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# THE EFFECTS OF CONCEPT MAPS ON REQUIREMENTS ELICITATION AND SYSTEM MODELS DURING INFORMATION SYSTEMS DEVELOPMENT

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**Abstract.** There are many problems associated with the development of information systems. Requirements elicitation is the phase of systems development when the systems analyst attempts to understand the user(s) concept for a particular system. Problems encountered or left unsolved from the requirements elicitation phase may worsen during the remainder of the systems development project. At the heart of the process is the need to create a shared understanding between the user and the analyst. One method for creating a shared understanding is the creation of a joint concept map by the parties involved. It is hypothesized that combining concept maps with requirements elicitation in an experimental setting will show the benefits of incorporating this technique into the requirements elicitation phase of systems development. An experiment was conducted involving analysts and users working together as a dyad across three treatment groups. The results indicate that the concept map did not assist the analysts during requirements elicitation. These findings are in the opposite direction of existing theory, prior research, and the hypotheses of this research.

## 1 Introduction

Successful information systems development depends heavily on the interaction of the users and systems analysts (Green, 1989). Due to the misinterpretation of and changes in user needs, however, information systems are constantly undergoing costly re-designs (Kara, 1997; Scott, 1988) which cause ill will between the users and systems analysts. The ability to improve this process is a major concern to the entire information systems development industry, primarily due to the monetary gains (and lack of monetary losses) from building the system correctly the first time (Kara, 1997).

During requirements elicitation, the analyst attempts to elicit and understand the needs of the user(s) and the organization. While requirements elicitation is an extremely difficult phase of systems development, it is one of the least supported (Jeffrey & Putman, 1994; Kim & March, 1995). It is during this phase, and not later in the development process, that the analyst must fully understand user expectations and the goals of the system (Holtzblatt & Beyer, 1995). With the proper requirements, the rest of the development process can proceed and lead to the final system. However, an incomplete requirements elicitation phase may hinder the successful completion of the rest of the development process.

Specifically, poor or error-prone communication between the user and analyst remains a major problem (Byrd et al., 1992; Marakas & Elam, 1998; Tan, 1994), even after several decades of research on improving requirements elicitation (Ackoff, 1967; Guinan et al., 1998). This lack for a shared understanding between the user and analyst may be corrected through the use of mental models during the requirements elicitation process. Mental models have been shown to be effective at creating a shared understanding between multiple individuals in many fields (Hoover & Rabideau, 1995; Malone & Dekkers, 1984; Trochim, 1989), thereby providing an impetus to apply them to information systems development.

## 2 Theory

Teichroew (1972) put forth the original call to improve communication between the user and analyst, and this need has remained strong within systems development research (Byrd et al., 1992; Marakas & Elam, 1998), and specifically regarding the creation of a shared understanding between the user and analyst (Butterfield, 1998; Tan, 1994). Shared understanding occurs when individuals communicate on a particular topic and then subsequently have the same understanding of that topic (Tan, 1994). Failure to achieve a shared understanding may be due to one or more of the following: a misinterpretation of verbal communication (Fraser, 1993; Tan, 1994); a misinterpretation of nonverbal communication (Foa et al., 1981); or a lack of communication in the first place.

These misinterpretations, or miscommunications, need to be repaired during communication in order to achieve a shared understanding (Schegloff, 1991). However, repairing the miscommunications does not need to be done verbally, as “any methodology that can improve interaction and communication within a group should improve the sharing of perspectives and reduce miscommunication,” (Massey & Wallace, 1996, p. 256). This includes nonverbal techniques such as gestures and pictures. Neilson & Lee (1994) specifically call for the combination of natural language (verbal) and graphics (nonverbal) as the means for reaching a shared understanding of the topic. Therefore, concept maps are suggested as a technique for creating a stronger shared understanding between the user and analyst during requirements elicitation.

