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EXPLORING ROOTS OF RIGOR: A PROPOSAL OF A METHODOLOGY FOR ANALYZING THE CONCEPTUAL CHANGE FROM A NOVICE TO AN EXPERT

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Abstract. During the course of science education one of the recognizable and desirable changes from a novice to an expert is in their language (knowledge representation). One noticeable change is that of weeding out ambiguous expressions bringing in clarity and rigor. However, this happens not by weeding out the concept names but by choosing more and more accurate linking words (relation names). By focusing on the relation names we report the results of a preliminary study that confirms that subject experts increasingly chose relation names (linking words) that come closer to formal descriptions. The significance of this observation to concept mapping community as well as to cognitive development is immense, for it provides a simple and effective method to study conceptual change, validates the use of refined concept maps in place of the traditional technique in science education, and also further strengthens the approach that relationship between nodes determine the semantics, and not the nodes per se.

1 Introduction

The context of the work is to analyze the transformations in knowledge representation from a novice to an expert. Several comparative studies were done by cognitive scientists, each of them focusing on some aspect. It is observed in one such study, that the expert's knowledge structure is coherent, economical and tightly integrated, while a novice's knowledge structure is often inconsistent, ambiguous, and loosely organized (Brewer & Samarapungavan 1991). Concepts in an expert's network are rich in interconnections than those of novice's network. Experts tends to focus on relations among concepts and while grouping of concepts, use the same relations criteria (Cooke, 1991. p. 38). Representations of expert's knowledge emerge over a period as a function of *repetitive refinements*. (Mack & Robinson, 1991, p. 265).

We focus in this work on the refinements that happen in the transformation of a novice to an expert in terms of the nature of changes in the knowledge representation. We use a variety of concept mapping technique for this analysis, focusing on the number and kinds of linking words used by novices and experts. Most significant focus of our study is on relations between the nodes (concepts), and not on the nodes per se. We follow the structuralist perspective that meaning of a node comes from the relations it has with other nodes. If meaning resides in the relations, as we assume, and given the fact that there occurs a change in meaning during the course of cognitive development, it is natural to look for the root of the change in the relations. We know that experts' knowledge is more rigorous and unambiguous than that of novices'. Can the roots of rigor and precision lie also in the nature of relations used by the experts? If so, what is that nature?

We hypothesize that during the cognitive development of a novice into an expert:

i. conceptual change happens due to re-writing the names of relations, and not due to re-writing the names of nodes,
ii. the number of relation names used progressively decrease,
iii. the same relation names are consistently used eliminating ambiguity and
iv. the number of relation names required for a formal representation in a given domain are not only finite but few. The lesser the relation names, the greater the formal character of the representation.

These proposals, if found to be true, will undoubtedly have a significant impact on cognitive development research, as well as implications to science education practice and research. They also have deeper epistemological implications. We must confess that we are neither providing conclusive verification to the proposal, nor are we examining the implications. That must wait for another occasion. Therefore, we are *not* attempting to provide a full empirical support in this paper, but we describe how a preliminary study was conducted, the nature of the analysis and how it can help to carry out a major study. The purpose of this paper therefore is to share our confidence in the strategy we are following, the details of the ongoing work, the methodology that we are following and some preliminary results. We welcome critical comments, falsifying cases, and possibly other methods of substantiating the above proposal.

2 The Method

The method constitutes in collecting the propositions of a member of a group, identifying the relation name (linking word) in a proposition, categorizing the relation names based on semantics, taking count of the number of relation names used in a fixed domain. The idea is to compare the sentences of a novice with that of the text book as well as subject experts for a given proposition selected from the same domain of knowledge.[1]

We collected the novice's sentences from a group of about 30 students of 9th grade eliciting their knowledge of a portion of cell biology (*structure and function of nucleus and mitochondria*), which is the domain for this comparative study. The student sample is a homogeneous group of 32 students, age 13-14 years, mixed gender from an urban school studying in English medium. The task given was to describe nucleus and mitochondria using simple sentences in about 45 minutes. The topic chosen was already covered in their school, and in addition to this the chapter was read out to the students before the responses were given. Their responses were compared with the sentences in the text book (NCERT, 2007) the students followed, by selecting the sentences stating the same proposition. We also took the sentences from two other text books (Campbell & Reece, 2005 and Taylor, et.al. 2003) prescribed for upto 12th grade, as an intermediary stage of the development. All these sentences were then compared with that of subject experts, by selecting the sentences from well known and authoritative books in the area of cell biology (DeRobertis & DeRobertis, 1995).

