Science teachers' construction of concept maps: A case study

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Abstract

One of the challenges in the teaching of science is the construction of valid scientific relationships between concepts. An investigation was done with 15 General Education and training (GET) science teachers to determine the challenges they have to deal with in constructing concept maps. Knowledge of how to construct concept maps is crucial since it can help teachers to plan the execution of instruction. The challenge to teachers was to arrange concepts in a hierarchy, the use of propositional linkages as well as cross-linking of concepts. The article suggests that interventions geared at addressing the challenges faced by teachers may include the teaching and learning strategies dealing with concept relations like concept mapping.

Key words: concept maps, concept mapping, science, teachers

Introduction

Science teachers are generally faced with a variety of challenges. One of the challenges in the teaching of science is the construction of valid scientific relationships between concepts. Most cognitive theories share the assumption that concept interrelatedness is an essential property of knowledge (Ruiz-Primo & Shavelson, 1996). A more complete picture of learner's and teacher's understanding emerges from incorporating aspects such as the shortcomings in the content and structure of the concept map (Van Zele, Lenaerts & Wieme, 2004). Moreover, it appears that teachers may possess understandings about science content which are not yet connected in a way that makes sense for them (Dawkins, Dickerson, McKinney & Butler, 2008). This is because many teachers hold ideas about scientific concepts that are not in accordance with the science view and often are similar to students' pre-instructional conceptions (Treagust & Duit, 2008).

The conceptual relationships in science and mathematics (Duit, Treagust & Mansfield, 1996) can be investigated by pencil-and-paper measures such as concept mapping, relational diagrams, tree construction tasks, graph construction, networks and semantic differentials. In general, learners do not understand scientific relationships and the teachers are expected to provide learners with effective pedagogical strategies to address scientific relationships (Dawkins et al., 2008). Concept maps, if used properly, can potentially increase a teacher's repertoire of instructional and assessment techniques (Ruiz-Primo & Shavelson, 1996). One of the benefits of using concept mapping is that it can be used to provide a visual representation of an individual's ideas about a concept or set of related concepts (Byrne & Grace, 2010). These ideas can represent some important aspects of the individual's existing knowledge in a content domain (Ruiz-Primo & Shavelson, 1996).

Ideas represented have the meaning or ideational frameworks specific to a given context (Novak, 1990). Representation of meaning draws upon and incorporates ideas from Ausubel (1968). Both Hodson (1998) and Watts (1994) emphasise that the basic premise of constructivism is that learners should construct knowledge. For learning theorists such as Lewin (Schein, 1995) and Piaget (1985), human inquiry is rooted within the individual, who constructs knowledge through his or her actions on the environment. Of relevance to the current study is the teacher's development of conceptual relations with no prior training on concept mapping. The meaning (Clark, 2006) attached to this conceptual relations and the process of constructing meaning (Oded & Stavans, 1994) were equally important in providing meaning to these concept maps.

Literature on concept mapping emphasises the use and importance of concept maps (Austin & Shore, 1995) and the benefits of using concept maps (Novak, 1990; Byrne & Grace, 2010). However, constructed concept maps may include different kinds of challenges. These include straightforward mistakes, faulty or vague descriptions, misconceptions, and completely or partially deficient relationships. Knowledge of these challenges may serve as important feedback for the teachers (Van Zele et al., 2004). For example, the teachers can pinpoint learners' difficulties and track down recurrent patterns or areas of vague or clouded learner understanding. The purpose of the study on which this article is based was to determine the challenges faced by science teachers in the construction of concept maps. Knowledge of these challenges (Van Zele et al., 2004) as well as how to construct concept maps is crucial since it can help teachers to plan the execution of instruction (Novak, 1990).

Literature review

Concept mapping originated within the education community as a tool to assess the understanding of school science learners (Novak & Canas, 2011). Researchers (Austin & Shore, 1995; Byrne & Grace, 2010; Novak, & Gowin, 1984; Novak, 1990; Novak & Canas, 2006; Ruiz-Primo & Shavelson, 1996) generally concur in phrasing the description of concept mapping. For the purpose of this study, concept mapping (Novak, & Gowin, 1984; Novak, 1990; Novak & Canas, 2006) is described as a technique involved in the organization of thoughts or ideas and relationships between them.