A concept map is a form of mental model – external models of a person's internal cognitive representation of his/her structural and conceptual understanding of a domain (Craik, 1943). Concept mapping, specifically, has been used in many fields, such as education, psychology, and management (Fraser, 1993; Novak, 1995) to visualize the mental "map" of concepts and their relationships, as well as the structure and hierarchy of these relationships. Concept maps can aide in "making externally explicit the individual's understanding of her cognitive structure" (Fraser, 1993, p. 40). Much of our knowledge is based on the understanding of the relationships among concepts within a domain (Goldsmith & Johnson, 1990), and concept maps, as structured representations, capture these relationships better than other techniques (Markham et al., 1994).

Concept maps consist of concepts (represented as nodes) that are connected to one another showing their relationships. The concepts themselves are words and terms representing events, objects, ideas, and even emotions regarding the particular domain. The relationships, represented as the connecting lines, state that the concepts are conceptually and logically related in some way.

When one person communicates her conceptual understanding of a topic to another individual through a concept map, there is a greater chance of achieving a shared understanding and reducing miscommunication (Fraser, 1993, Rewey et al., 1989). Concept maps have been shown to increase team performance (Blickensderfer et al., 1997) and collaboration (Howard, 1989). Trochim (1989, p. 1) argues that "concept mapping encourages the group to stay on task, results in an interpretable conceptual framework, expresses this framework in the language of the participants, yields a graphic or pictorial product, and improves group or organizational cohesiveness and morale."

It must be noted that concept maps are not intended to replace other methods of requirements elicitation. Concept maps are a technique to be used for representing the requirements and the business situation in an alternate manner, making the entire situation more understandable to the parties involved – the user and analyst – by creating a shared understanding. In the end, concept maps will provide a more complete understanding of the situation by combining the traditional verbal and text-based interview method with the pictorial map with few structural limitations.

## 3 Prior Research

Several researchers have used mental models in an attempt to improve the requirements elicitation process. Montazemi & Conrath (1986) showed benefits of using cause-effect maps during requirements elicitation, though they did not use analysts in their experiment. Instead, the researchers created the maps after interviewing real users, and then used the maps to create an operational system for the users. While shown to be effective for understanding the user and the complex relationships that were part of the domain, as well as easy to use, the cause-effect maps were not compared to any other technique, nor were they able to incorporate non-causal relationships.

Browne et al. (1997) also used mental models to successfully elicit a higher quantity and a higher quality of information from users, and in this study there was a control group with which to compare the results. Again, however, no analyst was part of the experiment as the researchers created the maps. Massey & Wallace (1996) also found mental models to have positive effects on problem definition, this time in a group setting. Burgess et al. (1992) showed that mental models were able to assist in overcoming communication obstacles during requirements elicitation, though again, the researchers created the maps and then showed them to the users.

McKay (1998) studied real users and real analysts in an action research setting and found that cause-effect maps increased shared understanding as well as provided an overall understanding of the situation and its scope. However, there were no comparisons to other techniques or any control group, leaving the results hard to interpret.

This current study will build on McKay (1998) and Burgess et al. (1992) by validating the use of mental models (specifically concept mapping) in a laboratory setting. The concept map will help the user express in a non-verbal form what is needed and help the analyst understand in a non-verbal form what needs to be done.

The concept map will serve as a bridge between the user and the analyst who may come from very different backgrounds, experiences, perceptions, and styles.

## 4 Hypotheses

This research proposes to combine (a) the need for a shared understanding between the user and analyst and (b) the need for the requirements elicitation process to be improved with (c) concept maps as the technique for this improvement.

Newburn et al. (1997) and Rewey et al. (1989) have shown that concept maps lead to a greater recall ability of the concepts modeled because their spatial nature simplifies complex concepts and enhances other concepts, and their structure aids future organization and recall via this spatial processing. Therefore, when concept maps are used during requirements elicitation, this recall effect should also be present and should be apparent during the subsequent drawing of the Data Flow Diagrams (DFDs) by the analyst. The effect should be enhanced since the analyst has the concept map in front of him/her as opposed to most previous studies where the map was not available during recall tests. This higher recall of the requirements and other information present in the concept map will lead to greater accuracy in the DFDs constructed by the analysts when user-analyst dyads use concept maps. This is expressed as Hypothesis 1.

