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The Role of Experimental Activities in Supporting Knowledge Constructionin the Ethiopian Secondary School Physics Textbooks

Samuel Assefa
College of Education, Hawassa University, Ethiopia

Abstract: The study was aimed at exploring the extent to which lab activities are integrated in the Ethiopian school physics in helping students construct scientific concepts. A qualitative content analysis design was used as a research design to help to understand the extent to which the Ethiopian secondary school physics experiments are integrated with theoretical concepts and also to show the ways experiments are suggested to be conducted. The study reveals that the lab activities suggested to be conducted in the secondary school physics textbooks were not integrated with theoretical concepts. Moreover, most of the experiments are suggested to be done only to help students see physical phenomena or show that certain principles or laws are valid. Therefore, it can be concluded that lab activities are designed no to serve as knowledge construction tools. Moreover, practical activities are considered as subordinate to theoretical classes; rather than as the very important components of teaching physics. Based on the conclusions made the study suggested curriculum developers, textbook writers and teachers to revisit their practices consistent with the constructivist principles.

Key words: Physics, experimentation, Knowledge construction, conceptual knowledge, integration

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I. THE PROBLEM

1.1. Introduction

In physics education school experiments serve primarily three educational purposes. The first one is helping students to construct scientific knowledge by facilitating the development of intellectual ability and scientific reasoning skills that help them understand the concepts of physics (Kopenen&Mantyla, 2006; Cakir, 2008; Utibeabasi&Mboto, 2010). The second role that experiments play is helping for development of scientific inquiry skills (Kirschner, 1992). The third role often implicitly expressed is helping students to develop scientific attitude about nature of science knowledge (Hodson, 1998). Although school lab activities are believed by many to serve educational purposes some science education scholars express their doubts on the effectiveness of laboratory experiences in enhancing students understanding of the concepts of science. For instance, based on empirical study science educators argue that students who have been exposed to laboratories did not do better and sometimes did worse, than students who have not been exposed to laboratories (Kirschner, 1992; Hodson, 1993). As a result, they suggest to lower the emphasis given by contemporary science education to practical activities (Hirvonen&Viiri (2002; Kopenen&Mantyla, 2006; Millar, 1989).Despite these criticisms, experiments are remained to be the vital components of school science throughout the world. Many science educators also note that lab activities are helpful in enhancing students' understanding of the concepts of physics. Hence, they suggest to placepractical activities at the center of school science curricula (Hirvonen&Viiri, 2002; Koponen&Mantyla, 2006; Duit&Confrey, 1996). However, scholars suggest the importance of giving opportunities for students to involve in meaningful hands-on-activities during every classroom instruction in science has been suggested (Utibeabasi&Mboto, 2010; Kirschner, 1992).

Traditionally lab activities are conducted with the purpose of illustrating theoretical concepts or to show that a certain physical principle, law and theory work in actual situations. One of the major roles that lab practices play is theory illustration because they are useful to create opportunities for students to feel the physical phenomena. However, placing much emphasis on these types of experiments would not help students to comprehend the concepts of physics that contribute for the development of reasoning and decision making abilities (Kirschner, 1992).

The second role that experiments play is theory verification or confirmation. The emphasis made on theory verification role of experiments emerged from the belief that practical work is only of use for verifying theories of physics which have already been studied from a theoretical standpoint (Hirvonen&Viiri, 2002; Berg, 2004). Engaging students in lab activities in order to confirm theoretical concepts assumes that experimentation provides reliable data about the validity of theories (Hodson, 1998; Hodson, 1985). Verificatory experiments are not only inappropriate in helping students to understand the underlying theory of physics but also have their own effects on students' conception of the nature of science (Hodson, 1985). Engaging students in confirmatory experiments means that experiments are able to provide reliable data about the validity of theories (Hodson, 1985, 1998). Wenning (2009) equated confirmatory experiments with the learning from sacred books because he argues these types of experiments essentially preaches faith in science based upon authority rather than science as an active mode of inquiry. The assumption behind conducting experiments after students have learned the theoretical concepts is that it encourages retention and easy transfer of knowledge gained in theory class to practical class (Utibeabasi&Mboto, 2010). Behind these types of experiments there is an objectivists' assumption that knowledge claims are justified by proving that they correspond to reality (Colliver, 2002). Behind these types of experimentation is also a positivists' assumption that by following a certain procedure in doing experimentation we can arrive at an authentic science knowledge (Machamer, 2002; Özdemir, 2007).The positivists emphasis on confirmatory experiments, denies the role of the historical and social accounts of science, presenting science as a linear succession of successful discoveries (Driver et al, 2000).