A number of different types of concept maps are reported in the literature. Examples of the concept maps include the spider concept maps, flow charts and hierarchical concept maps. These concept maps differ in terms of organization of concepts in a map. For instance, in the spider concept maps ideas are organized with the central theme in the centre of the map with sub-themes surrounding the central theme. With the flow chart, concepts are presented in a linear format, whereas in the hierarchical concept map ideas are arranged in descending order with the most important placed at the top. Hierarchy of concepts is a characteristic of many concept maps (Ruiz-Primo & Shavelson, 1996). This hierarchy of concepts and other related ideas on concept mapping are illustrated in the concept map showing key features of concept maps (Figure 1).

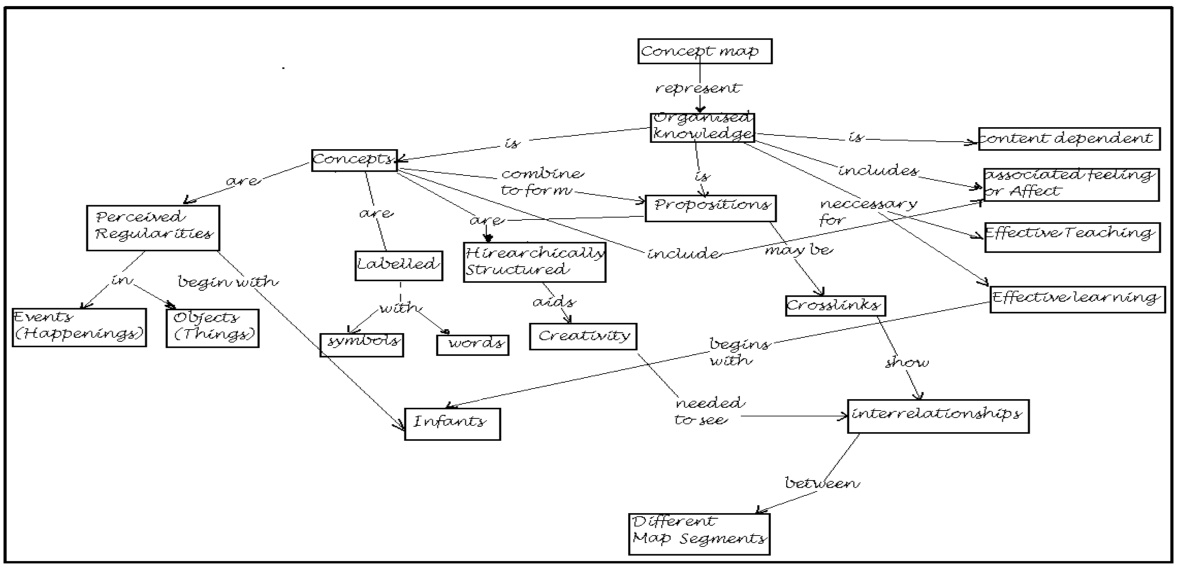

Figure 1 Concept map showing the key features of concept maps (Novak & Canas, 2008)

The concept map in Figure 1 provides a visual representation of how a concept map is constructed. The concept map drawn in Figure 1 provides answers to questions such as: What are concept maps?

(Representation of organized knowledge); Why are concept maps necessary? (May help in effective teaching and learning); What are the features of concept maps? (Concepts, propositions, cross-links, hierarchy, creativity, and labels). The construction of concept maps is dependent on the cross-links that show how concepts are related. The basic steps for creating a concept map have been widely described (Novak, Novak & Canas, 2008, Novak & Canas 2011). This steps starts with the definition of a focus question. Hereafter, key concepts are identified. The concepts are then are arranged spatially followed by the creation of links. The spatial arrangement of concepts is subsequently revised and cross links created.

