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TWO STRATEGIES FOR ENCOURAGING FUNCTIONAL RELATIONSHIPS IN CONCEPT MAPS

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Abstract. Two strategies for encouraging formation of dynamic relationships in Concept Maps (CMaps) are discussed and tested, namely concept quantification and a dynamic focus question of the map. Two experiments were conducted to examine the effects of these two approaches on dynamic thinking during the CMap construction task. The first experiment examined the impact of the quantification of the root concept in the map. The second experiment explored the effect of the focus question of the map. For both experiments, the content of CMaps was assessed for the number of dynamic propositions and the number of quantified concepts. The results showed that the quantification of the root concept and the dynamic focus question "how" significantly increased dynamic thinking. In addition, the focus question affected the selection of concepts used in the maps and how those concepts were used. The studies, the theoretical background, and the implications of the findings are discussed.

1 Introduction

The fundamental component of a Concept Map (CMap) is a proposition, which consists of two concepts and their relationship (Novak 1998; Novak & Gowin, 1984). We have argued that dynamic thinking reflects a proposition that captures and represents a functional interdependency between two concepts. In contrast, a proposition that represents the relative position of the two concepts in the hierarchy of meaning constitutes static thinking (Safayeni, Derbentseva, & Cañas, 2005).

Given that dynamic thinking is an essential aspect of scientific reasoning, the question arises as to how it can be encouraged within the context of concept mapping. Earlier, we showed that Cyclic CMap (where concepts feed into one another in a closed loop) promoted dynamic thinking during a map construction task (Derbentseva, Safayeni, & Cañas, 2004). In this paper we demonstrate that there are additional two ways of creating situations where dynamic thinking is more likely to occur.

First, we set to retest the effect of root concept quantification on the dynamic nature of propositions in maps suggested by Safayeni et al. (2005) and initially tested by Derbentseva et al. (2004). The basic underlying idea was that if the root concept in a map was quantified, the probability of dynamic thinking would increase.

Second, we hypothesized that dynamic thinking can be encouraged, if the focus question of the CMap requires it, because the map is supposed to answer the focus question. The basic idea was that some questions are better answered by dynamic thinking, whereas other questions might require static thinking.

The body of research investigating CMaps is primarily focused on the tool's application in education and its usage in the knowledge management area. In educational setting, CMaps have been applied as knowledge organizers during learning of new material (e.g. Daley, 2004; Markow & Lonning, 1998; Edmondson, 1995; Hall, Dansereau, & Skaggs, 1992) and as an assessment tool for the evaluation of students' knowledge (e.g. Williams, 1998; 2003; Ali & Ismail, 2004) with some reservations (e.g., Ruiz-Primo, 2004, Ruiz-Primo & Shavelson, 1996).

The use of CMaps in capturing knowledge of experts was reported by Coffey, Eskridge & Sanchez (2004) and Ford et al. (1996). Coffey et al. (2003) reported on a performance support system based on CMaps. Hoffman, Coffey, Carnot, and Novak (2002) and Zanting, Verloop, and Vermunt (2003) have empirically demonstrated the effectiveness of using concept mapping as part of a methodology for eliciting expertise.

Most of the studies conducted on the subject of CMaps have been concerned with the practical application of the tool usually reporting positive results. This paper closely follows our previous work on examining CMap's capability of encouraging and representing functional interdependence among concepts. We experimentally demonstrate the validity of the root concept quantification approach to stimulating dynamic thinking in concept mapping that was theoretically suggested earlier (Safayeni et al., 2005) but had not been verified empirically.

Furthermore, the effects of an additional new strategy of changing the focus question of a map from "what" to "how" on dynamic thinking are empirically evaluated.

2 Theoretical Argument and Experimental Hypotheses

A CMap is a knowledge representation tool that is designed to identify and represent relationships between different concepts in a domain. Safayeni et al (2005) suggested that it is important for CMaps to be able to encourage and represent not only concepts' hierarchical interconnections or static relationships, but also their functional interdependencies or dynamic relationships. The static relationships between concepts help to describe, define, and organize knowledge for a given domain. Classifications and hierarchies are usually captured in relationships that have a static nature and indicate belongingness, composition, and categorization. The dynamic relationship between two concepts reflects and emphasizes the propagation of change in the concepts. It shows how change in *quantity*, *quality*, or *state* in one concept causes change in *quantity*, *quality*, or *state* of the other concept in a proposition.