The third role, but not common role that experiments play is discovery. This approach assumes that students are able to make discoveries which are similar to a physicist performing research and thus the process of learning science is equated with the process of doing scientific enquiry (Tseitlin&Galili, 2005; Kirschner, 1992). However, it should be noted that although children should not be considered as empty vessels to be filled at the same time they shouldn't be required to discover all scientific knowledge for themselves because scientific theories and laws, which are constructed, validated, and communicated through the cultural institutions of science, are unlikely to be discovered, by individuals through their own empirical enquiry (Hodson, 1985; Driver et al, 1994). When students are required to be engaged in discovering scientific laws using experiments they may be forced to involve into a stage-managed pseudo-discovery of the inevitable"(Hodson, 1985:40). Thus as Gil-Perez &Carrascosa (1994) note direct engagement in scientific activities is a serious failure and thus shouldn't be the objective of science education. Similarly, Hodson (1985) argues that guiding students to discover the already established scientific laws or theories following a prescriptive procedure also instills in children a concern with what 'ought to happen' and projects an authoritarian, doctrinaire image of science.

The above arguments have been challenged from the constructivists perspectives. From the constructivists contend the importance of engaging students in the process of the construction of scientific laws and principles; rather than simply conducting experiments to view physical phenomena or to ascertain that certain physical laws holds true (Kirschner, 1992). From this perspective lab activity should be designed in facilitating students' conceptual understanding by engaging themselves in the process of the construction of scientific laws and principles (Kirschner, 1992; Hirvonen&Viiri, 2002). Therefore, experiments should not be seen as a means of making abstract physics concepts concrete; rather they should help learners to develop conceptual understanding that contribute for the development of reasoning and decision making abilities. From constructivists' perspective experiments are gateways leading to the world of scientific knowledge, rather than used as a means of verifying or justification of knowledge. In order that students' construction of scientific knowledge is facilitated experiments should be structured in such a way that they are able to form the meaning of theoretical concepts by establishing relationships among the physical phenomena, the laws of physics and the mathematical representations (Mbajiorgu& Reid, 2006; Koponen&Mantyla, 2006).

The researcher argues that, experiments do not necessarily lead to better understanding of science concepts its effectiveness largely depends how well we integrate with theoretical concepts. In this regard, Berg (2004) &Kopenen&Mantyla (2006) note that one of the reasons for the ineffectiveness of experiments is their straightforward use of experiments to show that the laws of physics are true or to confirm that what has already been taught theoretically do work. In this regard, science educators argue that, in order that experiments serve as knowledge construction tools, it is important to integrate practical activities with theoretical concepts (Elby, 2001; Gil-Perez &Carrascosa, 1994; Pomeroy, 1993). Empirical research on laboratory practice in science education also reveal that students who are taught by integrating practical work in physics with theory achieved academically higher than those who were exposed to practical work that is separated from theory (Utibeabasi&Mboto, 2010; Koponen&Mantyla, 2006).

Regarding the effectiveness of school lab activities, the researcher argues that doing experiments alone doesn't help students learn the concepts of physics in a better way; rather their effectiveness depends on the way they are used. With regard to the integration of experiments with theoretical concepts the researcher argues that physics experiments should give students opportunities to involve in the process of the construction of the physical concepts. In contrast when experiments are only given to provide hands-on experience, make abstract concepts concrete or to verify that the laws and principles of physics hold true they more likely tend to enhance rote memorization of scientific facts, formulas and procedures.The focus of this study was on how appropriately they are integrated with theoretical concepts to facilitate students' construction of physical concepts.

1.2. Basic questions

The study attempted to find answer to the following basic questions.

1. To what extent are lab activities integrated with theoretical conceits in the Ethiopian secondary school physics textbooks?
2. What educational purposes are dominantly served by in the Ethiopian secondary school physics textbooks?