The use of concept maps then requires that an individual should know the type of relationships that exist between concepts before deciding on the structure of the concept map. Hence, knowledge of the content is crucial. Figure 1 is an example of a concept map that combines types of concept maps, but it may be necessary to simplify the map so that the ideas are represented in a simplified and understandable structure. This may help in the visualization of the concepts.
Consequently, when a reader reads a concept map, the question normally asked is: What is this concept map all about? This means that a concept map should consist of the central theme. The central theme is generally called the main idea. When constructing the concepts related to the central theme, there should be what is termed 'linking words' (Novak, 1990). These linking words are written on the line connecting the concepts in order to form propositional statements. A proposition is the basic unit that should provide meaning in a concept map. It is generally used to judge the validity of the relation (line with an arrow) drawn between concepts (Ruiz-Primo & Shavelson, 1996). The meaning of a concept should be represented by all of the propositional linkages constructed, including that concept (Novak, 1990). The absence of these propositional linkages in the concept maps may affect the understanding of the meaning of these concepts. In the construction of concept maps the emphasis should incorporate the actual linking of new knowledge correctly to previously held knowledge (Novak & Gowin, 1984) in order to yield meaningful learning. However, if these links are incorrectly made, these might result in misconceptions or alternative conceptions. Moon, Hoffman, Eskridge and Coffey (2011) argue that not every feature of a concept map will apply to every map. Deviation from the standard steps and features is allowed for creativity.

The linking of concepts generally depends on the knowledge of subject content the individual possesses. The relationship between concepts is crucial in constructing valid links between concepts. Failure to make valid links may result in the distorted meaning of concepts. Each linkage should demonstrate coherent understanding of the content.

Different studies on concept mapping (Austin & Shore, 1995; Byrne & Grace, 2010; Novak & Gowin, 1984; Novak, 1990; Novak & Canas, 2006; Ruiz-Primo & Shavelson; 1996) concur on the benefits of using concept maps. The benefits of concept maps constructed by learners and by teachers can be summarised as follows:

- Learners can gain knowledge and insight about the topic.
- Alternative conceptions and misconceptions can be identified.
- Relationships between concepts can be assessed.
- Ideas can be organized in preparation for a lesson.
- Learners can use concept mapping to summarize lessons after teaching.
- Learners can use concept mapping to reflect on a lesson presented.
- Learners can share and work together to map out a topic.
- Visualization of concepts may be improved.
- Learners can learn to structure concepts.
- Teachers can use concepts to explain how concepts are related to each other.
- Teachers can organize concepts in a way that can be easily understood by learners.
- Concept maps can be used to assess learner's understanding of content.

Concept mapping generally has a positive effect on both learner achievement (Ingec, 2009) and learner attitude (Duit et al., 1996). When learners are asked to construct concept maps as routine part of their instruction, they can move away from patterns of rote learning (Novak, 1996). Effective concept mapping requires learners to be familiar with the concept mapping method. This will help them to focus on meaningful and insightful propositions, therefore they should be taught by trained teachers (Van Zele et al., 2004).

Against this background, the study was conducted to investigate how and the challenges faced by teachers in constructing the concept maps. This is because knowledge of how to construct concept maps is crucial since it can help teachers to plan the execution of instruction (Novak, 1990).

Research question

The research questions for this study were:

What are the challenges faced by General Education and Training (GET) science teachers in the construction of concept maps?

How do GET science teachers construct concept maps?

Research methodology

The study reported in this article was conducted in a South African education district. A sample of fifteen General Education and Training (GET) science teachers participated in this study. GET science teachers are teachers teaching grades 4, 5, 6, 7 and 9. Their experience in the teaching of physics ranged from 4 years to 17 years. The teachers did not have prior experience in the construction of concept maps. Furthermore, from the engagement with the teachers, it emerged that the majority of them do not have basic facilities to teach physics. They rely on textbooks supplied by the department of education to teach physics and other subjects. These science teachers were purposefully selected from a group of mathematics and science teachers who were invited to participate in a workshop on content enrichment.

This study was a qualitative case study. According to Babbie and Mouton (2001), a sample of five to twenty respondents is sufficient. In qualitative case studies, researchers study small or distinct groups. These are typically single-site studies. The data analysis focused on one phenomenon (in this case how do science teachers construct concept maps and the challenges they face in the construction of these concept maps) which the researcher selected to understand in depth regardless of the number of sites or participants (McMillan & Schumacher, 1997).

Data was collected through concept maps constructed by the science teachers. In addition, observations were made during the construction of concept maps and field notes were used to record observations. Questions on energy concepts were asked by the author during the workshop and recorded in the field notes. The author was a participant observer and played an active role during the construction of concepts maps. This helped the author to listen and observe the phenomena so as to understand it from the perspective of participants. This is because participant observation is based on the assumption that understanding of the inner perspectives of subjects can be achieved by actively participating in the subject's world and gaining insight by means of observation (Silverman, 2004).