H1: Analysts from dyads using concept maps as part of the requirements elicitation process will produce models of higher accuracy than analysts from dyads not using concept maps as part of the requirements elicitation process.

"Shared understanding of information requirements is argued to lead to greater confidence that the requirements are 'right', leading ultimately to 'better' information systems being developed" (McKay, 1998, p. 141). Since concepts maps are hypothesized to increase shared understanding, they are therefore also hypothesized to increase the analyst's level of confidence in his/her models. This prediction regarding perceived accuracy is expressed as Hypothesis 2.

H2: Analysts from dyads using concept maps as part of the requirements elicitation process will rate the perceived accuracy of their models higher than analysts from dyads not using concept maps as part of the requirements elicitation process.

## 5 Methodology

An experiment was conducted with dyads of simulated users and simulated analysts. The experiment took place in a laboratory setting to increase the precision and control of the measurements. The concept map is both a new technique (to the analyst) and a context-specific technique in that it is relevant to the task scenario and the production of the DFD. Therefore, the analysts in the concept map treatment group (Mx) were trained in a technique that is New and Contextual.

To eliminate the possibility that the results are caused by either the training in something new or the training in something relevant to the task, two additional treatment groups received training as follows. One group (Cx) was exposed to an interaction with the researcher using graphics to present material that was new but that was not contextual to the experiment – New and Non-contextual. A third treatment group (Dx) was exposed to additional rules and procedures regarding the creation of DFDs, also in a graphical and interactive nature, which was Non-new and Contextual. To eliminate the possibility that the training in concept mapping itself is the reason for any of the results, all three treatment groups received a similar amount of exposure and interaction. Data was collected from 8 dyads in each treatment group.

The users were recruited as volunteers from the senior-level, non-IS courses in the undergraduate program of a large, midwestern business school. Analysts were recruited from the senior-level, undergraduate IS courses at the same business school and had already completed at least one (and possibly two) systems analysis and design courses. All analysts received approximately 25 minutes of training and exposure to additional material (as described above) before they were given the scenario. The analysts that were assigned to the concept mapping group received training on creating concept maps based on Novak and Gowin's (1984) and Novak's (1998) introduction and training technique, though adjusted based on Shavelson et al.'s (1994) and Taber's (1994) modifications. Each analyst in this treatment group was given a short measure of his/her understanding of the components and rules regarding concept mapping. Following the training session, the analysts were given an abridged version of the scenario to use as a basis for discussion in the upcoming session with the user. While the analysts were receiving the appropriate training, the users received a full description of the scenario. They were told that they were to take on the role of one of the users of this system and to use the given information and nothing else. Before beginning the session with the analyst, the user was given a short test to assess his/her understanding of the scenario and his/her role in the upcoming session with the analyst

The dyads met for as long a period of time as they (the two individuals) felt necessary. Fatigue did not appear to be a factor for any of the analysts or users. The entire session was videotaped and timed, though the dyads were not aware of the timing. When the dyads felt that they were finished, the users were asked to leave and the analysts began to construct the DFD of the system. This, too, was timed unobtrusively.

## 6 Results and Analysis

Throughout the remainder of this document, the three treatment groups will be referred to as follows: **Control** – the group that received new and non-contextual material; **DFD** – the group that received additional exposure to DFD rules; and **Map** – the group that received training in concept mapping. The DFDs produced by the subjects were compared with the correct Data Flow Diagram and scored. Two independent judges familiar with the specific scenario conducted the evaluation. The inter-rater reliability was found to be 0.931. When the two judges' scores were not in agreement, the researcher reviewed the two coding forms in order to ascertain and agree on a final score for that Data Flow Diagram.