It is however possible to perform the study by several alternative ways. Our choices were mostly determined by what is possible within the time constraints. One distinct possibility is to do a cross age study collecting sentences from different groups exposed to increasingly greater exposure to a given subject domain. We are soon embarking on such a study. In this study however we took a rather complete sample for the novices, while a much shorter route for other stages by selecting sentences: (i) from two textbooks by authoritative undergraduate level books; (iii) from a standard advanced level book as representative of expert's stage, while considering the students of 9th grade as representative of the novices. The study can be further extended by collecting sentences from scientists, subject experts, researchers, science educationists, textbook writers, teachers, and students from different levels. Such a study may give highly granular picture of the process and verification or a falsification of the proposal.

We have also constructed sentences by following the relation names of the formal knowledge representation group (knowledge engineers), as a highly refined representation of the domain. When we create a concept map using the relation names suggested by the knowledge engineers we get, what we call, a *refined concept map* (RCM) (Refined Concept Map, 2006) as shown in Figures 1 & 2. The required relation names are selected from Relations Ontology (RO, 2006) to draw the RCM, with some exception as noted in the legend. Since, even subject experts often tolerate or commit non-rigorous expressions, particularly in biology (due to absence of formal representations), we consider the RCM, being a finer representation available, as a reference for the study and as a bridging tool for facilitating the transformation of a novice into an expert.

Dimension	**Relation Names (Relation Types)**
Part-Whole	• consists of • composed of • contained in
Class-inclusion	• includes
Spatial-inclusion	• surrounded by* • enveloped by* • covered by • located in • adjacent to • connected to • overlaps • wound around* • bound by* • occurs as*
Function	• has function
Attributes	• has nature • has size • has shape • has color • has property
Examples	• example • instance of

Table 1: Selected relation types recommended by the knowledge representation groups for the domain of cell biology. The names marked '*' do not yet have a formal semantic definition. A few of the relation names may be removed from the list, as and when some of them are defined in terms of the others. Also note that the list is not exhaustive.

3 The Analysis

The sentences written by the students to represent a proposition were selected, the nodes and the relation name used by them were marked. Then, we searched for the nodes and the relation names used by the text book and

1 We use the term 'sentence' for the various possible representations of a given assertion. And the term 'proposition' for the meaning of the several possible sentences.

by the subject expert (DeRobertis & DeRobertis, 1995), as shown in Table 1. For example, for the two nodes 'nucleus' and 'DNA' the relation names used are 'contains', 'comprised of', 'has', 'consists of', 'present inside' (inverse) by the students for the proposition 'nucleus contains DNA'. The textbook used the relation name 'contains'. The experts used 'contains' consistently. Our student sample however is large (n=32), while we considered only one subject expert. The text books of higher secondary level also used 'contains' consistently. This may be taken as an indication that experts completely weed out the other relation names. According to the knowledge representation experts, the relation name 'contains' is to be used only when expressing the relation between a material object with a region (such as a cavity or channel) (Smith, et.al., 2005).

The novice group used the relation names 'have', 'present in', 'consists of', and 'made of' for the two nodes 'chromosomes' and 'DNA'. The textbook used 'composed of', and the experts used 'made of', 'composed of' and 'complex of'. The incorrect relation names 'present in', and 'have' are considered weeded out in this case, with an additional relation name 'complex of' appearing in an expert's representation.