Teachers were requested to construct concept maps on energy. This was used as an introduction as well as to prepare teachers for the workshop, and as a way to introduce them to concept mapping as a technique. Concept mapping as a technique (Figure 1) was discussed with teachers. The concept mapping task better demonstrates and consequently promotes the development of a coherent knowledge structure (Van Zele et al., 2004).

Concept maps can help qualitative researchers in the design and development of data collection (Wheeldon & Faubert, 2009). Furthermore, the maps allow for the identification of concepts and connections based on how the participants frame their experience. Concept maps were selected as a research tool because they have been previously used to investigate conceptual relationships (Duit et al., 1996). For instance, Van Zele et al. (2004) used concept mapping qualitatively to investigate university-level engineering students' conceptual relationships on the concept 'atom'. Stoddart, Abrams, Gasper and Canaday (2000) concur that concept maps measure aspects of learning which conventional tests do not measure particularly well.

Five groups of three members were formed from the fifteen science teachers who participated in the study. It was necessary to construct the concept maps in groups because it was an opportunity for the teachers to share ideas. Furthermore, concept mapping provides an attractive basis for collaborative brainstorming and discussion, enabling groups to build a shared understanding (Van Zele et al., 2004). The researcher engaged with teachers for two days and five concept maps were constructed and transcribed. These concept maps were discussed with teachers during the workshop. Teachers were asked to critically discuss these concept maps. The discussion included the content of the concept maps and how the content is related. It was evident in the discussion that some of teachers lacked science content knowledge. The concept maps are included in this article and are labelled Figures 2, 3, 4, 5, and 6. The constructed maps were analysed in terms of the requirements of concept mapping as shown in Figure 1. The aim with the teachers' concept maps was to investigate how they construct concept maps and challenges the teachers face in relating concepts to concepts, in arranging the concepts hierarchically, in the cross-linking of concepts, and the use of propositional linkages.

The researcher acknowledges that there are a number of strategies (Ruiz-Primo & Shavelson, 1996; Wheeldon, & Faubert, 2009) which can be used to analyse concept maps. Still other approaches might involve considering how the maps were created based on the physical construction of the maps, the degree of formality involved, and any similarities or variances in the kind of concepts included (Wheeldon & Faubert, 2009). In this study, the author focused on the propositions. This means that the concept maps were judged from the propositions in a map, their accuracy, the cross-links, hierarchy levels, and labels provided. In addition, the teachers' abilities in clearly articulating the focus question (draw a concept map on energy), concepts related to energy, using linking words as well as propositions were evaluated. The teachers' concept maps were then evaluated to see whether they conformed to the requirements as indicated in Figure 1.

Results and discussion

The science teachers' workshop was based on the concept of energy. In preparation for the workshop, teachers were asked to discuss the definition of energy before they constructed the concept maps. The purpose with this, was to get teachers thinking about concepts related to energy. It was eminent from the discussion that teachers differed on the correct definition of energy. Teachers argued that most textbooks refer to energy as the ability to do work. These arguments led to some of them elaborating on the meaning of "the ability to do work". Some of the responses given by teachers are as follows:

- *"The power or ability to facilitate or do work"*
- *"The power that someone uses to bring change on an object"*

- *“The power that enable something to perform”*
- *“The energy is there”*
- *“Transformation of energy”*

The descriptions indicated that teachers confuse energy and power. Following a discussion on energy and definitions given by teachers a short lecture on energy was presented by the author. Teachers were then given an opportunity to construct the concept maps on energy. Teachers used lecturer notes and textbooks as references materials. Examples of prepared concept maps were shown to teachers. Teachers continued to argue during the construction of concept maps. Their continued debates were a learning curve for teachers hence they learnt from each other during the workshop.

The article reports on the concept maps constructed by teachers. These concept maps show how concepts are related. In addition, attention was given to how concepts are arranged hierarchically, cross-linking concepts, and using propositional linkages. A more detailed picture of the concept maps was extracted from a qualitative analysis of the concept maps (Figures 2, 3, 4, 5 and 6). Figures 2, 3, 4, 5 and 6 shows the concept maps of groups 1, 2, 3, 4, and 5. In these figures the original copy as well as the transcribed concept map is illustrated. The results of this study indicate that teachers do not possess the skill in constructing concept maps.