The concept maps were scored for the number of nodes, the number of links, and for the complexity of structure (extra links). To accomplish this, a common coding scheme was developed in order to accurately compare each map to one another and not to double-count or miss any nodes or links. An independent judge created this coding scheme so that if one map contains the term "employee" and another map contains the term "worker," the two maps could be compared based on the common concept.

### *6.1 Hypothesis 1*

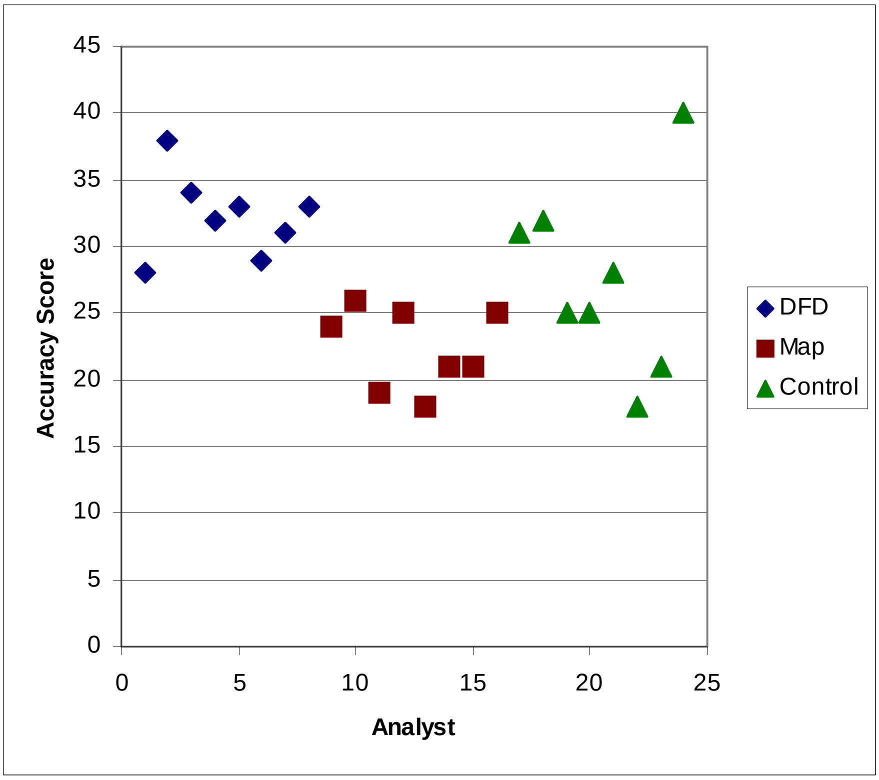


**Figure 1.** DFD Accuracy Scores Grouped by Treatment

H1 concerned the overall accuracy of the Data Flow Diagrams produced by the analysts following their session with the user. Specifically, this hypothesis stated that the analysts in the dyads using concept maps would create DFDs of higher accuracy than the analysts in the other dyads. The data for testing this hypothesis came from the Accuracy scores for the DFDs as described above. The p-value of 0.002 indicates that there is indeed a significant difference between the groups. Another way to view this data is to look at the individual DFD Accuracy scores as mapped against the treatment groups. As seen in Figure 1, all of the DFD group's scores were higher than all of the Map group's scores – there is no overlap between these two groups. In addition, the scores from the Control group are spread throughout the combined range of the DFD and Map groups. This figure clearly shows the Accuracy differences between the three groups, but most notably between the DFD and Map groups.

The data collected were significantly in the opposite direction of the hypothesis. The Map group's DFDs were significantly less accurate than even the DFDs from the Control group. In summary, Hypothesis 1 is rejected as both the DFD group and the Control group had higher DFD Accuracy scores than the Map group.