Consider, for example, the relationship between the concepts "Concept Maps" and "Effective Teaching." A static relationship between these two concepts may be "CMap is a useful tool for effective teaching," and a dynamic relationship may be "Improvement in the quality of a CMap may lead to more effective teaching." Whereas the static relationship identifies the importance of CMaps for teaching, the dynamic relationship points to the interdependence among these concepts, particularly as they change. For a more elaborate discussion on static and dynamic relationships, see Safayeni et al. (2005).

Previous investigation has indicated that the vast majority of CMaps' propositions represent static rather than dynamic relationships (Safayeni et al. 2005). It is important to recognize that static conceptual relationships are for describing and organizing a significant part of our knowledge, and existing forms of CMaps are a useful tool for such representations. However, it is important to investigate how CMaps can be extended to represent dynamic relationships. Safayeni et al. (2005) presented a theoretical argument stating that enforcing a cyclic structure on CMaps and also quantifying the root concept in a map will encourage representation of functional relationships between concepts and stimulate dynamic thinking. Derbentseva et al. (2004) provided an empirical support for the effect of the cyclic structure; however the support for the effect of the root concept quantification was not found. Below, we report two experiments. The first one was designed to test the root concept quantification effect on dynamic thinking in concept mapping when quantification was made more explicit. The second experiment examined the effects of changing the focus question of the map on dynamic thinking.

2.1 Encouraging dynamic thinking: "Quantifying" the concepts.

Safayeni et al. (2005) suggested that quantification of the root concept in a map makes the concept more dynamic, and could lead to the construction of more dynamic propositions. Quantification of the root concept makes the concept significantly more specific and draws attention to the particular property of the concept that can change. Quantification of the root concept refers to adding a quantifier to the concept itself. For instance, concept "soil" might be quantified by adding a quantifier "quantity" or "quality," making the concept into "quantity of soil" or "quality of soil," as opposed to simply "soil." The addition of the quantifier sets the concept "in motion" and allows it to vary along the specified dimension. In other words, quantification of a concept makes the concept dynamic as opposed to a static category such as "soil."

Thinking about the root concept that is changing is anticipated to stimulate dynamic thinking and raise 'what-if' questions that will affect the selection of other concepts for the map. These concepts most likely will be selected on the basis of the degree to which they affect, or are affected by, the change in the property of the quantified root concept. The specific hypotheses tested in Experiment 1 are that (Hypothesis 1a) quantification of the root concept in the CMap will increase the quantification of the other concepts compared to the non-quantification condition, and (Hypothesis 1b) quantification of the root concept in the CMap will result in more dynamic propositions compared to the non-quantification condition. Derbentseva et al. (2004) attempted to test these two hypotheses and failed to experimentally demonstrate the effects. The difficulties that authors ran into were attributed to the ambiguity of the selected stimuli for their study. Thus, we made another attempt at testing these hypotheses with more specific and less ambiguous stimuli.

2.2 *Encouraging dynamic thinking: Formulating a focus question.*

When a CMap is constructed, it is done so with a particular purpose in mind. More precisely, the map is constructed for a certain audience, and to answer a specific question, called the focus question (Novak, 1998; Novak & Gowin, 1984). The focus question is a vital piece of information for any given map because it explicitly defines the question the map is designed to answer, as opposed to all possible questions. Nevertheless, focus questions are often omitted and are not recorded anywhere in the CMaps (A. J. Cañas, personal communication, July 15, 2004; J. D. Novak, personal communication, August 21, 2004).

Most maps seem to answer a question of “What is ‘concept X’?” Such a question necessitates a description of concept X. The description of a concept mainly consists of identifying the concept’s components or parts (e.g., plant has roots, stem, leaves, may have flowers, etc.), and by specifying the categories to which the concept belongs (e.g., plant is a living organism, or bear is a mammal). Uses or functions of the concept can also be specified in the process of describing the concept (e.g., plants are used as food and medicine), which would also place the concept in more specific categories (e.g., plants are food and drugs). Such a description is most likely to be static, because it identifies what the concept is, but not how the concept may change. That is, it is unlikely to include functional interrelationships among the concepts. However, if the question is posed differently, it might prompt dynamic thinking. Questions such as “What happens when the ‘concept X’ changes?”, or “How does the ‘concept X’ work?” require one to think about change in the concepts and how they affect each other. That is, the focus question has a direct effect on the nature of the propositions in the map. We hypothesised that process-oriented focus questions will tend to be answered by reference to dynamic properties and interdependencies of the concepts. More specifically, the hypothesis tested in Experiment 2 (Hypothesis 2) is that the map constructed to answer the question “How does X work?” will tend to be more dynamic than the map that answers the question “What is X?”

3 Experiment 1

Experiment 1 was designed to test the effect of root concept quantification on the dynamic nature of constructed propositions and quantification of selected concepts.