1.3. Purpose of the study

The major purpose of this study was to examine the ways physics textbooks suggest physics experiments to be conducted. More specifically:

- To explore how well experiments are integrated with theoretical concepts
- To explore the major purposes that the Ethiopian secondary school physics serve

1.4. Significance of the study

Most physics education researches on experimentation focused on the presence or absence of practical activities. The extent to which teachers conduct lab activities, also took the planned curriculum for granted. As a result, they have focused directly on the transacted curriculum; rather than the planned curriculum. However, this study has made attempts to provide evidence of the extent of integration. This study could provide new insight about the Ethiopian school physics experimentation in many respects. For instance, it provides data for curriculum experts, textbook writers and teachers on the limitation physics textbooks have in helping learners understand physics concepts.   On the other hand, this study is not a mere repetition of what have been studied in certain contexts; rather it has raised new issues in science education research that could be used as a starting point for further investigation.

1.5. Scope of the study

In studying physics curricula, it was important to consider both the planned and the implemented curricula. However, this study focused on assessing the appropriateness of the ways physics experiments are provided in the textbooks.

II. METHODOLOGY OF THE STUDY

2.1. Research design

In this study qualitative research methodology was adopted as a guiding framework in understanding the way physics experiments are provided and the extent to which h they are intergrade with theoretical concepts in supporting knowledge construction. Qualitative content analysis was chosen due to its appropriateness in revealing and make inference about the implicitly held epistemological stances as communicated in the materials (Hsieh & Shannon, 2005; Cohen et al, 2000). The freedom it gives to purposely focus on certain activities that could provide relevant data; rather than gathering evidence from large amount of data using random sampling was the other reason to select qualitative content analysis design (Kreuger and Neuman, 2006). Focusing on certain statements or activities to find evidence and making inference is only allowed in qualitative content analysis design than in quantitative designs. Due to these reasons a qualitative content analysis design was found useful in revealing the meanings communicated in the Ethiopian secondary school physics textbooks.

2.2. Data sources and sampling strategy

Because the focus of this study was physics textbooks general secondary school level physics textbooks were used as the major sources of data because regardless of other curriculum materials school textbooks are the major curriculum resources that could serve as important tools for understanding the nature of school physics experiments (Hottecke& Silva, 2010). In this study I used grade nine, ten, eleven and twelve physics textbooks as data sources. The textbooks were selected purposely. On the other hand, to determine the number of experiments simple random sampling was employed. For the analysis two units were selected randomly from each grade level. From the units selected, the entire topics were taken. Thus, a total of 28 experiments were included in the study.

2.3. Method of data analysis

After the sources of data were identified, it is important to determine the methods of analyzing data. Data analysis and interpretation in qualitative content analysis requires coding raw data and generating certain analytical categories followed by interpretation or giving meaning to raw data **(**Starks & Brown, 2007; Given, 2008; Elo&Kynga, 2007). Content analysis consists of descriptive coding which involves simple tallying the types of experiments in the textbooks in their respective category. The occurrence of each category in textbooks was tallied to show the occurrence of each category. After the data were tallied to their respective categories analysis was made qualitatively and also using percentages. In this study data obtained from the textbooks were coded in each category qualitatively for analysis. In doing so each data was interpreted with respect to the criteria developed to judge the extent to which the experiments are integrated with theoretical concepts and the ways they are provided in helping students understand the concepts of physics. Therefore, the raw data gathered were put in each respective category and then interpreted with respect to the concepts developed as a result of literature review. Together with the qualitative analysis the frequencies of each category were presented in a table to show that how often each category occurs. After relevant data were brought from each textbook they were analyzed with respect to their categories. The research questions formulated were used to write the findings and the conclusions

2.4. Validity and reliability

Internal validity in qualitative research focuses on establishing a match between the constructed realities of respondents and those realities represented by the researcher (Merriam, 1998; Guba and Lincoln, 1989). In qualitative content analysis this means that the extent to which the researcher is able to present data as it is stated in documents. In this regard, criteria of assessment were developed together with physics and curriculum experts to minimize subjectivity or to make the findings of the study valid. The other attempt made was presenting the data from the textbooks without distortion. In doing the researcher directly taken typical examples from the textbooks so that one can judge how consistent is my discussions and conclusions with the data that appears in the textbooks.

