Using Semantic Reference Set of Linking Words for Concept Mapping in Biology

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Abstract. Inspired by the semantic network studies we propose additional conventions for choosing linking words and arrive at a Reference Set of semantically well-defined linking words drawn from the Knowledge Representation area of research in the domain of biology. Each linking word in the set is assigned a dimension: part-whole, class-inclusion, spatial-inclusion, function and attribution. We study expert representations by content analysis of biology texts at three levels of increasing subject complexity. We compare the linking words used in these representations with the Reference Set and find an increasing degree of proximity to the latter. This indicates that experts tend to use more well-defined linking words. Regarding this proximity as a characteristic of expertise, we can encourage novices to re-represent their concept maps using the linking words from the Reference Set. We discuss the implications of the approach for science education.

1 Introduction

The Concept Map method was developed by Novak and his group [1], influenced by the Ausebelian perspective of meaningful learning which posits that new knowledge is constructed by connections to the prior knowledge in the domain [2]. It has since been used widely in eliciting knowledge in a variety of domains.

A Concept Map is a graphical representation in which nodes (concepts) and connecting lines (linking words) are arranged in a dendritic form at various hierarchical levels. A scoring rubric assigns a score to each concept map depending on the number of propositions, levels of hierarchy, cross links and examples. There are standard conventions for creating and scoring a Concept Map. In science education studies, the Concept Map has been used extensively as a learning tool, as a way to study conceptual change and assess student knowledge, and model expertise (See, for example, [3]). Some later studies modified the rubric and included the number of concepts and branches for scoring; see, for example, [4].

For over a decade now, several researchers have adopted semantic network principles to concept mapping. The basic aim in concept maps is to create meaningful propositions. This requires explicit and semantically valid relations between concepts. Syntactic clarity is achieved by the mere presence of a linking word or phrase, but semantic clarity critically depends on the kind of linking word or phrase used [5]. Semantic based scoring rubric has been developed that evaluates concept maps taking

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propositions as semantic units, among other criteria, which shows a high inter-rater reliability measure [6]. In another study, semantic flow and clarity was one of the three aspects examined for readability of concept maps based on the Gestaltian law of proximity and law of similarity [7].

The general semantic network approach has had a long history. Perhaps the best-known theory of semantic networks to model the structure and storage of human knowledge is due to Quillian [8]. These comprise nodes and ordered relationships or links connecting them; they are not necessarily hierarchical. The nodes are instances of concepts or propositions, and the links describe the relationship between them. Semantic networking programs are computer-based, visualizing tools for representing semantic networks.

In a semantic network, each relation between concepts is given an explicit relation name. Holley and Dansereau [9], in their study on using networking as a spatial learning strategy, identified six relations – *part of, type of, leads to, similar to, has characteristics, indicates/illustrates*. In addition, these six relations were classified into three types of representational structures – *hierarchies (type-part); chains (lines of reasoning, temporal orderings, causal sequences);* and *clusters (characteristics-definitions-analogies).*

The act of naming relations is not necessarily a conscious activity unless it is required to be, and often the relation names are implicit in text and language. Therefore, analyzing relations and naming them so as to make them explicit is an important part of constructing a semantic network. Naming of relations is a challenging task, as it requires careful identification to capture and clarify the meaning, which otherwise could remain vague. The naming of relations enhances the depth of understanding and clarity of thought. These ideas were implemented in the knowledge construction tool called SemNet [10].

Faletti and Fisher [11], using SemNet in biology, reported 3 relations – *set/member, whole/part,* and *characteristic* – being used more frequently than other relations. In one of the studies on concept mapping, linking words such as – *is measure of, has property of, depends on, is a form of, is mass divided by, divided by volume, equals* were provided, and it was established that the scoring of maps in this case was straightforward, and hence could be applied for large scale assessment [12]. A form of concept map, called a knowledge integration map has been deployed in an online inquiry-based learning unit where it is suggested that students in a peer-review condition focused more on links and linking words [13].