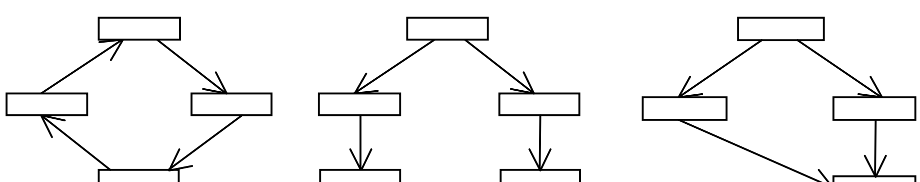
3.1 *Method*

3.1.1 Subjects.

Seventy five undergraduate university students participated in the experiment. All subjects were enrolled in the same course and were offered a partial credit toward their course mark for their involvement in the study.

3.1.2 Stimuli selection

To allow for the comparison of the results to the non-quantification condition and to examine any inter-structural differences, the same structure prototypes as in Derbentseva et al. (2004) were used in Experiment 1 (Figure 1). Each structure prototype contained a root concept “As the number of plants increases,” whereas all other boxes and arrows were left blank. Such root concept was selected to reduce the ambiguity in its meaning and make quantification more explicit. In the non-quantification condition the root concept in the structures was “plant.”



a) Cyclic structure prototype b) Hierarchical tree structure prototype c) Hierarchical cross-link structure prototype

Figure 1: Prototypes of a) cyclic structure, b) hierarchical tree structure, and c) hierarchical cross-link structure

3.1.3 Procedure

The subjects were asked to fill out concepts and linking phrases in one of the three structure prototypes provided to them. There were three experimental conditions based on the three structure prototypes described in the stimulus section. Participants were assigned randomly to the conditions.

3.1.4 Measures

Each CMap constructed by the subjects was analyzed and assigned two different scores; (a) the concept quantification score, reflecting the percentage of quantified concepts in the map, and (b) the dynamic score, reflecting the percentage of dynamic propositions in the map.

The concept quantification score for a given map was assigned based on the percentage of quantified concepts in the map, excluding the root concept. The concept was considered quantified if a quantifier was added to the concept. For example, concepts such as “rate of plant maturation,” “number of flowers,” and “growth of more plants” were scored as quantified, but not the concepts such as “roots,” “soil,” and “leafs.”

A dynamic score was computed for each map as a proportion of dynamic propositions in the map. Each map was analysed as a set of four independent propositions consisting of two concepts and a linking phrase between them. A list of 300 propositions was constructed. Each proposition was evaluated independently as to whether it reflected a dynamic relationship between the concepts. For example, a proposition “as the number of plats increases it leads to an increase in the process of photosynthesis” was classified as dynamic, and a proposition such as “plant has leafs” was classified as static.

3.2 Results and Discussion

The average scores for the two measures are presented in Table 1 for both, quantified condition (Experiment 1) and non-quantified condition (Derbentseva et al., 2004).

Condition for the root concept	Cyclic structure		Cross-Link structure		Tree structure	
	Concept Quant. Score	Dynamic score	Concept Quant. Score	Dynamic score	Concept Quant. Score	Dynamic score
Quantified	88.0%	93.5%	88.0%	95.0%	87.0%	92.0%
Non-Quantified	0.0%	45.4%	2.6%	21.1%	2.8%	13.54%

Table 1: Average values of the concept quantification and map dynamic scores for the three structure prototypes in both conditions.

Concept quantification scores and map dynamic scores of the quantification condition were compared to the concept quantification scores and map dynamic scores of the non-quantification condition between corresponding structures. The Wilcoxon-Mann-Whitney test results showed significant differences between quantified and non-quantified conditions of the same structure for all three structure prototypes and for both measures ($p < 0.001$).

The statistical analysis of the concept quantification scores provides strong support for Hypotheses 1a. For all three structure prototypes, the number of quantified concepts in maps dramatically increased in the quantification condition. The results of a Kruskal-Wallis test showed that there was no significant difference in the concept quantification scores among the three structures in the quantification condition ($\chi^2 = 0.06$, $p = 0.97$). This indicates that quantification of the root concept, regardless of the map’s structure, significantly increases the likelihood of quantifying the other concepts in the map.

The statistical analysis of the dynamic scores provides strong support for Hypothesis 1b. The dynamic scores significantly increased in all three structure prototypes, compared to the non-quantification condition. Although significant differences in the dynamic scores between structures were observed in the non-quantification condition, there were no significant differences among the structures in the quantified conditions ($\chi^2 = 0.94$, $p = 0.95$). These results suggest that concept quantification can override structural differences, at least with respect to the proportion of dynamic propositions.