### *6.2 Hypothesis 2*

H2 concerned the analysts' perceived accuracy of their Data Flow Diagrams. Specifically, this hypothesis stated that the Map analysts would have higher perceived accuracy ratings of their Data Flow Diagrams than the analysts from the DFD and Control groups. The data for this hypothesis were gathered on the post-experiment questionnaires given to the analysts. The analysts were asked to indicate their perceived accuracy on a 0-100% scale and to explain any rating that was less than 100%. No analyst had a ranking of 100% – the range was between 50% and 98%.

The ANOVA indicates an overall difference among the three treatment groups (p-value of 0.021). While the means are quite different for all three groups, the Map group's ratings were not significantly different from either of the other groups' ratings.

Besides the perceived accuracy scores, the correlations between perceived accuracy and "actual" accuracy were analyzed. The overall correlation coefficient was 0.199, indicating only a slightly positive correlation. However, the individual correlations within treatment groups revealed very interesting results. The DFD group (-0.317) and the Control group (-0.127) both had negative and non-significant correlations, while the Map group (0.814, p-value of 0.014) had an extremely high positive correlation.

In summary, Hypothesis 2 is rejected as there were no significant differences in Perceived Accuracy between the Map and Control groups or between the Map and DFD groups.

### *6.3 Content Analyses*

The concept maps can be analyzed in terms of the number of concepts (nodes) they contain, the number of links between the concepts, and the complexity of the structure. The complexity of the structure is defined as the number of links above the minimum required to connect all of the concepts linearly that are present on a given map. Table 1 shows the descriptive statistics for these three variables.

| | *Mean* | *Standard Deviation* | *Maximum* | *Minimum* |
|---|---|---|---|---|
| Nodes | 12.75 | 5.600 | 22 | 6 |
| Links | 18.5 | 8.246 | 34 | 10 |
| Complexity | 6.75 | 3.991 | 13 | 0 |

**Table 1.** Descriptive Statistics for Concept Maps

It is clear that given the identical introduction and training to concept mapping, analysts (with their user) still created very different concept maps in terms of these numbers, let alone the actual content. The "Maximum" numbers in Table 1 are all from the same concept map, as are the "Minimum" numbers for Nodes and Links. Correlations between DFD Accuracy and the number of nodes, number of links, and concept map complexity found no significant correlations.

There were 29 unique (appearing on at least one map) concepts across all of the concept maps, and each concept appeared on an average of 3.5 individual maps, or nearly half. Of these concepts, only three appeared on every map – Accounts Receivable, Credit Clerk, and Warehouse. This is interesting considering that the Order Entry Clerk played a very prominent role in the scenario and the Customer was also a major figure. However, the omission of certain concepts from one of the concept maps does not imply that this particular map is less accurate than any other map.

## 7 Discussion

The hypotheses were based on the prior literature and theories regarding the combination of requirements elicitation and concept mapping, but the results do not follow from the theories. Knowing that the concept map had a negative effect on the Data Flow Diagram accuracy, the perceived accuracy results are very interesting. Perceived accuracy is important because it is a measure of the analysts' level of confidence in their own work. It could be argued that these ratings are artificially inflated as a result of a desire to not rate your own work below average. However, there were still differences between the treatment groups in terms of the perceived accuracy ratings, and significantly so between the DFD and Control groups. High perceived accuracy ratings for the Map group would have indicated that there was something about the concept map that boosted the confidence of the analysts. Though the Map analysts' perceived accuracy was not the highest, and was also not significantly different from either of the other treatment groups, the interesting part is the correlation between perceived accuracy and actual accuracy.

The Map analysts were very accurate predictors of their actual accuracy (correlation of 0.814, p-value of 0.014). The other two groups had correlations that were not significant and were negative. The Map analysts seemed to know how much they knew and how much of the "correct" Data Flow Diagram they were able to create. In the other two groups, the analysts were less clear as to how much they knew. Still, the fact that the Map analysts' Data Flow Diagrams were significantly less accurate than both of the other groups' DFDs makes this correlation hard to interpret. These analysts were excellent predictors of accuracy, even though their accuracy was not very high!

