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EXPERIMENTS ON THE EFFECTS OF MAP STRUCTURE AND CONCEPT QUANTIFICATION DURING CONCEPT MAP CONSTRUCTION

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Abstract. Two experiments were conducted. The first experiment compared cyclic and hierarchical concept maps, and measured the impact of concept quantification on the construction of both types of maps. The second experiment examined the preference for the two concept map structures. The results showed that structure does have a significant effect on the extent to which propositions imply a dynamic relationship. However, the quantification of the starting concept did not increase the number of dynamic propositions in any of the structures. The second experiment indicated a preference for a cyclic concept map, primarily for structural reasons. The studies, the theoretical background, and the implications of the findings are discussed.

1 Introduction

Most of the studies conducted on the subject of Concept Maps (CMaps) have been concerned with the practical application of the tool rather than its evaluation. The aim of this research is to investigate the tool itself and provide a better understanding of the capabilities and limitations of CMaps.

The basic premise of concept maps has been the representation of knowledge in a hierarchical form. Some researchers have questioned the hierarchical structure as the only means of linking concepts together (Ruiz-Primo & Shavelson, 1996). For example, one suggestion has been that the structure of the map should follow the structure of the knowledge and not the other way around.

We propose (see theoretical section) that the structure of the map influences the type of relationships that are likely to be constructed in a proposition that links two concepts together. The prediction is that the Cyclic CMap (where concepts feed into one another in a closed loop), rather than a hierarchical structure, is more likely to generate dynamic propositions. Further, it is hypothesized that the expression of concepts in a more quantified form will also increase the probability of dynamic propositions. It is reasoned that using a quantified concept such as "number of cars," instead of the concept "cars," is more likely to lead to another quantified concept like "number of accidents." The attempt to link them may increase the likelihood of propositions that account for the relationship between the two constructs as one of them changes. Finally, it is predicted that a Cyclic CMap will be preferred to a hierarchical CMap structure.

This paper begins with a review of the literature on Cmaps. The theoretical arguments and the experimental hypotheses are then presented, followed by a description of the methodology and results of the experiment. Finally, the hypotheses are discussed and the conclusions of the study are presented.

2 Concept Map Research

A CMap (Novak & Gowin, 1984; Novak, 1998) represents a collection of interconnected concepts with specified relationships between pairs of concepts identified on the links connecting them. The nodes and their relationships are organized in a certain structure in a CMap. Initially, the hierarchical structure in concept mapping was strongly encouraged (Novak, 1998). However, this inclination was questioned by Ruiz-Primo and Shavelson (1996) and Hibberd, Jones, and Morris (2002), among others. Several types of structures have been discussed such as hierarchy, chain, spider-maps, and networks that could be closer to the actual mental representation of the knowledge embedded in one's long-term memory. Safayeni, Derbentseva, and Cañas (2003) argued that a CMap with a cyclic structure encourages representation of dynamic relationships between concepts and stimulates systems thinking. There is no strong agreement among researchers on the type of structure a CMap should have, although it has been acknowledged that the structure of a map should suit the content.

Research on CMaps has been done mainly in the context of the tool's application in education and its usage in the knowledge management area. For example, Edmondson (1995) discussed the positive effect of the use of CMaps in the development of a problem-based veterinary curriculum. Willerman and MacHarg (1991) examined the use of CMaps as an “advance organizer” for eighth-grade students in a science unit. They reported significant differences in performance of a CMap group at the end of the unit over a control group that did not use CMaps. Soyibo (1995) described the use of concept mapping to identify differences in the presentation of the topic of respiration in six biology textbooks. The author suggested that the analysis of CMaps is an appropriate way of comparing the textbooks. Markow and Lonning (1998) tested the effect of CMap construction in college chemistry laboratories. They reported that students had a strong positive attitude toward the use of Cmaps, despite the lack of difference in performance on multiple choice assessment tests between the experimental and control groups.