Inspired by the semantic network studies, we adopt additional conventions for choosing linking words for obtaining a Reference Set of semantically well-defined linking words drawn from the Knowledge Representation area of research in the domain of biology, and propose the use of the Re-represented Concept Map (RCM) in biology education. In Sect. 2 we provide the motivation for our work and situate it in the framework of science education studies. In Sect. 3 we briefly describe the relational ontology in biomedical domain (Open Biomedical Ontologies (OBO)) developed by the KR community and the Reference Set of semantically well-defined linking words in cell biology. In Sect. 4, we describe the method of content analysis with reference to three internationally known biology texts of increasing expertise level in the topic of cell biology. We then carry out the re-representation of the propositions using the

Reference Set of linking words. A Re-represented Concept Map (RCM) is illustrated. Section 5 is devoted to data analysis and results. We end with some remarks on the implications of the study in science education.

2 Motivation and Rationale for RCM

The motivation and rationale for RCM in science education derives from a number of considerations:

1. The Standard Concept Map (SCM) method is intended to organize knowledge in terms of concepts and their relations to promote meaningful learning. However, the linking words reflecting the connections in a SCM are generally an unconstrained set drawn from natural language. Since natural language is tolerant of semantic ambiguity, the SCM is vulnerable to the same. Thus disambiguation of linking words seems essential in mapping of knowledge.
2. Student difficulties of comprehending scientific texts arise as much from the imprecise and inappropriate use of grammar as from the unfriendly technical terms [14]. Since grammar resides in the connections between words, the difficulties may be regarded as relating essentially to the kinds of linking words used. Again this means linking words in a text need to be well-defined and unambiguous.
3. Linking words along with their characteristics of *connectedness*, *link quality*, and *link variety*, have been considered to be indicators of expertise. Experts not only use appropriate linking words, but also use a diversity of linking words. On the contrary, the links used by novices are often inappropriate, and the same linking words are used for various kinds of links resulting in ambiguity, and lack of clarity and precision in expression [15].
4. Re-representation (Representational Re-description) of knowledge from implicit to explicit form is now thought to be the hallmark of cognitive development. The explicit knowledge undergoes the successive phases of conscious, and conscious and verbal knowledge in natural language [16]. In this important theoretical perspective, expert scientific knowledge may be viewed as yet another re-representation of novice knowledge. Representations of expert's knowledge emerge over a period as a function of repetitive refinements [17]. In the context of concept mapping, this would entail making the linking words increasingly more precise and explicit.

These theoretical insights and empirical studies all point in the same direction, namely that we must use semantically precise linking words in a concept map. As our general domain of interest is biology, we turn to a major international effort to formalize the content and structure of this domain—the development of Open Biomedical Ontology (OBO) as part of KR. The KR research community is basically involved in re-representation of existing scientific knowledge in formalized ontologies of concepts and relations in different domains. Our work appropriates this massive resource for re-representing the linking words for concept mapping. The re-represented concept map (RCM) results in disambiguation and explicitization of meaning and can facilitate meaningful learning with rigor.

3 Additional Conventions for RCM and Reference Set of Linking Words

3.1 Additional Conventions for RCM

Recently, the conventions and specific criteria for constructing good standard concept maps have been reviewed [18]. The criteria are: to mention an explicit focus question, to avoid redundancy (i.e. not repeat the same concept in a map), use one or a few words for a concept, to use one or a few words for a linking phrase, not to use concept words on linking lines, to have hierarchical organization of concepts, to link three-four sub-concepts below a concept (branching), and to add cross-links as interrelationships between two sub-domains at the end.

We follow all the above conventions, and in addition suggest some more conventions focusing on the nature of linking words to be used in the propositions (see Table 1). It is important to mention that our proposed conventions are suggested to be supplementary to the existing conventions and not alternative or competing. These are informed by the guidelines suggested by Jonassen [19] for the words and phrases used for links in a semantic network: preciseness, succinctness, parsimony and consistency.

Borrowing from Wittgenstein's [20] definition, *"a proposition is either true or false"*, we suggest that concept map should express only propositions that can be decided to be true or false (semantic criterion). If the linking words are *prepositions* (*of, with, from, on,* etc.) the resulting relations between ideas form at best an expression and would not be qualified as *propositions*.