Although, the cyclic structure generated more dynamic propositions than the other two structures in the non-quantified condition, the tree and the cross-link structures with the quantified root concept produced significantly more dynamic propositions than the cyclic structure with the non-quantified root concept (Z = -5.27, $p < 0.001$ and Z = - 5.690, $p < 0.001$ for the tree and the cross-link comparisons, respectively). The results of this experiment demonstrated that concept quantification is a very powerful technique for encouraging dynamic thinking in CMaps - more powerful than the cyclic structure alone.

4 Experiment 2

Experiment 2 was designed to examine the effect of the focus question on the content of CMaps, and to test the second hypothesis.

4.1 Method

4.1.1 Subjects

Eighty one undergraduate university students participated in the experiment. All subjects were enrolled in the same course and were offered a partial credit toward their course mark for their involvement in the study.

4.1.2 Stimuli selection

The stimulus for this experiment was a structure with six unconnected boxes arranged in a circle. Only the top box had a concept, "cars," written in it, and the remaining boxes were empty to be filled out and connected by subjects answering a given focus question. The stimulus is presented in Figure 2.

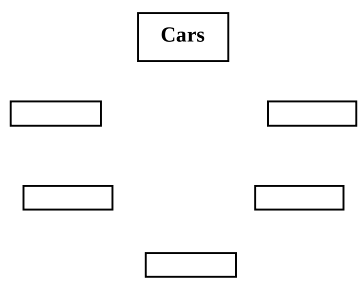


Figure 2: Stimulus used in experiment 2.

4.1.3 Procedure

The subjects were assigned randomly to the two conditions in this experiment - one for each focus question. The two focus questions were "What is a car?" and "How does a car work?" All other instructions and materials were the same for the two conditions. Participants were asked to answer one of the two focus questions by filling out the structure (Figure 2) with relevant concepts and linking phrases.

4.1.4 Measures

Similar to the first experiment, the maps were assigned the concept quantification scores and the map dynamic scores based, respectively, on the proportion of quantified concepts and the proportion of dynamic propositions in each map. The procedure for assigning the scores was the same as described in Experiment 1.

4.2 Results and Discussion

The maps in the "How" question condition generated significantly more dynamic propositions than the maps in the "what" question condition. The average map dynamic scores for the "What" and "How" question conditions were 21.0% and 55.0% respectively (Z = -4.84, $p < 0.001$). This result provided a strong support for Hypothesis 2.

There were no significant differences for the concept quantification scores of the two conditions. The average concept quantification scores for the "What" and "How" question conditions were 2.5% (STD = 0.08) and 1.0% (STD = 0.04) respectively ($Z = -0.89$, $p = 0.37$). That is, the focus question influenced the dynamic score of the map, but had little impact on the quantification of the concepts.

Comparison of the data of Experiment 2 with the non-quantified condition from Table 1 showed that the dynamic question "how" condition and the cyclic structure with no quantification produced similar results on both measures. That is, the cyclic map structure and the dynamic focus question made the relationships between concepts more dynamic, but did not quantify the concepts.

Furthermore, the dynamic focus question condition resulted in more dynamic maps than either the cross-link or the tree structures in the non-quantified condition. This effect is particularly interesting because it emphasizes the significance of the focus question. One may think of the two structures, the tree and the cross-link, as representing the "usual" way of concept mapping, which resulted in minimal dynamic thinking. In contrast, posing the dynamic question "how," without any structural constraints, significantly increased the number of dynamic propositions.

4.2.1 Additional findings

The root concept "Cars" was used significantly more often in propositions in the "What" question condition (average of 59.5%) than in the "How" question condition (average of 44.5%). The frequency of usage of the concept "Cars" in the two experimental conditions indicates that the root concept was more central in answering the "What" question rather than the "How" question ($Z = -2.99$, $p = 0.003$). Fairly low proportion of propositions starting with the root concept were dynamic (13% in the "What" maps and 18% in the "How" maps) with no significant difference between the two conditions ($Z = -0.877$, $p = 0.381$). However, 81% of the propositions that ended with the root concept were dynamic in the "How" maps, while only 17% of such propositions were dynamic in the "What" maps. It is also worth noting that in the "How" question condition propositions ended with the root concept significantly more often than in the "What" question condition ($Z = -2.863$, $p = 0.004$) which might be an indication of "How" maps being less hierarchical (with more "up-flows") than "What" maps.

Analysis of the concepts from the maps in the two conditions revealed that the sets of concepts differed to some extent. Table 2 summarizes the observed frequencies of some of the concepts for each of the two conditions.

