Refined Concept Maps for Science Education: A Feasibility Study

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Refined concept map (RCM) is comprised of node names and a well-defined, invariant, minimal set of relation names. Using RCM as a methodology, it can be applied to study the changes in the knowledge structure, as a tool for analysis of forms of representations. In this paper, we discuss the study conducted to test the ease and feasibility of RCM by comparing it with other modes of representation. A homogeneous sample of school students were assigned the same task from a specific domain. The analysis shows that it was easy and feasible to use RCM by the school students. The fixed set of relation names, does not affect the expression of knowledge and at the same time helps in representing accurate knowledge. The constraints in the RCM served as an anchoring and a facilitator for representing scientific knowledge.

Introduction

Concept maps are two-dimensional graphical representations of one's knowledge of a domain (Novak & Gowin, 1984), based on Ausubel's theory of meaningful learning in the classroom (Ausubel et al., 1978). Over the past three decades, concept maps are being used effectively for eliciting knowledge, for meaningful learning, recording the conceptual changes during cognitive development, for evaluation, etc. (Mintzes, et al. 1997 & Mintzes, et al. 1998). The main elements in concept maps (henceforth traditional concept maps) are *node names* and *relation names*. Wherever applicable, a seed list of node names is provided for a domain and the relation names are chosen from the natural language. This, at times, leads to ambiguous maps. Therefore, it becomes very essential to focus on choosing the appropriate relation names in order to apply rigor to the maps (Kremer 1995, Sowa 2006). One such methodology which suggests refinements based on the usage of the relation names (aka relation types) is *Refined Concept Maps* (RCM) proposed in Kharatmal & Nagarjuna (2006), which provides a mapper with a known finite set of relation names followed from the formal knowledge representation (KR) group. In the state-of-the-art research areas of ontologies such as FMA (2008), GO (2008), OBO (2008) and bioinformatics the node names (referred to as classes) are modelled using specific kinds of relations (referred to as properties). These relations are formally defined, are finite, also seem to be exhaustive (RO, 2008) and are available in the public domain. It is known that since there exists thousands of node names, the relation names that are required to network these node names are minimal for a given domain. These relation names act as knowledge organizers (Kharatmal & Nagarjuna, 2004).

Refined concept map (RCM) is an eminent tool for representing scientific knowledge. In this method, only minimal set of relation names are used while constructing the maps for a given domain as shown in Table 1. On the contrary there is no such constraint in the traditional concept map (TCM). The purpose of the TCM is for eliciting knowledge and for meaningful learning and it is claimed to be useful in science education. However, this claim is misleading because TCM lacks rigor and cannot be used in science learning since science is a rigorous body of knowledge (Kharatmal & Nagarjuna, 2006).

But by applying refinements in concept maps, it can be used more effectively in science education. Figure 1 shows a RCM on nucleus which is based on the school level text. Research studies suggest that an expert's knowledge structure is coherent, economical and tightly integrated, while a

Part-Whole: consists of / part of; composed of; contained in	Spatial-inclusion: surrounded by*; enveloped by*; located in;
Class-inclusion: includes	Function: has function
Examples: example; instance of	Attributes: has nature; has size; has shape; has color; has property

Table. 1. List of relation names provided with RCM for the domain. The relation names marked '*' are not in the formal groups' relations vocabulary.

novice's knowledge structure is often inconsistent, ambiguous, and loosely organized (Brewer & Samarapungavan, 1991). While attempting to organize knowledge, an expert starts with the core concepts, however a novice starts to organize the knowledge from periphery. The approach followed by an expert is principled, i.e., logical, which is not the case with a novice. Concepts in an expert's network are found to be richer in interconnections than those of novice's network. Experts tend to focus on relations among concepts and while grouping of concepts, use the same relation names (Cooke, 1991, p. 38). Representations of expert's knowledge emerge over a time as a function of *repetitive refinements* (Mack & Robinson, 1991, p. 265). If it is the case that the subject experts and KR are related, then the use of RCM in scientific representation and in teaching of science becomes relevant.