Whenever we use *'has/have'* as linking words we seek to replace them by explicating the intended meaning explicitly by the relation that actually holds between them (e.g. *'consists of', 'enveloped by'*, etc.). This additional constraint as a convention provides an opportunity for reflection and critical thinking, and weeds out ambiguity. Further, disambiguation requires us to replace lone uses of *'is/are'* with appropriate linking phrases (e.g. *'is/are divided into', 'is/are located in'*, etc.).

In addition to disambiguation, parsimony is considered to be a hallmark of expert articulation of knowledge. Thus for a given intended meaning, the same linking word should be used throughout. Thus if part-whole relation is intended, the same linking word *'consists of'* should be used.

Hierarchical organization of knowledge is another distinguishing characteristic of expert knowledge. While talking about the need for hierarchy in concept maps, Novak refers to Ausubel's notion of *subsumption*. In a concept map, relations used in a hierarchy are not necessarily logically transitive. The additional conventions for RCM facilitate identifying hierarchical relations that are logically transitive by simply looking at the repetition of a linking word. Thus RCM affords a new scoring measure for counting hierarchy.

Table 1. The proposed list of additional conventions for using re-represented linking words (RLWs).

Principles of mapping	Conventions
Propositions as unit of analysis	Linkage between the two concept terms should yield a proposition that can be decided to be either true or false
Disambiguation	Replace lone use of *'has', 'is/are',* etc. by the linking word that conveys the intended meaning explicitly
Parsimony	Use the same linking word for the same meaning in all parts of the map
Hierarchy	Count hierarchy levels only when the relations are transitive i.e. the same linking word is used

3.2 Reference Set

Although the semantic principles were laid down in 1960's [8], their wider use is being implemented in the growing interdisciplinary research area of Knowledge Representation (KR) which draws on computer science, linguistics and philosophy. KR in terms of vocabulary, glossaries, thesauri, taxonomy is thought to bear weaker semantics; while ontologies, databases, and formal languages involve stronger semantics.

An ontology defines terms referring to classes of objects, properties, events, processes and relations in every domain of reality. Domain experts define ontologies of a given domain that are logically well-formed and scientifically accurate. There is a collective of ontology developers that are committed to collaboration and adherence to the shared principles of KR. The integration of semantic web strategies into ontology development uses the formalized languages OWL/RDF [21]. A collection of ontologies related to anatomy, processes, events, for the domain of cell, gene, plant, mouse, fly, zebra fish, neuroscience, semantic science, etc. have been published at NCBO Bioportal [22]. An OBO Foundry (http://obofoundry.org/) hosts ontologies related to open biomedical ontologies.

To illustrate, definitions of two relations: *'part-of'* and *'located in',* are given by Relations Ontology (RO) group as follows [23]:

part_of =def. For continuants: C part_of C' if and only if: given any c that instantiates C at a time t, there is some c' such that c' instantiates C' at time t, and c *part_of* c' at t.

located_in =def. C located_in C' if and only if: given any c that instantiates C at a time t, there is some c' such that: c' instantiates C' at time t and c *located_in* c'.

For arriving at a Reference set of linking words for our study, we referred one such site called 'Ontobee'. This page lists the detailed information of Gene Ontology, annotations, and terms. In the third section, the list of linking words related to Gene Ontology can be viewed from 'Object Properties'. The linking words listed therein are: *'ends during', 'happens during', 'has part', 'negatively regulates', 'occurs in', 'part of', 'positively regulates', 'regulates', 'starts during'*. Out of these, we extracted the linking words relevant to mapping the domain of *'Cell Structure and Function'* in our study. A partial list of the selected linking words and the sources is shown in Table 2.

Table 2. Partial list of RLWs from the reference set.