Concepts unique to one of the conditions	% of maps in "How" question condition	% of maps in "What" question condition	Concepts used in both conditions	% of maps in "How" question condition	% of maps in "What" question condition
Transportation	0%	50%	People	2%	30%
Keys	37%	0%	Steering	27%	5%
Shape/color	0%	28%	Energy	83%	35%
Travel	0%	25%	Engine	73%	50%
Ignition	20%	0%	Wheels	37%	40%

Table 2: Frequency of concepts in the maps of the two conditions in Experiment 2

Table 2 shows that some concepts were unique to only one condition (e.g. "transportation" and "keys") while other concept were used in both conditions, some with different frequencies (e.g. "people" and "energy") and others with relatively similar frequencies (e.g. "wheels" and "engine").The differences can only be explained by the difference in the focus questions, because everything else was the same The data in Table 2 suggest that some concepts were more appropriate to answer one question than the other. For example, to answer the question "What is a car?", it would seem reasonable to place the concept "car" into a super-ordinate category of "transportation," whereas to answer the question "How does a car work?", a reference to a category of "transportation" is not helpful. The concept "wheels" is particularly interesting case since it appeared with fairly same frequency in both conditions; there was no difference in the number of propositions constructed with this concept between the conditions ($Z = -0.385$, $p = 0.707$). Similarly, there was no difference in the location of this concept in the propositions (i.e. being in the beginning of a proposition ($Z = -0.106$, $p = 0.935$) or in the end of a proposition ($Z = -0.084$, $p = 0.935$)).

However, the propositions constructed with the concept “wheels” were significantly more often dynamic in the “How” question condition than in the “What” question condition ($Z = -3.416$, $p = 0.001$). This analysis suggests that even when the same concept with the same frequency is used to answer a different focus question, it is used differently. A typical proposition with the concept “wheels” in a “What” question map was “Cars have wheels,” and in a “How” question map “Wheels move cars.” Needless to say that concepts with different frequencies are also used differently, that is, constructing more dynamic propositions in the “How” condition.

The difference in the selection of concepts and their meanings depending on the question to be answered might seem intuitively obvious; however, the focus question in concept mapping has often been omitted or unintentionally replaced with a “what” type question. Given the important role of the focus question in the selection of concepts, the concept mapping community should pay much more attention to the focus question. It is worth pointing out that Novak and Gowin (1984) recognized the importance of the focus question, and thus, one may wonder why the focus question has so often been ignored.

5 Conclusion

The research in this paper was based on the premise that knowledge can be viewed as having both a dynamic and a static components. The typical applications of CMaps have concentrated on the static dimension. Although, the static representation provides a useful means of organizing knowledge and noting significant relationships, both static and dynamic relationships are necessary for adequate representation of knowledge.

Two experiments were designed to test the effects of root concept quantification and formulation of a dynamic focus question on dynamic thinking and representation in CMaps.

A comparison of the results from the two experiments reported here and that reported by Derbentseva et al. (2004) suggests that both the cyclic map structure and the focus question “how” increase the number of dynamic propositions without increasing the concept quantification score. On the other hand, the concept quantification condition provided the strongest effect not only on concept quantification scores, but also on the number of dynamic propositions. For both scores, this effect was stronger than the cyclic structure with no quantification, or the dynamic focus question “how.” One possible explanation of this effect is that concept quantification acts as a constraint on an individual and forces them to construct dynamic propositions with another quantified concept. This constraint is so powerful that it is hard to imagine how a proposition can be completed without making it dynamic.

The quantification of the root concept in Experiment 1 is an extreme version of the idea of concept quantification. The concept was not only quantified, but it was set in motion: a dimension was specified (“number of plants”) and the direction of change was indicated (“as the number of plants increases”). It is worth pointing out that, studies reported by Derbentseva et al. (2004) that only quantified the concept, without setting it in motion, did not produce any effect. The extent of concept quantification is an area that merits further investigation.

The results of the reported studies should be treated with caution. This is primarily because the measure of the dynamic score of a map was based on scoring each proposition independently, and thus other properties of the map were not captured. CMaps most likely have other properties related to dynamic thinking that were not picked up by our measures.

There are several practical implications from this study. First, there are, at least, three ways in which dynamic thinking can be encouraged. Second, concept quantification may be the most robust way of encouraging dynamic thinking. Third, the practitioner should pay close attention to the focus question; it not only influences the selection of the concepts, but also their relationship to each other. Still, more research is needed to improve the dynamic measure of a map as a system, and to develop an overall measure of the degree of unity and interdependence of concepts in a CMap.

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