Discussion of Group 1 Concept Map

The teachers indicated the main idea in the concept map, but the concept map lacked clarity because the structure of the map does not make it clear how concepts are related. An attempt was made to organise concepts hierarchically at the top, with sources of energy followed by an example (sun). Although sources of energy are specified, only one source of energy is pointed out.

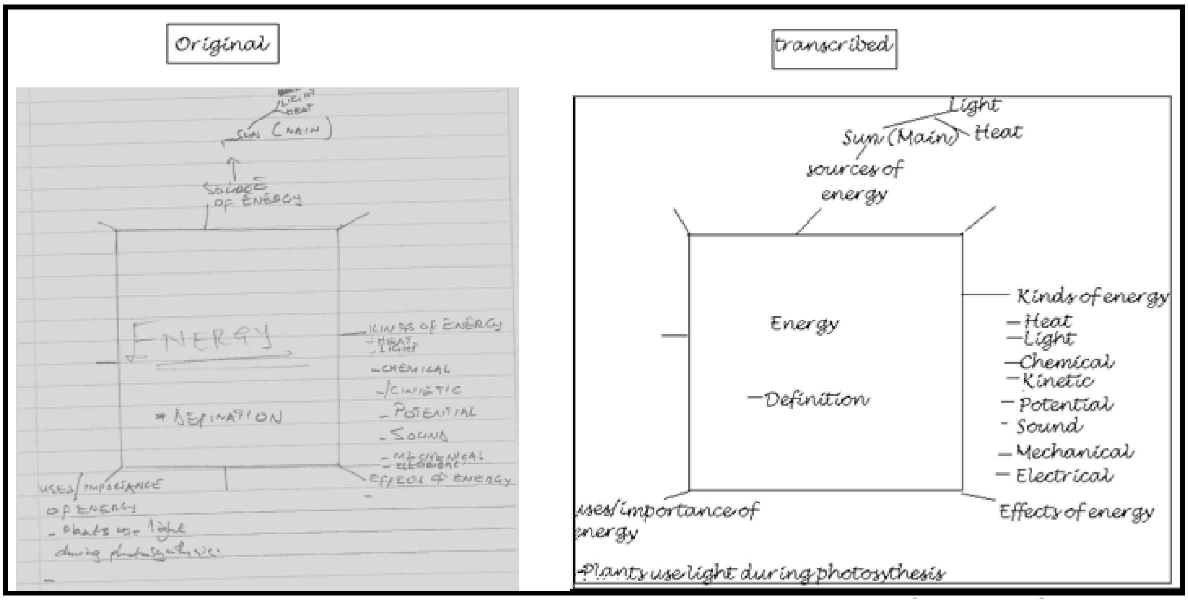

Figure 2

The map (Figure 2) shows that the sun is related to light and heat but it is not clear how they are related. The assumption is that the sun produces light and heat. The map illustrates kinds of energy, and examples thereof include kinetic, heat, light, potential, sound, mechanical and electrical energy.

Furthermore, the teachers included the phrase ‘uses/importance of energy’ and mentioned that ‘plants use light during photosynthesis’. In the centre of the map, the teachers wrote the word ‘definition’ with no concepts linked. The latter is consistent with what transpired in the beginning of the workshop where teachers could not agree on the correct definition energy.

Discussion of Group 2 Concept Map

The teachers who constructed the concept map that is presented as Figure 3 attempted to organise concepts hierarchically. The main idea in the concept map is the concept ‘sun’ (the main source of energy). The supposition made by the author is that the teachers’ concept map sketches the methodology they adopted when introducing the concept of energy. The map shows that the teachers introduced the concept of energy by first talking about the main source of energy (the sun). The map explains how energy from the sun is converted to heat, light and kinetic energy. However, the concepts ‘heat energy’ and ‘light energy’ are repeated four times in different parts of the map, while ‘kinetic energy’ is repeated three times. The map demonstrates insufficient coherence and limited hierarchy of concepts.