Dimension	Linking words	Found in ontology	URL
Part-whole	Consists of/part of	Cell line ontology	http://www.ontobee.org/ontology/GO?iri=http://purl.obolibrary.org/obo/BFO_0000050
	Composed of	Relations ontology	http://www.ontobee.org/ontology/RO?iri=http://purl.obolibrary.org/obo/RO_0002473
Class inclusion	Classified into/divides into	*Subclass relation*	*Logic*
	Includes		
	Kind of/type of		
Spatial-inclusion	Attached to	Relations ontology	http://www.ontobee.org/ontology/RO?iri=http://purl.obolibrary.org/obo/RO_0002371
	Bound by/bound to	Foundational model of anatomy	http://www.ontobee.org/ontology/FMA?iri=http://purl.obolibrary.org/obo/fma%23bounds
	Contained in	Cell line ontology	http://www.ontobee.org/ontology/CLO?iri=http://www.obofoundry.org/ro/ro.owl%23contained_in
	Enclosed	Human phenotype ontology	http://www.ontobee.org/ontology/HP?iri=http://purl.obolibrary.org/obo/UBERON_0012467
	Envelopes	Gene ontology	http://www.ontobee.org/ontology/GO?iri=http://purl.obolibrary.org/obo/GO_0031975

(*Continued*)

Table 2. (*Continued*)

Dimension	Linking words	Found in ontology	URL
Function	Has function/helps/performs	Biological collections ontology	http://www.ontobee.org/ontology/BCO?iri=http://purl.obolibrary.org/obo/RO_0000085
	Has role/plays role	Biological collections ontology	http://www.ontobee.org/ontology/BCO?iri=http://purl.obolibrary.org/obo/BCO_0000058
Attribution	Has length	Phenotypic quality	http://www.ontobee.org/ontology/PATO?iri=http://purl.obolibrary.org/obo/PATO_0000122
	Has property/has characteristics/has nature	Physico-chemical methods and properties	http://www.ontobee.org/ontology/FIX?iri=http://purl.obolibrary.org/obo/FIX_0000481
Others	Similar to	Semantic science integrated ontology	http://www.ontobee.org/ontology/SIO?iri=http://semanticscience.org/resource/SIO_001156
	Proposed by	NIF gross anatomy	http://www.ontobee.org/ontology/NIF_GrossAnatomy?iri=http://www.w3.oorg/2004/02/skos/core%23related

The full Reference Set used in our study is available at: http://gnowledge.org/~meena/Ontology/reference-set.pdf. The dimension to each linking word in the Set is discussed in Sect. 4.

To summarize, the RCM is a re-representation of the standard concept map wherein the unconstrained set of linking words/phrases is replaced by a controlled vocabulary of a parsimonious set of unambiguous linking words drawn from the OBO of the KR community.

4 Research Question and Methodology

Having motivated the need for RCM, we pose the main research question of this study: Does the choice of linking words characterize expertise? To answer this question, we carry out a detailed qualitative content analysis of three biology texts at increasing levels of subject complexity. This involves the following steps:

1. *Content choice*. The study was based on the content of cell biology from three textbooks which are used in many countries for teaching biology at three different stages of college education: UG-1 [24], UG-2 [25], and UG-3 [26]. As the text books under consideration are very detailed, it would have been difficult to analyze the entire topic of cell biology. Therefore, for the analysis, we focused on just two topics: *'Mitochondria'* and *'Nucleus'*. Only text passages were extracted from the books, excluding activities, questions, exercises and pictures.
2. *Paraphrasing*. Each passage on a topic comprises a number of sentences, simple and complex/compound. The latter kind can be equivalently written as two or more simple sentences. Each simple sentence is paraphrased in the form of concept–linking word–concept (C-LW-C) proposition(s). A simple sentence can yield a number of propositions. Thus a given passage is converted into a large number of propositions. These propositions when represented graphically constitute the standard concept map (SCM). This method of paraphrasing is similar to that of translating online content into basic propositions, as, for example, adopted in creating Medical WordNet from WordNet database [27].
3. *Re-representing*. The verbatim set of linking words in the extracted propositions from the texts are replaced by the controlled vocabulary of linking words from the Reference Set discussed in Sect. 3. This process is not as mechanical as it might seem. It involves the following steps:

Informed by the classic work of Winston et al. [28] we assign to each linking word of the Reference Set a dimension from the following list: *part-whole, class inclusion, spatial inclusion, function and attribution*. See Table 2.