Dimension	**Students**	**Textbooks**		**Experts**
		Secondary level	**UnderGraduate level**	
Part-whole •nucleus contains chromosomes	• nucleus *is comprised of* DNA • nucleus *consists of* DNA • nucleus *contains* DNA • nuclues *has* DNA *present inside* • nucleus *has* DNA	• nucleus *contains* DNA	• nucleus *contains* DNA	• nuclei *contain* DNA
	• nucleus *contain* proteins and DNA • nucleus *consists of* chromosomes, DNA, proteins • nucleus *has* chromatin	• chromosomes *composed of* DNA, proteins	• Chromatin *is made of* proteins • Chromatin *is made of* DNA • Chromatin *composed of* coils of DNA	• chromatin *is a complex of* DNA and Histones
Spatial Inclusion • nucleus enveloped by nuclear membrane	• nuclues *contains* a nuclear membrane • nucleus *has* a nuclear membrane	• nucleus *is covered by* nuclear membrane	• nucleus is *enclosed by* nuclear envelope	• nucleus *is surrounded by* an envelope

Table 2: Sample propositions from various groups used for comparison and analysis.

The relation 'consists of' is indeed a part-whole relation, but does not specify the stronger constituent sense, that 'composed of' or 'made of' provide. Knowledge representation experts also recommend the use of 'composed of' when a whole constitutes parts materially (Keet, 2007). Mixing of spatial relations (containment) and parthood relations are often used interchangeably by the novices. This is noticed even among the experts. For example, in 'DNA is present in chromatin' and 'Chromosomes contain DNA', we see that containment relation is used in place of composition. However, such instances are found very sparingly.

The distinction between component and compartment is not noticed among the novices. Though the text books did not use relation names incorrectly, the novices tend to use 'consists of' and 'composed of' in a similar sense. No explicit mention of the distinction is found in text books, except among the subject experts. Historically, e.g. nucleus was considered a component, but as ultrastructure of the cell was revealed and dynamic aspects of cell cycle unraveled, nucleus becomes a compartment. This conceptual change that we witness in history can also be seen in the transformation of a novice to an expert.

In the proposition 'nucleus is enclosed by nuclear membrane' the concepts 'nucleus' and 'nuclear membrane' take part in a spatial and not part-whole relation. Therefore the more accurate linking word can be 'enclosed by' which we see was used by the experts. However the students' group used 'contains', 'has' and the textbook used 'covered by' which is similar to the expert's name. The usage of linking words 'contains' and 'has' can be said to be inaccurate in this context since the former is spatial and latter is ambiguous. The experts group has accurately used the linking word and the textbook group in this case is quite close to the proposition. Few more elaborated examples of comparison of the relation names used in a sentence by the novice (students) and an expert are depicted in Table 3.

Dimensions	Students	Expert
Part-whole	• nucleus is *comprised of* DNA • nucleus *consists of* DNA • nucleus *contains* DNA • nucleus *has* DNA present inside • nucleus *has* DNA	• nuclei *contain* DNA
	• nucleus *contains* chromatin • chromatin *is present inside* the nucleus • chromatin *is inside the* nucleus • nucleus *consists of* genetic material	• DNA *is present in* chromatin
	• chromosomes *have* DNA which *contain* the information	• chromosomes *contain* DNA
	• chromatin network *are made up of* DNA and protein • chromatin *contains* genes	• chromatin is a complex of DNA and Histones • chromatin *contains* DNA, RNA, basic proteins called histones, non-histone proteins
	• nucleus *contains* genetic material called genes • chromatin *contains* genes	• genes *present in the* chromosomes are found in pairs called alleles • genes *are made up of* DNA • genes *are located in* chromosomes
	• mitochondria *has its* own ribosomes and DNA • mitochondria *consists of its* own ribosome and DNA • mitochondria *have their* own DNA and ribosomes to produce proteins • mitochondria *have their* own genetic material like DNA and ribosomes • mitochondria *contains* its own DNA and ribosomes • mitochondria *has* its own ribosomes	• mitochondria *contain* DNA and ribosomes • *within the* mitochondrial matrix are small ribosomes and a circular DNA
Class-inclusion	• mitochondria *is a* double-layered cell organelle • mitochondria *is a* double layered organelle • mitochondria *is a* cylinder shaped important organelle • mitochondria *is a* cell organelle which is double layered membrane	• the inner membrane *divides the* mitochondrion into two chambers or compartments-outer and inner chamber
Spatial-inclusion	• nucleus *contains* chromosome which are visible as rod shpaed objects • nucleus *contains* entangled mass called chromosomes which become rod-like structures when the cell is about to divide	• nucleoli *can be observed inside* the nucleus • chromatin *associated with* nucleolus; nucleoplasm

