD) were also used to identify basic content requirements. Once content is identified the teacher sets out objectives for the lesson activity as basic statements of achievement expected from the learner by the end of the lesson activity. The general process of learner centred investigative practical lessons used in the study can be summarized as shown in figure 4.

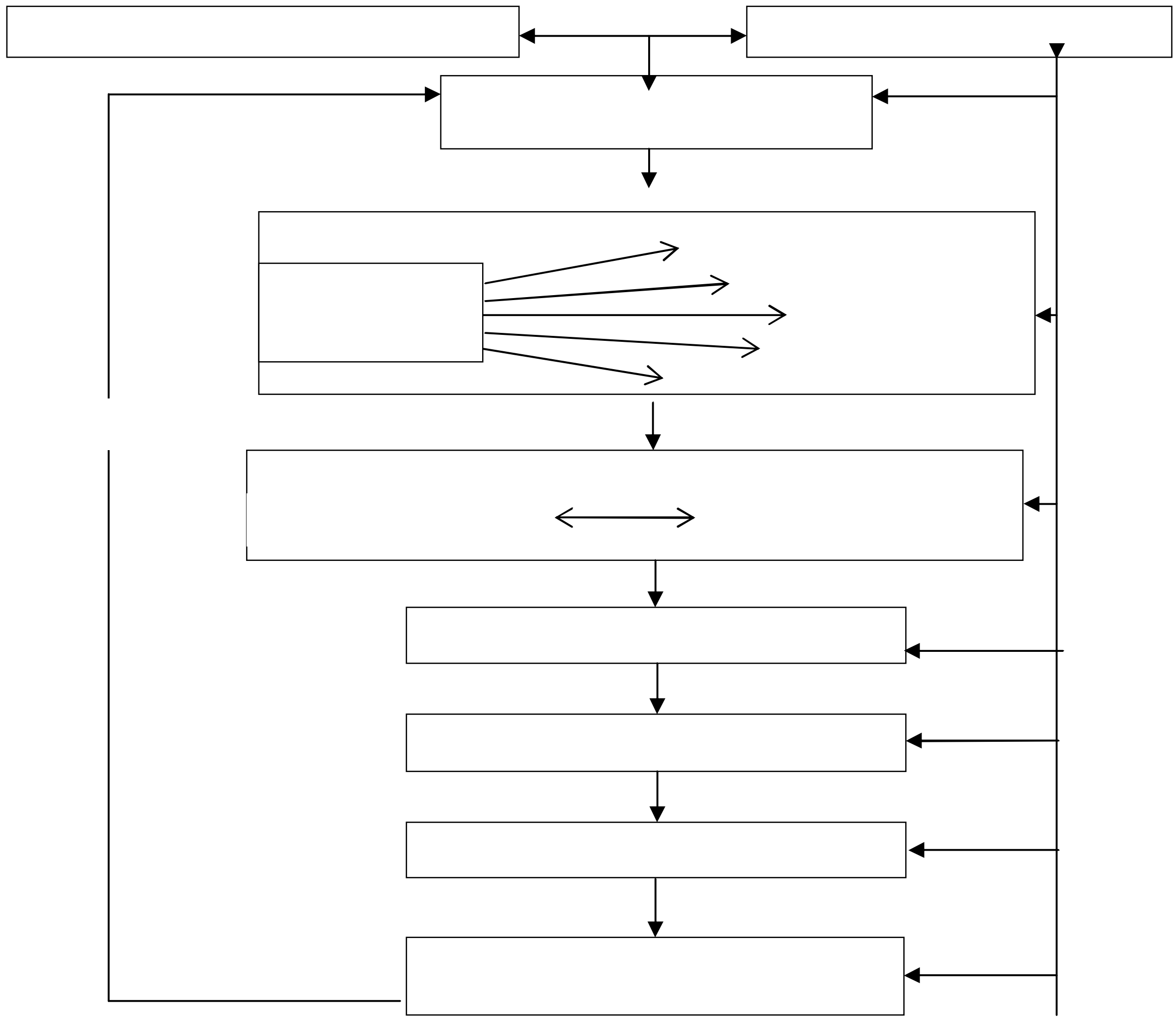

Figure 4: Model for organizing and sequencing instructional activities in practical work

Planning involves designing the activity, identification of required materials and safety precautions. Detailing background information helps the teacher and the learner to understand the activity to be performed. A Lesson description is then provided to provide a brief overview of the activity to be carried out. Design of the activity as outlined in the teacher guide provides detailed ideas on how to introduce the activity which could be through a simple exercise, prediction, observation, examples or discussion. The discussion is tailored to assess relevant prior knowledge, identify preconceptions or misconceptions in science learning related to the particular activity. The teacher is guided to use open-ended driving question that would arouse learners' interest in the activity (Krajick et al 2007).

The lesson development section is broken further into sections of planning for the activity, plenary discussion of the procedures set and the carrying out of the actual activity. Learners are grouped in small groups of 2-4 learners and allowed to brainstorm on ways (procedures) of carrying out an activity to achieve the objective(s) set.

They are provided with the apparatus or list of apparatus to use and allowed to plan for the investigation. Learners then develop their own experimental procedures. After the discussion of the procedures in groups, the learners are called to attention for plenary discussion with the teacher. The outcome of their discussions is presented and the teacher guides through the refinement of the procedures. The learners are allowed to carry out the practical activities using the procedures they have developed. They record their findings in their note books as they progress with the activity. Consolidation and discussion of results is done after the learners have carried out the activity. This involves pooling together their findings by receiving feedback from groups of learners. The teacher should then guide learners to make meaning of their discussion, and make conclusions related to the focus question or prediction, evidence and connection to the real world. The discussion eventually leads to generalizations and understanding of underlying theories, laws or principles. More activities, assignments or references can be given to further the understanding of the acquired concepts.

This model serves as conceptual framework for organizing and sequencing a set of instructional activities to build meaningful student learning. It can be used by chemistry teachers and other science subject teachers to develop strategies for teaching chemistry practical work through investigative designs.

8. Conclusion

Teachers have a facilitative role in the learning of Chemistry when using practical work. They can re-design the commonly used procedures of teaching practical work into investigative activities involving: planning and designing practical activities, implementing their plans, carrying out analysis and interpretation of the results and applying the knowledge they acquired as a result of taking part in investigative practical work. It was deemed important to provide and guide the teachers on instructional materials with sufficient details that support these activities.

Instructional materials used in this study were a useful guide to the teachers in organizing learning resources, preparing students for the concept of the study, guiding students during their practical work activities and assisting learners in constructing meaning of the results of the activity. Most of the teachers were able to guide learners through development of the procedures using the teacher guide provided. This provided the lesson with the much desired characteristic of being 'minds on' as well as 'hands on' activities. During the initial lessons, teachers felt that the approach was very demanding but with time they found the activities very fulfilling.

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