CMaps have also been used to capture the knowledge of experts. For example, Ford et al. (1991) described the knowledge acquisition tool ICONKAT that uses CMaps along with Kelly’s (1955) repertory grid to elicit knowledge from experts. Ford et al. (1996) described a nuclear cardiology expert system, NUCES, in which a system of CMaps created during the knowledge elicitation stage is also used as the navigation system for its explanation component. Coffey et al. (2003) reported on a performance support system with embedded training for electronic technicians based on CMaps. Hoffman et al. (2002) empirically demonstrated the effectiveness of using concept mapping as part of a methodology for eliciting expertise.

The use of CMaps for evaluation of students’ knowledge has been reported by many researchers. For example, Williams (1998) and Markham and Mintzes (1994) compared CMaps constructed by novices to those made by experts. Both studies reported significant differences in the CMaps of experts and novices; whether the findings were based on subjective comparisons (Williams, 1998) or numerical scores (Markham & Mintzes, 1994). The authors argued that CMaps are able to capture differences in the knowledge and understanding of the subject matter, and they can be used as a research and evaluation tool (Markham & Mintzes, 1994). Generally, there is a positive attitude toward using CMaps as an evaluation tool, because it is argued that CMaps are powerful in revealing students’ misconceptions (e.g., Roberts, 1999; Kinchin, 2000). However, some authors warn against the lack of reliability and validity in concept mapping techniques and scoring practices, insisting on more research on the tool’s effects before it can be used for the formal assessment of students’ knowledge (e.g., Ruiz-Primo & Shavelson, 1996). In response to these criticisms, McClure, Sonak, and Suen (1999) compared six existing scoring methods of CMaps and found support for the validity of five of them as well as some degree of correlation among all six measures.

Two studies compared concept maps to other forms of knowledge representation with respect to learning new material. Lambiotte and Dansereau (1992) compared CMaps to lists and outlines such as those used for lecture aids, and assessed differences in students’ recall of the presented material. They reported no significant difference between the effect of CMaps and the other two lecture aid forms. Contrary to these results, Hall, Dansereau, and Skaggs (1992) reported a significant difference in the recall of material presented in the form of a CMap when compared to a normal text presentation for only one of the two subject domains tested. These findings raise more questions than they answer, especially regarding the usability and suitability of CMaps in different contexts.

Most of the studies conducted on the subject of CMaps have been concerned with the use of the tool rather than with an evaluation of the tool. The aim of the research effort presented here is to investigate the tool itself and provide a better understanding of the capabilities and limitations of CMaps.

3 Theoretical Argument and Experimental

3.1 Structure of the Map as a Means to Encourage Dynamic Representation

The concept map is a tool designed to identify and represent relationships between different concepts in a domain. Safayeni et al. (2003) distinguished between two types of relationships among concepts, static and dynamic. Static relationships reduce the uncertainty in the labels by connecting the concepts in a proposition, whereas dynamic relationships are concerned with covariation among the concepts.

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 hierarchical character of CMaps is a natural form for the representation of classifications and hierarchies.

A dynamic relationship between two concepts reflects and emphasizes the propagation of change in these concepts. The dynamic relationship shows how change in *quantity*, *quality*, or *state* of one concept causes change in *quantity*, *quality*, or *state* of the other concept in a proposition. In other words, a dynamic relationship reflects the functional interdependency of the two or more concepts involved. For a more elaborate discussion on static and dynamic relationships, see Safayeni et al. (2003).

As science has progressed, it has moved away from the creation of hierarchies and categorizations, and toward establishing functional relationships among concepts (Lewin, 1935). The greatest advances of science are represented in the form of dynamic relationships as embodied in the laws of physics and captured in the form of mathematical equations. Dynamic relationships among concepts might not be as well formulated in other domains of knowledge, making it impossible to represent them in the language of mathematics. However, if the dynamic relationships are established to some degree, then the representation of such relationships is possible using an ordinary language, although the loss of information is inevitable. If a CMap is to be considered a valid knowledge representation tool, it is important to investigate the CMap's ability to represent dynamic relationships.