The question remains, however, of why the concept map did not have the hypothesized effects. Based on the concept map introduction and training sessions, the results from the concept map quizzes given to the Map analysts, and the concept map analyses, the analysts understood the technique of concept mapping, and they created the concept maps based on the instructions given to them. However, it is possible that the analysts understood how to create a concept map and the technique of concept mapping, but they didn't understand how to apply the technique in order to effectively use a concept map. Similarly, it may be that mastery of the concept mapping technique may take much time with continual exposure and practice as it is part science and part art form. It appeared in this study, however, that subjects had received and grasped enough training in concept mapping that there should have been some benefits derived from the technique if any were to be derived. The training used in this study was based on the previous literature in concept mapping from Novak (1998) and Novak & Gowin (1984). Future studies with different training techniques may be able to rule out whether the degree or nature of training is in fact the reason for the non-support of the hypotheses.

The Data Flow Diagram exposure focused the DFD group analysts onto the task of creating a Data Flow Diagram and so they were acting, thinking, and questioning with that goal in mind. The Map analysts knew that they had to create a concept map with the user and so they weren't able to focus on the end-result of the Data Flow Diagram as much as the DFD group. Therefore, their questions and thought processes weren't as polished or "on target," and the concept map couldn't make up the difference. This would explain higher scores for the DFD group over the Map group, but this does not explain the higher scores for the Control group over the Map group in terms of Data Flow Diagram accuracy. At worst, the Map and Control groups should have performed equally well if the only reason the DFD group performed better was due to the extra exposure to Data Flow Diagramming. Since the Control group also outperformed the Map group, there must have been something else going on with the concept map to cause lower scores.

It is possible that the exposure to concept mapping simply interfered with the analysts' ability to think about DFDs and create DFDs. The concept maps may have prevented adequate reactivation of the analysts' more traditional knowledge of DFDs, hindering their DFD modeling ability and resulting in the lower DFD Accuracy scores. This negative priming of the analysts' prior knowledge due to their exposure to an unrelated technique is consistent with Dalrymple-Alford & Marmurek's (1999) study of priming effects. The analysts that were given additional DFD exposure had their ability to think about and create DFDs activated/enhanced, resulting in the higher DFD Accuracy scores. The Control analysts, who received no exposure to either concept mapping or DFDs, did not have their DFD knowledge hindered or enhanced.

## 8 Conclusion

The main concern of this experiment was the accuracy of the Data Flow Diagrams produced by the analysts. Not only was the hypothesis incorrect, but both of the other groups had Data Flow Diagrams of significantly higher accuracy than the Map group. There were differences between the treatment groups in terms of the perceived accuracy ratings, and significantly so between the DFD and Control groups.

Concept mapping theory, which states that they are universal communication tools, did not hold in this context. Therefore, additional studies need to be conducted to further investigate the incorporation of concept mapping into requirements elicitation and to determine if concept mapping and requirements elicitation can be combined effectively. Possible manipulations to this current study include varying the scenario's length and/or complexity, varying the level of training in concept mapping given to the analyst, varying the level of training given to the user, and varying the systems experience of the analyst.

While there were results here that were in the opposite direction of the hypotheses, this study still makes a contribution to the Information Systems literature and to the Concept Mapping literature. First, this study shows that a very useful technique for enhancing communication and creating a shared understanding does not work in all situations and contexts. Without positive accuracy results (or even non-negative accuracy results) in this or in similar contexts, the concept map should not be utilized given that Data Flow Diagram accuracy is the measure that will strongly influence the remainder of the systems development project. Second, this study further supports the fact that requirements elicitation is a vital part of information systems development and that problems remain with the communication between the analyst and user – i.e., not all techniques for communication will be successful when used in a requirements elicitation session. Finally, this study suggests that perhaps all that is needed for increased DFD modeling accuracy is more and/or more formal training in Data Flow Diagramming.

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