Table 3: Comparison of Students and Experts Relations

Thus we see that experts, either tacitly or consciously, do use accurate relation names expressing the desired meaning. To fill the gaps in our study we need to include the groups of students, say of higher secondary, under graduate and graduate level. This kind of analysis though is time consuming, the method is simple and can be effectively carried out. We also think that the method can be used for studying conceptual change in all developmental studies, whether the development is ontogenic or phylogenic. By holding the relation names as constant, we can probe the kind of nodes that were used correctly and incorrectly by the agents, and similarly, by holding the nodes constant we can take notice of the kinds of relation names used. This preliminary study we carried out at least demonstrates that such a study is feasible and could throw more light on the changes, and possibly may become an effective methodology for understanding conceptual change and if the proposed hypotheses are proven we come close to the roots of rigor.

4 Discussion

The study if extended to a large number of groups along the course of cognitive development, we hope will provide more substantiation or may even falsify the claim. Instead of analyzing the text books, which are usually meticulously crafted before publication, it is worth studying either by interviewing the subject experts or by administering questionnaires. Since authors of text books do keep in mind the level of audience while writing the book, the language used can be used as a reasonable indicator of the group. We plan to repeat this study by selecting four to five text books of each grade, keeping the domain of knowledge constant.

We notice that, some experts whose focus is on the molecular biology did not even consider the need to assert a relation between "nucleus" and "DNA". Nucleus, being a transient structure the emphasis of the subject expert shifts to the basal components like "DNA", proteins and their assembly into nucleosomes. In the book on *Molecular Biology* by Watson (2004), there exists no entry for "nucleus" in the index. This indicates that some node names like "nucleus" so to speak pushed to the periphery. As already noted, several components eventually are recognized more aptly as compartments. Thus, the method suggested in this paper can provide such revealing observations that happen during the development.

Our claim that the nodes do not get replaced by others may be questioned on the ground that further nodes that get added haven't been considered, for the study systematically avoids them. Since, it is necessary to study how the same proposition is expressed by the experts, we did not consider other node names. However, even when we take them into account, we do see that very few relation names, often well defined, get in at later stages, while more nodes do get into the discourse as well. In a sense, the claim is that during the course of development process, knowledge gets added with just a few relation names but with more of nodes. As the knowledge gets represented in more formal terms, the relation names decrease progressively. Thus effectively all the nodes are handled by minimal relation names. Parsimony therefore can be redefined in terms of relation names.

These claims, we are aware, are little far fetched based on the current level of the study. We nevertheless make them to report the nature of implications a study like this may have. We report the partial results to elicit comments and suggestions and of course criticism. We plan to continue the study by adding more nodes into the knowledge base, and characterizing in greater detail the changing profiles during the development by including the groups of students, say of higher secondary, undergraduate and graduate level as well, and also performing analysis of at least five text books of each level keeping the domain constant.

Ever since, Thomas Kuhn (1960) highlighted the changes in the conceptual schemes occurring during the scientific revolutions, several scholars took notice of this to study the paradigm shifts. Paul Thagard (1992) used a crude form of concept maps to highlight the changes in the schema. Nancy Nersessian (1989) used concept maps to visually provide differences in the changes. These maps captured the network of ideas, shows the location, and exhibit changes throughout the network more clearly. Among the cognitive studies, Susan Carey (1986) carried out, by pointing out the transformation from a novice to an expert, the changes in knowledge structures from weak to strong restructuring. In the process, she points out, that the changes are not only *accretion* of concepts but also new concepts gets *subsumed* in a network. In the science education domain, concept maps have been used to explore the conceptual changes by demonstrating that students depict changes in the critical concepts, propositions and their maps become intricate and hierarchical in representation (Wallace & Mintzes, 1990, pg. 1038). Mintzes (2007) demonstrated a *punctuated model* of conceptual change with the use of concept maps, wherein the weak restructuring of the subsuming of concepts were punctured by strong restructuring involving integrating of concepts with relations. In another form of representation by Fisher used concept mapping to determine the processes of conceptual changes by focusing on the linking words in a semantic network (Fisher, 1990).