Safayeni et al. (2003) argued that CMaps, while robust in representing static relationships between concepts, lack the potency for encouraging and representing dynamic relationships among concepts. The authors argued that this deficiency is mainly due to the endorsement of the hierarchical nature of CMaps. Reported analysis of 34,000 propositions extracted from various CMaps revealed that no more than 4% of these propositions could potentially be classified as dynamic.

At the same time, Safayeni et al. (2003) proposed Cyclic Concept Maps (Cyclic CMaps) as an extension to traditional Cmaps, to facilitate the representation of dynamic thinking in concept mapping. In its simplest form, the Cyclic CMap has a cyclic structure in which all concepts are connected in the form of a loop, each having one input and one output. In this structure, concepts are highly interdependent because of the cyclic nature of the relationships. A change in state of any concept affects the states of all other concepts. Therefore, Cyclic CMaps are considered to be an appropriate tool for representing knowledge of functional or dynamic relationships between concepts. High structural interdependence of the concepts in such maps represents a system of interrelationships rather than a collection of independent propositions, as often occurs in the hierarchical structures. Moreover, high structural interdependence of the concepts formed by a cyclic structure encourages the representation of dynamic relationships between concepts. Thus, the following hypothesis can be formulated.

H1 Structure effect: A cyclic structure encourages the construction of more dynamic relationships than does a hierarchical structure.

3.2 Quantification of Concepts as Another Possible Solution to Encourage Dynamic Representation

Safayeni et al. (2003) suggested that quantification of the starting concept in a map makes the concept more dynamic, and thus leads to the construction of more dynamic propositions. Quantification of a concept reduces variability with respect to the possible set of meanings the concept could potentially refer to, while drawing attention to the specific property of the concept that can change its value. Quantification of a concept makes reference to change much easier because it selects a single dimension of change for that concept. For instance, it is hard to imagine a change in the whole concept "soil," but it is much easier to imagine a change in the concept "quality of soil." In fact, when the quantifier "quality" is added to the concept "soil", one right away starts thinking about "quality of soil" being rated from good to bad or high to low, thereby setting this concept "in motion" and allowing it to change. Thinking about the change in the starting concept 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 starting concept. Therefore, the following hypotheses are formulated.

H2a Quantification effect: Quantification of the starting concept in the hierarchical structure will result in more dynamic propositions compared to a nonquantification condition.

H2b Quantification effect: Quantification of the starting concept in the cyclic structure will result in more dynamic propositions than that of a nonquantification condition.

A cyclic structure represents not just a collection of segregated propositions, but also a system of interconnected concepts on a given topic. The system representation and interconnectedness of concepts should appear intellectually more meaningful than a hierarchical representation of the same topic. Thus, the following hypothesis is formulated.

H3 Preference: When given a choice, subjects will prefer a cyclic over a hierarchical representation of the same topic.

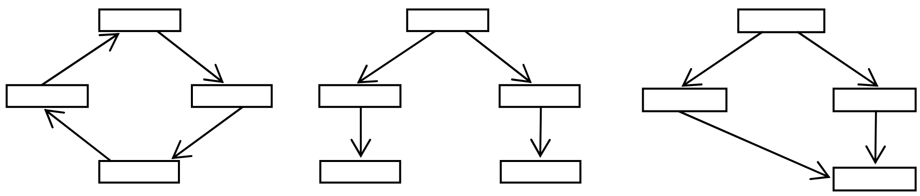
4 Experiment 1 (Map Construction)

The purpose of Experiment 1 was to investigate the structure and quantification effects on the dynamic nature of the constructed propositions by testing the first two hypotheses.