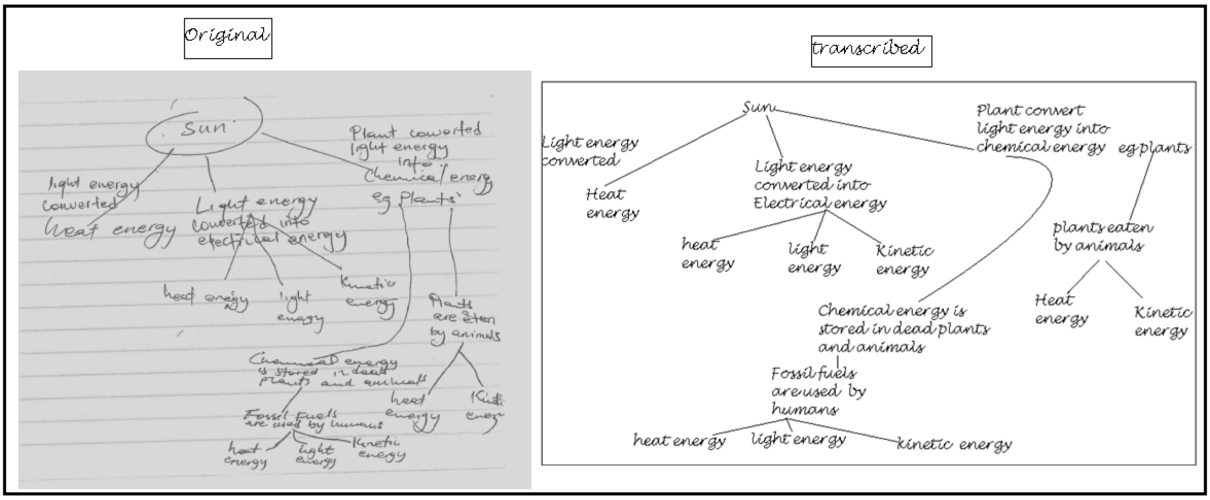

Figure 3

The concept map in Figure 3 illustrates that teachers could not understand that the main idea in this case should be energy. This may have implications in the teaching and learning of the concept energy. Teachers should think carefully before choosing the concepts that can be used to introduce a related concept. Figure 3 was supposed to be a concept map on the concept of energy, but teachers constructed a concept map on the sun. Constructing a concept map requires active involvement in identifying the central idea and relating concepts to each other in a meaningful way (Slotte & Lonka, 1999).

Discussion of Group 3 Concept Map

Observations made during the discussion and construction of this map is that teachers could not agree on the content to include and the structure of the map. At the end of their discussion they included only the examples of energy. In spite being given the example of a concept map, teachers did not take into consideration that the lines they draw should have meaning when drawn between concepts. Their (group 3) discussion of energy concepts yielded a map illustrated in Figure 4.

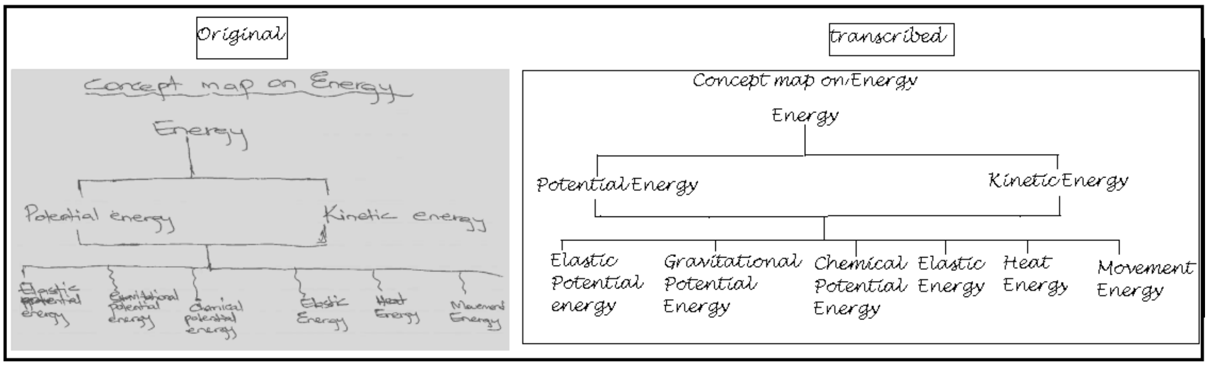

Figure 4

Although there is no propositional linkage between the concept 'energy' and the two concepts 'kinetic energy' and 'potential energy' (Figure 4), the teachers who constructed this map attempted to show the hierarchy between the concepts of energy and kinetic and potential energy. However, 'kinetic energy' and 'potential energy' should have been connected by a linking word to 'energy'. The two concepts (kinetic energy and potential energy) are types of energy, but it is not clear from the map. If the linking word was included it would be clear to the reader.