One of the criticisms from quantitative researchers to qualitative studies is the issue of external validity. The notion of external validity, which is concerned with the ability to generalize from the research sample to the population using the principle of randomization and applying statistical tests is one of the key criteria of determining the quality of good quantitative research (Kreftng, 1991, Merriam, 1998, Shenton, 2004, Mays& Pope, 1995). However, in qualitative content analysis because the sampling is purposive the researcher cannot extrapolate from the sample to the population (White and Marsh, 2006). On the other hand, since the major purpose of qualitative research is to understand than to generalize, external validity is not so much concerned. However, this doesn't mean that the results of qualitative inquiries are not totally used because they can be applied to similar cases.

Reliability is related to objectivity and is measured in quantitative content by assessing inter-rater reliability. However, in qualitative research findings are confirmed by looking for if the data support the conclusions (White and Marsh, 2006). Hence, I have tried to be objective by linking the data with the interpretations and the conclusions. In other words, it is concerned with reporting the findings from the perspectives of the data sources rather than from the researcher's point of view (Thomson, 2011). This can be done by showing that there is a conceptual consistency between observation and conclusion.

To ensure reliability the researcher have attempted to show how the necessary relationships that exist between the raw data, the discussions and the conclusions. Data were also provided together with the analysis and interpretation by (Bashir et al, 2008; Thomson, 2011; Thomas, 2006). Reliability in qualitative research can also be done by providing evidence how the researcher accounts for changing conditions in the phenomena. Because this study used published documents and one of the strengths of documents as a data source lies in the fact that they already exist in the situation they do not alter the setting and also they cannot be distorted (Merriam, 2002; Morrow, 2005).

III. DISCUSSION OF FINDINGS

In the following sections the data obtained from the textbooks are presented and discussed with respect to the basic questions formulated. The basic questions formulated were:

1. To what extent are lab activities integrated in the Ethiopian secondary school physics textbooks?
2. What are the dominant approaches employed in the Ethiopian secondary school textbooks?
3. What educational purposes are dominantly served by in the Ethiopian secondary school physics textbooks?

In order that students' construction of scientific knowledge is to be facilitated experiments should be structured in such a way that they are able to form the meaning of theoretical concepts; rather than used as a means of verifying or justification of knowledge. In this regard, although there are very few attempts made by the textbook writers to design experiments in this manner most of the experiments are structured to either showing the physical phenomena or check the validity of physical laws and principles. In fact, attempts were made by the writers of the textbooks to include many experiments in every part of the textbooks. However, it seems that practical activities are seen by the writers of the textbooks as subordinate to the theoretical concepts rather than being an integral part.

Regarding the ways experiments are provided from the constructivists' experiments are structured in such a way that they help students comprehend the concepts of physics by creating opportunities for students to be engaged in the process of the construction of scientific laws and principles(Kirschner, 1992; Cakir, 2008; Novak, 2002). Based on the analysis made in the physics textbooks although there are some experiments provided to assist students in constructing scientific concepts the dominant ways experiment structured were theory illustration and verification without giving opportunities for students to construct the scientific meanings of concepts.

The experiments provided in the textbooks were categorized into two major categories: (1) Illustrative- that are structured to help students experience, feel or make sense of physical phenomena and (2) Verificatory- that are structured to ascertain the validity of scientific laws and principles and (3) Constructive- that are used to help learners construct scientific laws and principals. Each category was further divided into sub categories based on the extent to which they engage students in the process of experimentation.

In order to determine the purposes textbook experiments, serve the searcher analyzed 48 suggested practical activities. In the following table the data obtained from the textbooks is presented.