4.1 Method

4.1.1 Stimuli selection

Simple prototypes of cyclic and hierarchical structures were constructed to be used as stimuli, and are presented in Figure 1. The prototypes reflected the main properties of the represented structures, while having minimal complexity. Two variations of the hierarchical structure were included; a classical tree structure, which is rarely used in CMaps, and a cross-link structure, in order to provide a fair representation of a classical CMap. The unit of analysis in this experiment was a proposition. The number of propositions was kept the same in all three prototypes.



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

4.1.2 Subjects

The subjects for this study included 112 undergraduate students from the University of Waterloo. All were enrolled in the same course and were offered a partial credit toward their course mark for their involvement in the study.

4.1.3 Procedure

Subjects participating in Experiment 1 entered concepts and linking phrases in one structure prototype provided to them. The top-most box of the structure had a concept written in it, whereas all other boxes and arrow labels were blank. For each of the three structure prototypes, quantification and nonquantification conditions were tested, for a total of six conditions. All maps of nonquantification conditions started with the concept “plant”; and all maps in quantification conditions started with the concept “number of plants”. Subjects were assigned randomly to the conditions.

4.1.4 Measures

Each concept map constructed by the subjects was analyzed and assigned a dynamic score. The dynamic score reflected the number of dynamic propositions in the map, and ranged from 0 to 4.

In order to analyze the propositions, the maps were broken down into individual propositions consisting of two concepts and a linking phrase between them. Each proposition in every map was analyzed individually and separately from the rest of the map. Each proposition was evaluated to determine whether it reflected a dynamic relationship between the concepts involved. Relationships that reflected how change in the quantity, quality, or state of one concept resulted in a change in the quantity, quality, or state in the other concept were classified as dynamic. For example, the propositions {“More green and bright colors” <reduce> “Sense of anxiety and stress”} and {“Planting seeds” <will lead to> “Growth and maturation of the plant”} were classified as dynamic. For more information on the scoring of the propositions please contact the first author.

The scoring of all 448 propositions was performed two times separately. Each time the order of the propositions was randomized, and the information about the map was hidden from the scorer. A high degree of reliability was obtained in the blind rescoring; only 6% of the total number of scores deviated.

4.2 Results

The results for testing hypothesis H2 are reported first, followed by the test of hypothesis H1 and hypothesis H3. Hypothesis H2 was tested first so that the data could be combined to test hypothesis H1.

4.2.1 Testing hypothesis H2

A visual examination of the data for all six conditions suggested that there was not much difference between quantified and nonquantified propositions in any of the structures. Because the requirements of normality of the sampling distribution and equality of the variances were not met, nonparametric statistical tests were applied. A Wilcoxon-Mann-Whitney one-tailed test showed no significant differences between quantification and nonquantification conditions in all three structural prototypes. The obtained p values were 0.432, 0.312, and 0.396 for the cyclic, cross-link, and tree structures, respectively.

Therefore, hypotheses H2a and H2b were rejected. That is, the quantification of the starting concept does not increase the number of dynamic propositions in the cyclic structure or in either of the forms of the hierarchical structure.

4.2.2 Testing hypothesis H1

To analyze the structure effect on the dynamic nature of the constructed propositions, data from the quantification and the nonquantification conditions of the same structure were combined because there was no statistical difference between them. The Kruskal-Wallis test was administered for the among groups comparison, the obtained value $p < 0.001$. This result yielded that at least one group among the three is significantly different from at least one other group in the sample. To achieve pair-wise comparison, the Wilcoxon-Mann-Whitney test was performed. For the cyclic – tree comparison $Z = -4.403$ ($p < 0.001$); for the cyclic – cross-link comparison $Z = -3.407$ ($p = 0.001$).

The analysis provided strong support for hypothesis H1, which states that the cyclic structure encourages the construction of more dynamic propositions than does either of the hierarchical structures. It is worth noting that a significant difference was achieved not only for the case of tree structure, but also for the case of cross-link structure.