We conducted a study to show similarities between subject experts and knowledge engineers (Kharatmal & Nagarjuna 2008). In these various forms of representations that of learners, science teachers, subject experts, knowledge engineers, we see a progressive increase of rigor. During this progression, the relation names used get *re-represented.* This is consistent with Karmilloff-Smith's theory of *Representational-Redescription* (1995) and *repetitive refinements* theory suggested by Mack & Robinson (1991). Can we identify exactly what aspect of representation brings out the change in the knowledge structure? Our hypothesis is that the changes can be explained as re-representation of relation names (Kharatmal & Nagarjuna 2008). Given a TCM, it is possible to obtain a RCM by replacing the relation name, keeping the concept names more or less constant. Since we think that RCM representation is closer to that of subject experts and knowledge engineers, we can introduce RCM as a tool that facilitates the required conceptual change. On this basis, we recommend the use of RCM for facilitating learning of sciences.

Is there any empirical support for the claim that the experts tend to use progressively lesser number of relation names? How do we demonstrate that RCM is closer to expert's expression? Can RCM be used in the classroom? Is it feasible and easy? Since RCM uses minimal set of relations can there be loss of expression? These questions, we think, must find an answer, if we wish to confidently use RCM as a tool for science education. It is, however not possible to address all these questions in this paper. The first two questions find a partial answer in Kharatmal & Nagarjuna, 2008, while the other questions are discussed in this paper. The objective of this study, therefore, is to test the tool, RCM, for its ease and feasibility in scientific representation. We conducted a study with a homogeneous sample of students, who were assigned three different modes of representations and were asked to represent the same domain. The propositions were identified, and the node names and relation names were marked, scored and analyzed. Elaboration follows.

Method

Three different methods—description, traditional concept mapping, refined concept mapping—were considered for the study and accordingly three groups were formed. All these methods can be used to express the knowledge. A homogeneous sample of students (age 13-14 years, mixed gender) studying in grade IX from a local urban school were considered for the study. The domain chosen was a chapter on "The Fundamental Unit of Life" from grade IX Science Textbook (NCERT, 2007). All the three groups were assigned the same task—to describe "the structure and function of nucleus and mitochondria". The research design comprised of a one-shot study wherein three different activities were administered to three different groups. Group 1 (n=32) was asked to complete the task using description (DES) mode using simple sentences (without any constraints). Group 2 (n=30) was asked to complete the same task by using the TCM (seed node names provided, relation names not provided). Group 3 (n=30) was asked to complete the same task by using the RCM (seed node names and set of relation names provided). At the time of this study, the students were already taught the above chapter by their science teachers as per their classroom schedule. However, just to help them recall their knowledge, the same chapter was read out to all the three groups. Prior to assigning the task of representing the domain for the groups 2 and 3, an introduction, familiarization and practise session of concept mapping technique was conducted.

Results & Analysis

Concept names (nodes in the map) are considered to be the building blocks of sentences and relation names provide meaning to these sentences. The units of analysis were *node*