Theory illustration N=30 (62.5%)		Theory verification N=18 (37.5%)		Total
Not integrated N=28 (93.33)	Integrated N=2 (6.67%)	Not integrated N=16 (88.88%)	Integrated N=2 (11.12)	

3.1. Theory illustration

In physics, illustration means for example making abstract concepts comprehendible to students by giving concrete examples. These types of experiments are often used to help students to view or experience physical phenomena. Making abstract physical phenomena concrete can be one of the goals of school science experimentation. The basic assumption behind these types of experiments is that "because science involves highly abstract and complex concepts that are difficult to understand practical experiences can be used to give firsthand concrete experience to students" (Hofstein&Lunetta, 1982). However, as it is argued in the previous sections, lab work should not be seen as only a means of concretizing abstract knowledge but rather as means of helping students comprehend the most important aspects of physics learning i.e., conceptual understanding.

Illustrative experiments were further categorized into illustrative experiments that are intended to help students view physical phenomena and illustrative experiments that are intended to help students not only view physical phenomena but also to experience physical phenomena by engaging them in the process of experimentation.

Illustrative experiments can serve as knowledge construction tools if they are integral parts of the theoretical concepts, conceptually demanding and engage learners in the process of the construction of the physical laws and principles; rather than simply showing the end products of science. However, based on the analysis made in the textbooks it was found that 30 experimentsi.e62.5% wereintended to make abstract concepts concrete or to help students view or make sense of physical phenomena. However, most i.e. 28 (93.33%) were intended to simply showing the physical phenomena without engaging students in the process.

Below is given a typical example taken from Grade 9 physics textbook page 154. The purpose outlined in the title is "to show that how pressure varies with depth".

"Take a tall tin can and carefully make several holes going up and one side (three or four should do it). Quickly fill the tin with the water and observe how the water squirts out of the holes. You will notice the stream from the bottom holes travels faster. This is because the water is under more pressure at the bottom of the can".

In the above activity the textbook writers require the students to conduct an experiment by requiring to be engaged in hands-on practical activities. However, in order that school experiments achieve the broad goal of learning physics i.e. conceptual understanding they need require students to describe and explain physical situations by making association between the experienced phenomena and the physical laws. This could have been done, for instance, by asking them in which hole/s the water travel/s faster and require them to reason out or explain by themselves why the water coming out of the bottom holes move faster than the upper ones. In addition, this experiment on the one hand is given at the end of the theoretical discussion and is thus separated from its theoretical idea. Therefore, it is provided only to make students view or experience the physical phenomena; rather than helping them comprehend the physical concept by engaging them in the process of the construction of scientific concepts.

In order to make illustrative experiments support students' construction of scientific concepts they should attempt to engage them in process of the construction of the scientific knowledge; rather than simply providing the end products of science. In this regard, I obtained very few experiments that attempt to engage students in the process of science by requiring them to describe and explain their observation. The experiments provided in this section do not only require the students to view or experience physical phenomena but give opportunities for them to be involved in the process of the construction of the physical laws and principles reflecting a more or less constructivists' epistemology that focuses on knowledge construction.

3.2. Theory verification

To verify means to make sure or demonstrate that something is true, accurate or justifiable and to justify means to prove that something is right or reasonable. In physics it means to prove or demonstrate by experiment that a certain law or principle is correct or right. In physics it means to ascertain through experimentation that scientific laws and principles are true and certain often intended to convince the students that scientific theories are valid (Hodson, 1985). The emphasis made on verificatory experiments emerges from the belief that practical work is only of use for verifying scientific theories which have already been studied in theoretical sections.

Theory verification can be one of the purposes of doing experiments. However, as it is argued in the previous sections in order that these types of experiments serve as knowledge construction tools it is important to give opportunities for students to be engaged in the construction of the laws and principles of physics; rather than simply showing that the laws and principles hold true.

From the analysis made 18 (37.5%) of the lab activities were intended to verify or ascertain that the physical law or principle hold true. Based on the analysis made on the textbooks, there are 16(88.88%)experiments intended either to show that the laws of physics hold true or to show that certain laws or principles are applicable in actual situations; rather than leading students to construct their understanding by requiring students to be engaged in the process of the construction of the scientific laws. These types of experiments are those given separate to the theoretical concepts and are often given to ascertain that the physical law or principle hold true by following certain prescriptive procedures. This approach is the dominant ways in which physics experiments are structured in the Ethiopian secondary school physics textbooks.