In the next part of the map, six concepts are mentioned. These are elastic potential energy, gravitational potential energy, chemical potential energy, elastic energy, heat energy and movement energy. These concepts are joined to both kinetic and potential energy. Again the map is silent about the relation of these concepts to kinetic and potential energy.

The arrangement of concepts in this concept map (Figure 4) illustrates limited content knowledge of teachers. It is possible that the teachers were not using concept mapping as a teaching strategy in their respective schools. For this reason they could not arrange concepts in a way that is understandable to the reader.

Discussion of Group 4 Concept Map

There is a possibility that teachers who constructed this map (Figure 5) did not remember the effects of energy or they did not know them. This is because some parts of the map were incomplete. Omitting the relevant concepts and examples from the maps is related to the inability to apply them (Slotte & Lonka, 1999). Teachers constructed these maps in groups and the expectation was that they would help each other and construct complete concept maps.

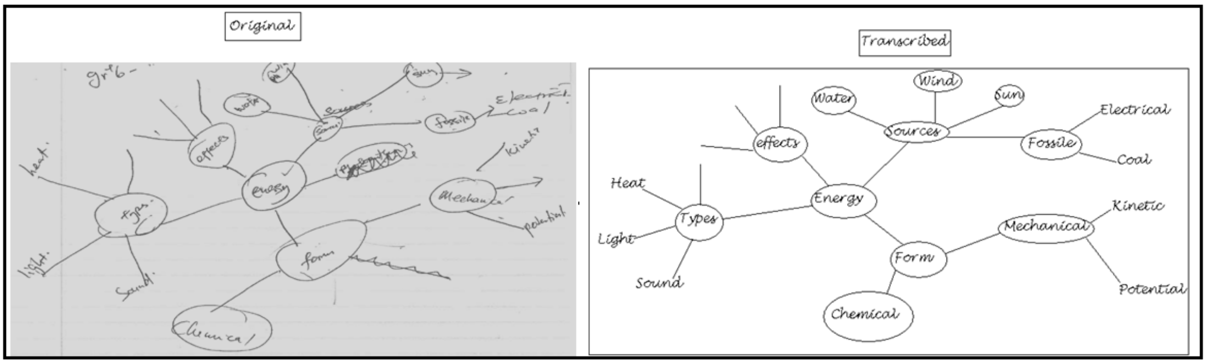

Figure 5

The concept map in Figure 5 was fairly attempted. Nevertheless, it was difficult to locate the main idea in the concept map since the main idea does not stand out clearly. The teachers managed to hierarchically link energy to types, effects, and forms of energy, but failed to complete few parts of the map. The concepts in this map are linked using lines with no linking words. The teachers have drawn a line between concepts like 'effects' and 'energy' and three lines outwardly from the concept "effects" with no concepts written in the lines.

Discussion of Group 5 Concept Map

Despite similar challenges with other groups of teachers, the concept map in Figure 6 shows that the teachers managed to mention concepts related to energy together with examples, including types of energy, sources of energy, forms of energy as well as uses of energy.