We next look at the role of the original linking word and see if it is a *structure-structure, class-subclass, structure-region, structure-process, and structure-property relation*. This requires some domain familiarity. We then identify the appropriate linking word of the relevant dimension from the Reference Set and replace the original linking word by it. In case the original proposition already uses the linking word from the Reference Set, it remains as it is. Note that the concept names and terms are not changed in re-representation. The re-represented propositions when displayed graphically constitute the RCM. Figure 1 schematically shows the procedure of paraphrasing and re-representing. Table 3 gives re-represented propositions of a sample text passage at UG-3 level. Figure 2 gives the corresponding SCM and RCM for the sample text.

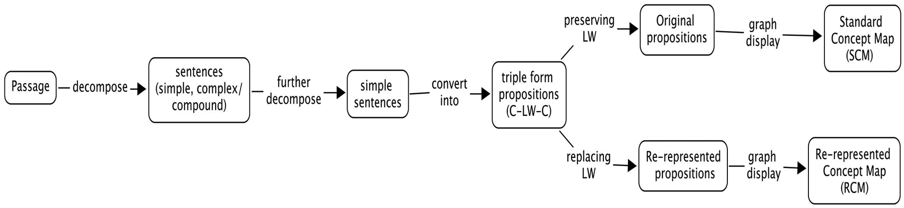

Fig. 1. The procedures involved in content analysis.

Table 3. Example of re-represented propositions of a sample text.

Verbatim sentences	Paraphrased propositions (SCM)	Re-represented propositions (RCM)
• Mitochondria has atleast two membranes separating the innermost space from the cytosol	• Mitochondria *have* two membranes • Two membranes *separate* the innermost space from cytosol	• Mitochondria *consists of* two membranes • Two membranes *have role in* separting the innermost space from cytosol
• Their membrane proteins are made not by ER, but by free ribosomes in the cytosol and by free ribosomes contained within the organelles themselves	• Membrane proteins *not made by* ER • Membrane proteins *made by* free ribosomes • Free ribosomes *in* cytosol • Ribosomes *contained in* organelles	• Membrane proteins *not synthesized by* ER • Membrane proteins *synthesized by* free ribosomes • Free ribosomes *located in* cytosol • Ribosomes *contained in* organelles
• These organelles have ribosomes, also contain a small amount of DNA	• Mitochondria *have* ribosomes • Mitochondria *contain* small amount of DNA	• Mitochondria *consists of* ribosomes • Mitochondria *contain* small amount of DNA
• Mitochondria are semi-autonomous organelles that grow and reproduce within the cell	• Mitochondria *are* semi-autonomous organelles • Semi-autonomous organelles *grow, reproduce* within cell	• Mitochondria *are kind of* semi-autonomous organelles • Semi-autonomous organelles *has property* to grow, reproduce within cell
• Some cells have a single large mitochondrion, but more often a cell has hundreds or thousands mitochondria	• Some cells *have* a single large mitochondrion • More often cell *has* hundreds or thousands mitochondria	• Some cells *consists of* single large mitochondrion • More often cell *consists of* hundreds or thousands mitochondria

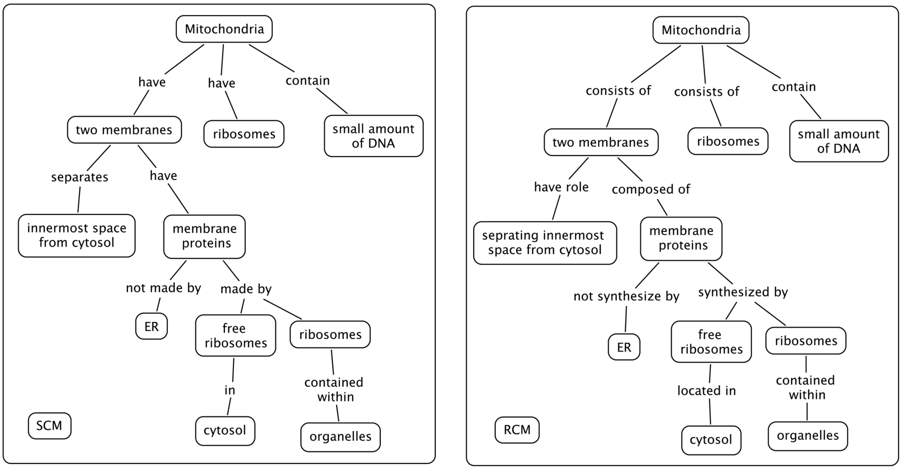

Fig. 2. An example of SCM and RCM on the topic of mitochondria.