There are very few 2 (11.22%) that were integrated with theoretical concepts to help students construct scientific knowledge. A typical case is taken from grade 9 physics textbook page 150. This activity is structured to show how pressure varies with depth.

Fill a tall jar with water. Submerge a long rubber tube so that it fills with water. Leave one end in the water, close the other end with the fingers (to prevent the water running back), and lift it out of the jar. Lower this end until it is below the water level in the jar. Open it and let water flow out into a second jar. The water flows so long as the end C is below water level A. The further C is below A, the faster the flow of water. Now raise the second jar until it is higher than the first. *Water flows in the other direction.* (The tubing must always be full of water and its ends must be under the water). The pressure at A and B is atmospheric. Therefore, *the pressure of C is atmospheric pressure plus the pressure due to the columns of water BC.* Hence, the pressure at C is greater than atmospheric and the water can push its way out against the atmosphere.

In contrast to most of the experiments, the above lab activity is structured as being integral to the theoretical concept of physics. Instead of showing that a certain physical law is true it tries to lead students find the relationship between the phenomena and theoretical ideas. It doesn't tell the physicists' interpretation of the physical; rather it tries to explain the concept based on what students have known and experienced. It also requires students to relate their observation with theoretical concepts.

IV. CONCLUSIONS

School experiments are considered as playing vital roles in the learning of science in general and physics in particular. From the constructivists' experiments are structured in such a way that they help students comprehend the concepts of physics by creating opportunities for students to be engaged in the process of the construction of scientific laws and principles(Kirschner, 1992; Cakir, 2008; Novak, 2002).Their role is primarily to enhancing students' understanding of the concepts of physics. In order that students' construction of scientific knowledge is to be facilitated experiments should be structured in such a way that they are able to form the meaning of theoretical concepts; rather than used as a means of verifying or justification of knowledge. In order to determine the appropriateness of experiments in enhancing students' understanding of scientific concepts the secondary school physics textbooks were analyzed. Based on the discussion made in the preceding sections the following conclusions were made.

Although there are very few attempts made by the textbook writers to design experiments in this manner most of the experiments are structured to either showing the physical phenomena or check the validity of physical laws and principles. In fact, conducting lab activities to show the validity of certain physical laws is sometimes important when it is the dominant strategy it may not be useful in helping students understand the concepts of physics. However, the constructivists' perspective experiments are gateways leading to the world of scientific knowledge, rather than used as a means of verifying or justification of knowledge. In fact, attempts were made by the writers of the textbooks to include many experiments in every part of the textbooks. However, it seems that practical activities are seen by the writers of the textbooks as subordinate to the theoretical concepts rather than being an integral part. On the other hand, it should be noted providing as many experiments as possible doesn't necessarily help students learn the concepts of physics meaningfully. In other words, meaningful learning does not occur by increasing the number of students' laboratory activities unless equal emphasis is given to “minds on” activities that could lead students to construct their understanding by engaging themselves in the construction of the concepts.

In order that experiments serve as knowledge construction tools they should be structured appropriately in helping students construct scientific knowledge. The experiments provided in the textbooks were classified into two major categories, which in turn were grouped into two sub categories based on the extent to which they give opportunities for students in involving in the process of science as process and product oriented. Based on the analysis made in the physics textbooks it can be inferred that although there are some experiments structured to assist students in constructing scientific concepts the dominant ways experimentprovided were theory illustration and verification without giving opportunities for students to construct the scientific meanings of concepts.

V. RECOMMENDATIONS

Based on the conclusions made the following recommendations were forwarded. The study reveals the dominant ways experiment provided were theory illustration and verification without giving opportunities for students to construct the scientific meanings of concepts. These types of experiments, though important, should be integrated with theoretical concepts. Therefore, curriculum developers, te4xtbook writers and teachers should be aware of the benefit of lab activities in enhancing students understanding; rather than seeing them as subordinate to theoretical discussions. In the Ethiopian context the ministry of education in its various documents tells us that the constructivist theories of learning are used to guide curriculum development. However, unless this can be seen in developing school curriculum materials such as textbooks it is very difficult to help students develop conceptual understanding they help them develop critical abilities. Hence, the ministry of education should revise curriculum materials consistent with the principles they thought govern the Ethiopian science education.

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