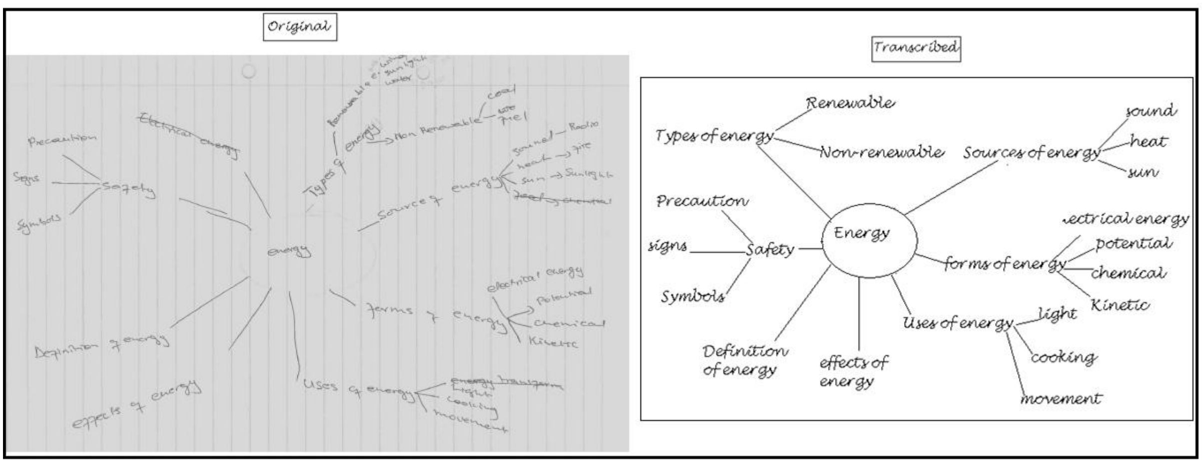

Figure 6

However, they mentioned effects of energy without providing examples. Although, the concept map has been drawn with no cross links and labels, an attempt was made to organise the map hierarchically.

Conclusion

The results of this study show that the teachers' concept maps varied substantially in their scope and complexity meaning that there was a varied level of conceptual understanding among the teachers in this study. This is the result of the different cognitive structures teachers have. Consequently, if one asks two experts to develop maps on the same topic, it is likely that these maps will look different because they reflect the cognitive structures of different people (Daley & Torre, 2010). Since the concept maps are the results of a group effort, their efforts was expected to yield improved concept maps. However, the results show that the teachers did not have experience in the construction of concept maps. However, these concept maps can be used in classrooms to spark debates on content and concept relations. For an introduction of a lesson on a topic of energy, the prepared concept maps can be used to facilitate learning and teaching in science classrooms. Learners and teachers can use such concept maps to construct knowledge and prepare new concept maps. Having said that, it was necessary to let teachers have a practical experience on the construction of concept maps. Teachers should also engage learners in the construction of concept maps. Even though there are challenges in the construction of maps, the skill to construct concept maps is important for both teachers and learners.

Some of the concept maps displayed lack of content knowledge. Apart from knowing the skill to construct the concept map, content knowledge is a major concern because it dictates what should be in the map and how it should be arranged. The lack of content knowledge has implications on the teaching and learning of science in schools.

Although the concept mapping technique was discussed with teachers, their concept maps could not match the criterion map indicated in Figure 1, thus it is evident that these teachers are not competent in the construction of concept maps. The concept maps did not conform to the established requirements of concept maps. This is because it may take time McNeese & Ayoub, 2011) for teachers to acquire the skill.

The results of this study show that teachers face challenges in the construction of concept maps. The concept maps constructed by teachers who participated in this study show that teachers struggled to illustrate how concepts are related to one another. This finding is consistent with Ingec's (2009) conclusion that teachers have difficulty establishing relationships among concepts. Arranging concepts in a hierarchy, using propositional linkages and cross-linking concepts was a challenge to teachers. The concept maps displayed very few hierarchies and incomplete cross-linking between concepts. None of the concept maps showed linking words between concepts. For this reason, the accuracy of the maps was affected. The accuracy of maps is related to understanding scientific content (Slotte & Lonka, 1999). The results of this study show that the teachers' concept maps are not entirely wrong and that the challenges identified can be used as a starting point to channel appropriate professional training of science teachers to include a focus on understanding of scientific relationships among concepts. Training should include revising and revisiting our teaching methodologies to incorporate the training of teachers in concept mapping.

The purpose of the study on which this article is based was to determine the challenges of science teachers in the construction of concept maps. The author is aware of the many challenges teachers face in the teaching of science. However, this article serves to inform the readers that some of the challenges are embedded in the understanding of relationships between concepts as depicted in the concept maps constructed by teachers.

It is suggested in the article that interventions geared at addressing the challenges teachers face should include the teaching and learning strategies dealing with concept relations. However, more time is needed to incorporate the use of concept mapping as a learning and teaching strategy since it requires adjustment on the part of both learners and teachers. The teachers who participated in this study experienced difficulties in constructing concept maps. This could suggest that teachers regularly need to practise the construction of concept maps.

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