5 Data Analysis and Results

We return to our research question on the connection between expertise and the choice of linking words. In the analysis of college textbooks, the topics on *'Mitochondria'* and '*Nucleus'* were considered as the units of analysis. Table 4 shows the linking words used and their frequencies of usage for the topics from all the three textbooks, and their classification on the basis of their semantic dimension. The frequency of each linking word indicates wider and greater use of a specific linking word in the text. For example, the linking words, '*consists of'*, *'made of'*, *'contains'*, *'enclosed by'*, *'has function'* are most widely and repeatedly used.

Table 4. List of linking words used by college textbooks at UG-1, UG-2, UG-3 levels for the topics of *'Mitochondria'* and *'Nucleus'*. The frequencies of each linking word is indicated in the parentheses.

Dimension	Linking words UG-1	Linking words UG-2	Linking words UG-3
Part-whole	Composed of (1), exists (1), in form of (1), may be present in (1), not consists of (1), perforated by (1)	Consists of (9), is perforated by (1), made of (5)	Composed of (1), consists of (5), is associated with (1), is interrupted by (1), present/seen in (3)
Class-inclusion	Includes (1), kind of (1), type of (2)	Divides into (1), includes (1), kind of (2), type of (1)	Divides into (1), includes (1), type of (1)

(*Continued*)

Table 4. (*Continued*)

Dimension	Linking words UG-1	Linking words UG-2	Linking words UG-3
Spatial-inclusion	Bound to (1), contains (11), covered with (1), is continuous with (1), located inside (1), occur near (1), packed in (1), surrounded by (2), wound around (1),	Are continuous (1), contain (6), enclosed by (5), exit through (1), extends through (1), is lined by (2), is organized (1), separated by (2), located (3), occurs in (1),	Aligned (1), attached to (4), contains (10), continuous (1), encloses (1), located between/are situated between (2), occupied (1), packed in (1), projects into (1), separated by (2), surrounded by (3), is traversed by (1)
Function	Are sites of (3), formed by (1), has function (6)	Are sites for (2), has function (11), play role (1), synthesized by (1),	Is site for (1)
Attribution	Has diameter (1), has form (1), has length (1), has property (1), has shape (1), has size (1)	Appears as (1), has form (3), has length (1), has nature (3), has number (2), has property (2), has size (1)	Has form (1), has nature (3), has shape (1), has size (1)
Others	Called (5), means (1)	Called (1)	Called (1)

An overall summary of results from the content analysis is provided in Table 5.

Table 5. Summary of results of content analysis of college textbooks.

	College textbooks		
	UG-1	UG-2	UG-3
Sentences	32	49	45
Propositions	60	72	53
Concepts	63	74	80
Linking Words (LW)	30	35	29
LWs match with reference set	25	30	26
Required re-representation	5	5	3
Re-represented Linking Words (RLW)	29	33	26
Proximity (%) with reference set	83	86	90

Figure 3 depicts part of the data in Table 5 concerning the number of concepts, linking words and re-represented linking words in the sample text at different levels.

Two noteworthy features emerge from the data:

(i) As the subject complexity increases from UG-1 to UG-2 to UG-3, the number of concepts increases, but there is no significant change in the number of linking words or the number of re-represented linking words. Thus the number of RLWs (which is only slightly less than the number of LWs) seems to show the property of *saturation*. This property was seen even more markedly in our earlier study of school level texts for the entire topic of cell biology [29].

(ii) The proximity index is calculated as the number of common linking words between the LWs and RLWs divided by the number of LWs for a topic. The *proximity* (or overlap) of the LWs in the college texts with the RLWs of the Reference Set increases with UG level 1 to 3. The increase is not dramatic since the UG-1 level text already has excellent proximity (83 %). This trend is more apparent when the same analysis is carried out for school texts where the proximity is found to be only about 50 %. The implication of this finding is clear: proximity of linking words used in a text with those of the Reference Set correlates with expertise.