Thus, it is well known that conceptual change happens due to restructuring, and the structuralist approach that meaning of a concept emanates from the relations it has with other concepts, we further explore to operationalize this research using refined concept mapping by focusing on relation names. This is also in line with the observations made in the knowledge representation community that the regular or traditional concept map was not found to be apt for depicting scientific knowledge due to the presence of ambiguities, and inconsistencies in the usage of linking words (Kharatmal & Nagarjuna 2006, Sowa 2006, Kremer 1995).

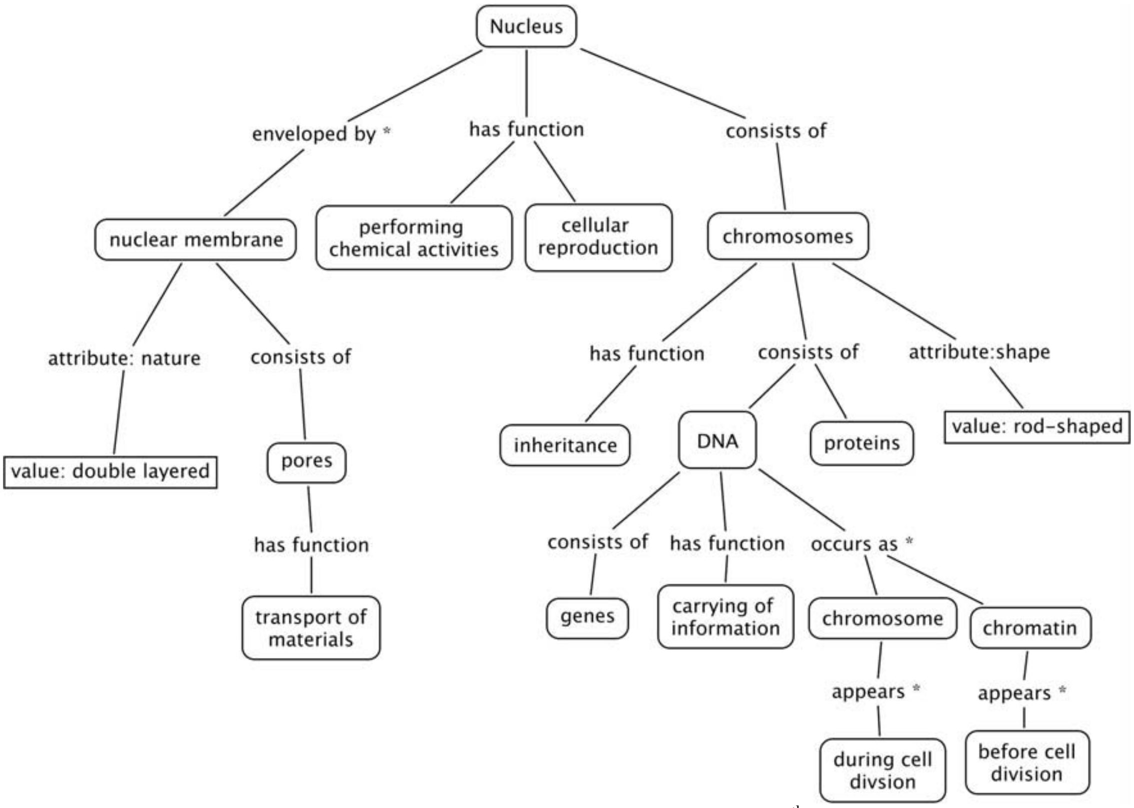

Figure 1: A refined concept map on *nucleus* drawn by the authors based on the 9th grade textbook (NCERT 2007). The relation names with * are not in the formal groups' relation vocabulary. Keeping in mind the level of the text, we used them based on the text to ensure proper mapping.