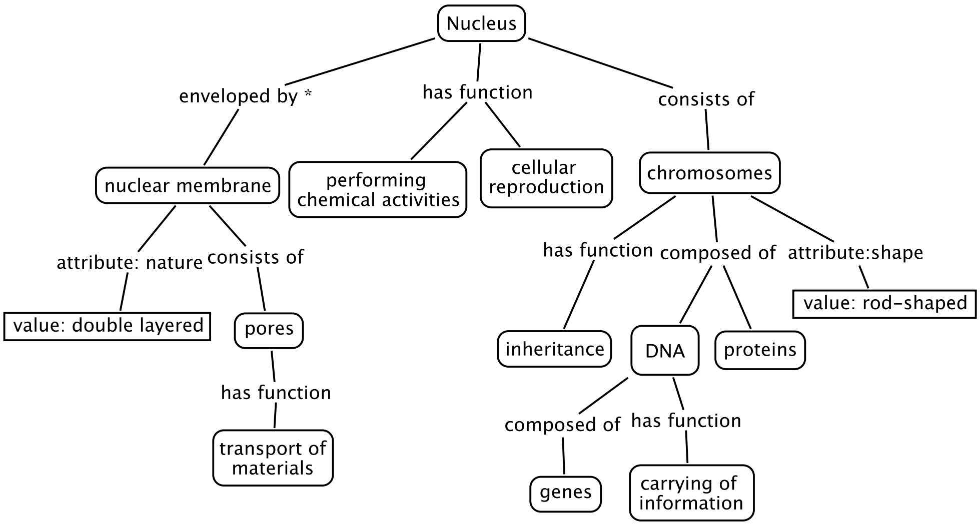

Fig. 1. Refined Concept Map drawn using constraint set of relation names. The relation names with * are not in the formal groups' relation vocabulary.

names and scientifically accurate *relation names* in the domain. The chapter from the textbook was considered to be control for the group 1. A criterion traditional concept map and a criterion refined concept map were used as controls for group 2 and group 3 respectively. The criterion map (expert's map) was created by the researcher following the RCM approach, i.e., using the minimal set of relation names. Almost all the critical concepts and propositions that were required to represent the domain, were represented by all the three groups.

The relation names were categorized into different dimensions such as – *part-whole*; *class-inclusion*; *spatial-inclusion*; *function*; *attributes*, based on the kinds of relation names used. A selected list of propositions from the three groups with a comparison with expert is shown in Table 2. During the analysis, the number of relation names used for a given sentence by all the three groups was compared. For instance, the sentence "nucleus is *surrounded by* nuclear membrane" was found to be represented by using different kinds of relation names such as - *made of, consists of, contains, has, divided into* by groups 1 and 2. An account of the kinds of relation names used in all the three groups was taken. The study revealed that the students from group 1 used 30, group 2 used 42 and group 3 used 7 (already provided) relation names to represent the same domain. This means that when the relation names are used freely as seen in groups 1 & 2, the sentences are ambiguous and therefore there is no parsimony in the map. It may be observed that there is some correlation with the number of linking words used and correct relation. The lesser the linking words used more is the number of correct relations. In the groups 1 & 2, the correct relations have been found to be less in number than that of the group 3. This indicates therefore that the constraints does not hinder the expression of knowledge, since the group 3 had more number of correct relations even with a fixed number of relation names.

In addition to the above, incorrect relations were identified based on the incorrect choice of relation names. These were found to be more in the groups 1 (average for nucleus=1.73; average for mitochondria=0.4) and 2 (average for nucleus=1.16; average for mitochondria=0.48) than those found in group 3 (average for nucleus=0.66; average for mitochondria=0.19). With regard to the depiction of incorrect relations, the more the number of linking words used, the more it was prone towards inaccuracy. The group 3 used quite a small set of relation names and it had a less number of incorrect relations as compared to the groups 1 & 2.

Another point to note is that in the description mode there were quite a few misconceptions, idiosyncratic ideas seen in the group 1. Some of these are— "if the nucleus is removed, the protoplasm dries up and the cell dies"; "mitochondria has genetic material like ribosomes"; "if mitochondria is removed from the cell, it will not get energy and will dry & die"; "nucleus contains membrane bound structure called chromatin"; "nucleus contains ribosomes". Some from the group 2 used long sentences by drawing them apart into node names and relation names. Whereas, in the group 3 there were almost no such misconceptions or idiosyncratic representation, as there is no scope for depiction of such ideas since the RCM method imposes a constraint which in turn aids students to represent knowledge meaningfully. An important point to highlight is that although the