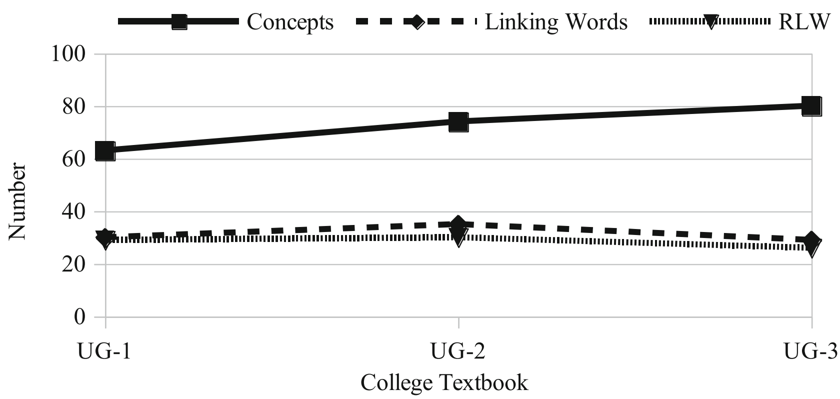

Fig. 3. Graph depicting the results, showing the proximty of linking words to Reference Set of linking words.

6 Concluding Remarks

In this work, we follow the semantic web principles and ontology based research to obtain a Reference Set of semantically well-defined linking words in the domain of biology. To enable us to choose the appropriate linking word from this set in a proposition, each linking word is assigned a semantic dimension: part-whole, class-inclusion, spatial inclusion, function and attribution. Using the Reference Set, we obtain the RCMs of the topics of '*Mitochondria*' and '*Nucleus*' appearing in three well-known college texts at UG-1, UG-2 and UG-3 levels. The qualitative data thus obtained show two clear features: saturation of the number of linking words used, and increasing proximity of linking words with those in the Reference Set as we go to higher levels of subject complexity.

Generating an RCM involves an iteration of representational re-descriptions: (i) sentences to C-LW-C propositions and (ii) C-LW-C to C-RLW-C propositions. Iterative representational re-descriptions of knowledge, according to Karmiloff-smith's [16] model referred to earlier, helps make implicit knowledge explicit and underlies the novice-expert transition. The proximity of RCM with expert knowledge suggests that the process of achieving expertise entails acquiring re-represented linking words, if only unknowingly, in the attempt to express clearly and economically. Turning the argument around, an explicit use of RCM can aid novice-expert transition. It is then plausible that the method of RCM which imitates the same process consciously may aid in cultivating expert-like thinking.

Some characteristics of expert knowledge are already well-known: hierarchically and tightly organized coherent structure of concepts and their relations. Meaning in the Ausebelian sense derives from this structure and this is what motivated the concept map technique. Higher level of expertise needs the additional notion of rigour for its characterization. Now we cannot have one model of meaning and another for rigour. Rigor may be best viewed as repetitive disambiguation of meaning and that is precisely the objective of RCM. In other words, the SCM gives meaning to knowledge and RCM adds rigour to it [30].

The implications of the work for science education are then clear. Concept maps have been widely used as an instructional strategy to facilitate novice-expert transition. The use of RCM for the purpose involves just one modification of the strategy. We provide the set of RLWs to students when generating concept maps. When the set is provided, the learners can carefully choose which linking word to use for depicting the dimension of the relation in question. The learner's focus is to choose the linking word that leads to a meaningful and unambiguous proposition, thus enhancing rigour of the representation.

Yin et al. [12] referred earlier have shown that providing linking words in concept mapping was effective in scoring concept maps with high inter-rater reliability. Providing RLWs during mapping can be similarly useful for reliable scoring on a large scale. Lastly, as we found in an earlier study [31], generating RCM is a perfectly feasible exercise even at the school level since the vocabulary for linking words, though controlled, consists of simple non-technical words of everyday natural language.

To conclude, the RCM method, motivated as it is by a convergence of several theoretical perspectives, is equally a practical modification of the existing SCM method for learning and assessment. Its effectiveness for achieving learning goals is, however, yet to be ascertained empirically on a large scale.

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