Because both the tree structure and the cross-link prototypes are based on the hierarchy of concepts, there was no reason to expect them to produce different results. Indeed, the Wilcoxon-Mann-Whitney test found no statistically significant difference ($p = 0.25$) between these two prototypes.

5 Experiment 2

The purpose of Experiment 2 was to identify any subjective preference for the cyclic structure over the hierarchical structure. Similar to Experiment 1, the cyclic structure was compared to the two variations of the classical concept map hierarchical structures (the tree and the cross-link).

5.1 Method

5.1.1 Stimuli selection

CMaps for Experiment 2 were selected from the pool of CMaps constructed by subjects in the first experiment. Maps with the highest dynamic score were picked out for each of the structural prototypes. Care was taken to select maps with similar content from the three structural representations. Using similar maps reduced the variability in the selection due to nonstructural effects. In the experiment each structural prototype was represented by one map. The three chosen maps were used to generate pair-wise comparison conditions.

5.1.2 Subjects

The subjects for Experiment 2 included 72 students from the University of Waterloo. All were enrolled in the same course and were offered a partial credit toward their course mark for their involvement in the study.

5.1.3 Procedure

In Experiment 2, subjects selected the more “interesting” map between the two presented to them, and then explained their choice. The three conditions that were tested in this experiment consisted of pair-wise comparisons among cyclic, cross-link, and tree structure prototypes. Twenty-four subjects were assigned randomly to each of the conditions.

5.1.4 Measures

Subjects made a binary choice between the two maps presented to them. The number of times each type of map was selected in a given comparison condition was counted. This represented a selection score for each structure in a given comparison condition.

Subjects were also asked to provide reasons for their choice. These responses were analyzed and categorized based on the similarity of their meaning. All reasons given by the subjects for all three comparisons were grouped into three categories:

- reasons that addressed the structural properties of the maps;
- reasons that commented on the informative properties of the structures;
- reasons that pointed out differences in the content of the maps or specific words used.

The separation of the comments into these three categories was helpful in attributing a preference for a certain prototype to specific properties of that prototype.

5.2 Results and Discussion

5.2.1 Cross-link – tree comparison

In the cross-link – tree comparison condition, 58% of the 24 subjects tested selected cross-link as more “interesting.” A Binomial test indicated no significant difference in preference between the cross-link and tree structures ($p = 0.541$) conditions, so the data were combined.

Qualitative analysis was conducted on the subjects’ comments. Pros and cons for each of the structures appeared in the subjects’ comments, and the distribution of these among the three categories is reported in Table 1.

Category of comments	**In favor of cross-link**	**In favor of tree**	**In opposition to cross-link**	**In opposition to tree**
Structural properties	10 (37 %)	7 (28 %)	4 (80 %)	9 (82 %)
Informative properties	5 (19 %)	11 (44 %)	1 (20 %)	0
Content	12 (44 %)	7 (28 %)	0	2 (18 %)

Table 1: Distribution of number of comments among the categories for the cross-link – tree comparison

A chi-square test showed that comments in favor of either cross-link or tree were distributed virtually randomly among the categories of comments ($p = 0.527$, $p = 0.236$ for cross-link and tree, respectively). It is worth pointing out that the significant number of comments in favor of a map is related to the content in both cases. This could be explained by the sufficient degree of similarity in the two structural variations that forces subjects to retreat to the minute differences in the wording. The number of comments in opposition to either structure was too low for any meaningful statistical treatment.

The two analyses above indicate that the choice between the cross-link map and the tree map was random. No significant preference or perceived difference between these two variations was found. This result was not surprising, because the cross-link was considered to be a variation of the tree structure. Therefore, further analysis was conducted to examine the comparison of the cyclic structure to both forms of hierarchy, combining the data for cross-link and tree structures.

5.2.2 Testing hypothesis H3

Out of the 48 subjects tested, 79% selected the cyclic structure as more “interesting.” The result of the Binomial test between cyclic and hierarchical structures was highly significant ($p < 0.001$). This illustrates that the cyclic structure was not only able to represent dynamic relationships, but was also more appealing to people.