Dimensions	Group 1 (DES)	Group 2 (TCM)	Group 3 (RCM)	Expert
Part-whole	nucleus *is comprised of* DNA nucleus *consists of* DNA nucleus *contains* DNA	nucleus *has* DNA nucleus *is made up of* DNA	nucleus *consists of* DNA	nuclei *contain* DNA
	mitochondria *has* its own DNA and ribosomes mitochondria *consists* of its own DNA and ribosomes mitochondria *contains* its own DNA and ribosomes	mitochondria *have* DNA and ribosomes mitochondria *made up of* DNA and ribosomes mitochondria *consists of* DNA and ribosomes mitochondria *contains* DNA and ribosomes	mitochondria *consists* of DNA and ribosomes	mitochondria *contain* DNA and ribosomes
Spatial-inclusion	mitochondria *is a* double layered organelle mitochondria *is a* cell organelle which is double layered membrane mitochondria *has* double membrane mitochondria *divided into* double membrane	mitochondria *have* two membrane mitochondria *consists of* two membrane, outer and inner the double layered membrane *is made up of* outer and inner membrane mitochondria *has* double layered covering	mitochondria *is surrounded* by double membrane	mitochondria *is surrounded by* double layered membrane

Table. 2. A comparison of few sentences over the different groups with expert's representation. In each proposition, the node names and the relation names (italicized) were analyzed.

group 3 applied a constraint set of relation names, the students represented the same domain without any loss of knowledge. It was not the case that the critical propositions of the respective domains were not represented by the group 3 given the fact that there was no freedom in choosing the relation names freely.

For all the three groups, a score of 1 each was assigned to each non-redundant concept and a score of 1 each for valid relation of nucleus and mitochondria. The scores are indicators of students' understanding of the domain. We believe that the scores for concepts and relations are proportional to their understanding. The data were treated for parametric test. A single factor analysis of variance (ANOVA) was used to compare the variance of the three groups. For the node names of nucleus the $F(2, 89, 91) = 2.66$, $p>0.05$ was found non-significant. However for relations of Nucleus the $F(2, 89, 91) = 8.20$, $p<0.05$; and for the node names of mitochondria the $F(2, 89, 91) = 4.13$, $p<0.05$; and for the relations of mitochondria the $F(2, 89, 91) = 4.50$, $p<0.05$ were found to be significant.

In order to further analyze which of the three groups produced significant results a t-test was performed. We have found significant differences in the relations that have been depicted for nucleus $t(49.45) = 3.6$, $p<0.05$ and mitochondria $t(50.93) = 3.59$, $p<0.05$. In these two cases, the refined concept mapping is significant over the description mode and traditional concept mapping mode $t(51.30) = 2.6$, $p<0.05$. As far as the depiction of node names, there has been no significant differences in the traditional concept mapping method $t(56.52) = 1.75$, $p>0.05$ and the refined concept mapping method $t(57.02) = 0.8$, $p>0.05$, which shows that the refined concept mapping does not affect the representation of critical concepts.

Interestingly it was observed that there was no difficulty by the group 3 (RCM) to learn and use the concept mapping technique during the study. In fact the students felt at ease and were happy when they were provided with cues for node names as well as relation names. This reminds us of Ausubel's (1978) theory of anchoring while organizing a new concept with the already existing concepts. This has already helped in achieving the primary objective of the study.

Conclusion

We compared the RCM tool with the other modes of representations by assigning the same task to a homogeneous sample and analyzed the node names and relation names. While the other modes—DES and TCM used 30 and 42 relation names respectively during accomplishment of the task, the same domain was represented with only 7 relation names. From the study, it can be observed that RCM is parsimonious and it does not hinder the representation of critical concepts. Interestingly, a significant change in correct relations in group 3 shows that there appears no loss of knowledge in the RCM thereby indicating there is no inconvenience in retrieving and eliciting the knowledge of the domain. In fact, the constraints served as facilitator which enabled them to represent scientific knowledge. Although there is a constraint applied with the tool, on the one hand it helps in expression of accurate knowledge and on the other it lessens with inaccurate expression.

In this paper, we conclude that we have demonstrated the feasibility of the RCM as a tool at least in the domain discussed above. In order to generalize for other domains of scientific knowledge, we need to replicate the study in other domains.

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