Accordingly, by identifying certain anomalies in the existing concept mapping methodology and by suggesting some refinements in the concept mapping methodology was proposed by Kharatmal & Nagarjuna (2006) to make concept maps effective for science education. By restricting the set of relation names, formally defined names provided for each domain more rigorous maps can be made without loss of knowledge (Kharatmal & Nagarjuna 2009). If we assume that the objective of science education can be best met by facilitating restructuring and re-representing of knowledge structure, then this disciplined method aids in such a transition.

In a more general theory, Karmilloff-Smith (1995) argues that during cognitive development the knowledge gets recursively *re-represented* and in the process implicit knowledge transforms into explicit knowledge. In these terms, it can be stated that well-defined relation names are the means of the transition from implicit to explicit. Formal knowledge being the most explicit consists of nothing other than the well-defined invariant relations keeping the nodes as variables. Thus the roots of rigor reside in relations. Given that meaning resides in relations, facilitating meaningful learning (Ausubel, 1978; Mintzes, et.al., 1997; Mintzes, et.al., 1998; Novak, 1984) must focus on the use of the few invariant relations while teaching science.

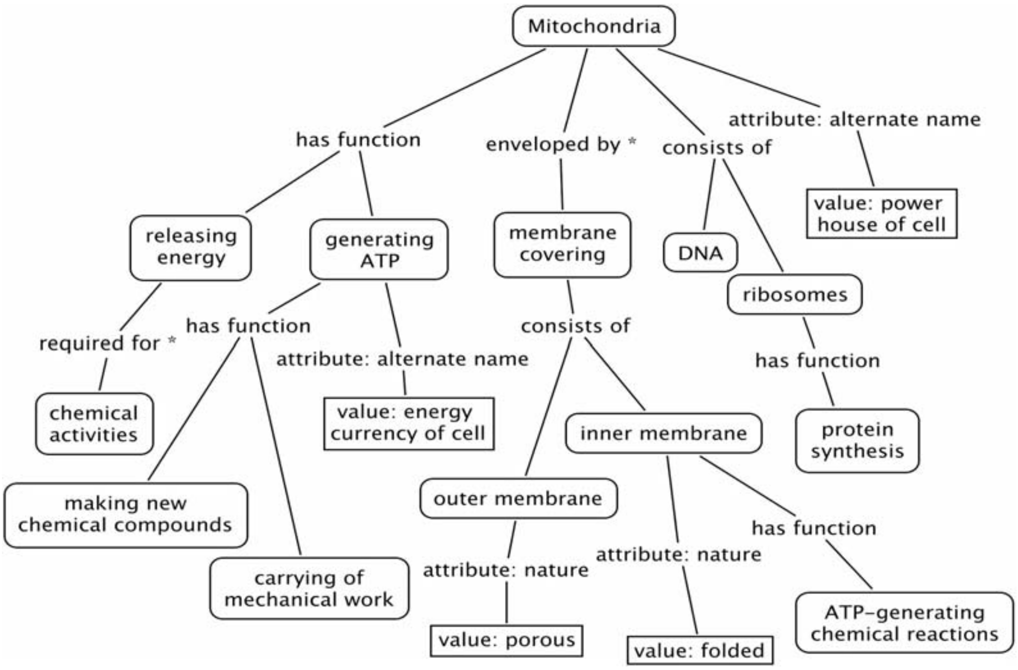

Figure 2: A refined concept map of mitochondria drawn by the authors based on the 9th grade text book (NCERT 2007). The relation names with * are explained in the legend of Figure 1.

To conclude, we submit that this preliminary study does not provide conclusive evidence to the hypotheses proposed, but the study does point to new possible methodology that can help us in studying the conceptual change from novice to an expert.

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