Based on the above findings, hypothesis H3 was supported. That is, there was a strong subjective preference for the cyclic structure prototype over the hierarchical structure. The distribution of the comments given by the subjects to support their preference among the categories is presented in Table 2.

Category of comments	**In favor of cyclic**	**In favor of hierarchy**	**In opposition to cyclic**	**In opposition to hierarchy**
Structural properties	57 (84 %)	7 (39 %)	3 (75 %)	22 (67 %)
Informative properties	11 (16 %)	9 (50 %)	1 (25 %)	11 (33 %)
Content	0	2 (11 %)	0	0

Table 2: Distribution of number of comments among the categories for the cyclic – hierarchy comparison

From the numerical analysis of the comments favoring a cyclic CMap, it was clear that subjects attributed their preference to the structural properties of the cyclic CMap. In fact, the cyclic structure was described as “cycle clearly shows how each concept is related to the other,” “cycle is a self-sustained system,” “complete circle,” “cyclical relationships make more sense,” “cyclic structure is more intuitive,” “circular pattern shows continuous process,” and so on. Also, structural weaknesses of the hierarchy were major reasons reported in opposition to selecting a hierarchical map. Comments such as “in <hierarchy> there seem to be missing relationships,” “in <hierarchy> structure there are ‘dead ends’,” “<hierarchy> structure’s flow is only one way,” and “it does not allow us to see the whole picture” were reported as weaknesses of the hierarchical structure. On the other hand, the subjects who selected hierarchy for their preference justified their choice by comments such as “<hierarchy> is laid out in a more hierarchical manner,” and “<hierarchy> is straight forward and easy to understand.”

It is worth pointing out that only 2 out of 123 comments were directed toward the content of the maps in the cyclic versus cross-link and tree selection conditions. This suggests that there were sufficient structural and informative differences between the cyclic and the two hierarchical prototypes.

6 Conclusion

The predicted effect of the structural properties of a map on the dynamic nature of the propositions was supported by the experimental results. As was expected, the cyclic structure produced significantly more dynamic propositions than either form of hierarchy. Quantification of the starting concept in a map was expected to increase the number of dynamic relationships, however, no effect was observed in the experimental data. One plausible explanation is that the phrase “number of plants” was interpreted as “the population of plants” and not as the “quantity of plants,” as was intended by the researchers. The first interpretation is not a quantified version of the concept “plants,” but rather refers to a group of plants. The second interpretation is a quantified version of the concept “plants,” and it refers to the property of quantity. The question of the concept quantification effect on the characteristics of the propositions can be further explored by quantifying a concept more explicitly, for example, by using the phrase “increasing the number of plants.” This version of concept quantification is less likely to lead to misinterpretations and may allow the true effect of concept quantification on the property of the constructed linking phrases to be observed.

As was expected, subjects preferred the cyclic structure over the hierarchical structure. The majority of the subjects found the cyclic CMap more “interesting” than the hierarchical map. The analysis of reasons provided by the subjects suggested that this preference was due to the structural properties of the maps. Eighty-four percent of the reasons for choosing the cyclic structure were attributed to its structural characteristics whereas 67% of the reasons for not choosing the hierarchy were attributed to the hierarchy’s structural characteristics.

The data show that the form of representation influences the content of the constructed CMap. Moreover, a cyclic structure leads to an increase in the representation of functional dynamic relationships between concepts. Despite some authors’ arguments that CMaps are not purely tree-like structures due to the use of cross-links, the present study shows no difference between a pure tree structure and its cross-link variation on any of the measures used. This suggests that CMaps need more drastic changes than a mere use of cross-links to be suitable for capturing and representing knowledge of dynamic relationships. Safayeni et al. (2003) proposed such a change, called Cyclic Cmaps. The present study provides experimental support for the Cyclic CMaps extension as an appropriate tool for representing dynamic relationships in a single system.

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