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The Retention and Usefulness of Concept Maps as Advance Organizers

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Joining the Penn State engineering faculty a year ago, my professional interests as an instructor of engineering are developing and refining methods of engineering instruction that will allow students to gain confidence and to increase their own success. Previous experiences in the metals and piping industry as a principal engineer have allowed me to promote necessary skills which need to be developed in the classroom so that the students have success upon graduation.

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1. Introduction:

A concept map is a type of node-link diagram designed to show the interconnected knowledge structures that a person possesses in a particular subject area [1]. The diagram consists of nodes, representing key concepts in the given subject area, and links representing key relationships between those concepts. An example of a concept map of engineering structures can be seen in Figure 1 below.

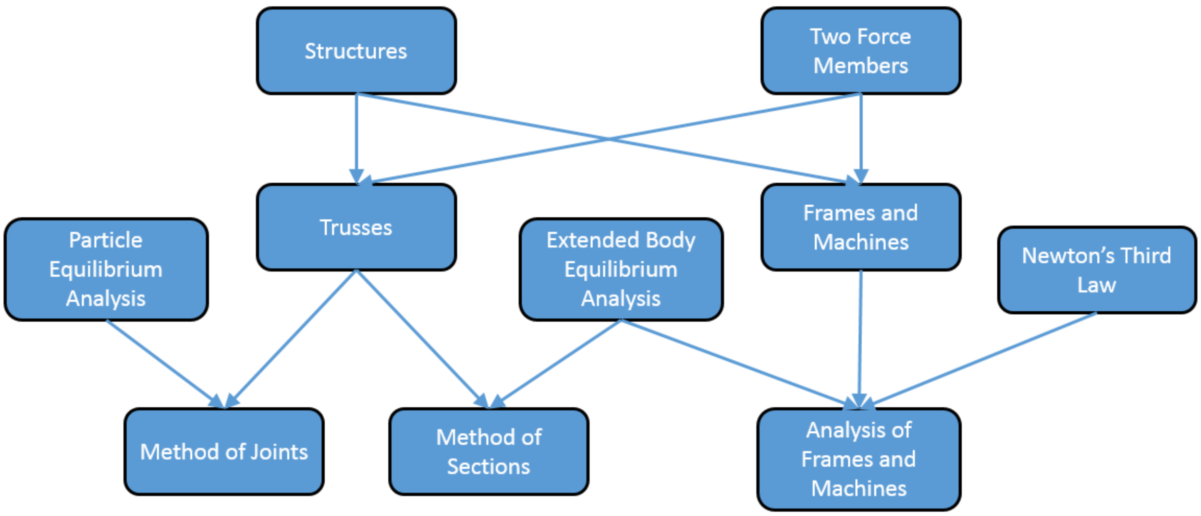

Figure 1: A Concept Map of Engineering Structures (Created by Instructor A)

Concept mapping has been used in many contexts and with many strategies over the years, and has generally been shown to have positive impacts on student learning [2]. Though both the theoretical basis for why concept maps should work and the end result in the form of improved student learning are well researched (as discussed in the literature review), there remain gaps in the literature linking the theoretical basis of concept mapping to the measured learning gains. This study aims to shine a spotlight on some of those links and to explore more detailed aspects of concept maps and student learning.

With a better understanding of how concept maps can be used to promote student learning, engineering educators can better implement these techniques in the classroom. Students in engineering mechanics courses, such as the statics courses in this study, often have difficulty developing conceptual understanding [3]–[5], and any avenue to improve conceptual understanding in this area would have a ripple effect in later courses that assume an understanding of mechanics content as prerequisite knowledge.

2. Literature Review:

2.1 The Origins and Theoretical Basis of Concept Maps:

Concept maps were originally developed as a tool by Joseph Novak and colleagues to visualize student knowledge structures for researchers examining cognitive development [6]. Novak's idea for concept maps came from Ausubel's Cognitive Assimilation Theory [7]–[9], which identifies interconnectedness of student understanding as the key difference between rote learning and meaningful learning. Rote learning allows students to reflect back what they have been told and even follow procedures when there are no deviations, but meaningful learning builds on that to add conceptual understanding in a way that allows students to innovate and problem-solve in creative ways. Because of the importance of innovation and problem-solving in engineering education, it is particularly important to make sure engineering educators promote meaningful learning, not just rote learning.

Linking the discussion back to concept mapping, Pearsall and her colleagues [10] conducted a study looking at student-generated concept maps over the course of a semester in an introductory biology course. Among other things, the study found that students who self-reported more meaningful learning strategies, rather than rote memorization, developed larger and more complex concept maps with more interconnections. Here, the interconnectedness of concept maps is directly mapped back to meaningful learning, in which the key element is highly interconnected knowledge structures.

2.2 Concept Maps and Student Learning:

Though originally developed as a research tool, concept maps are now overwhelmingly used as a learning tool. They are primarily used in one of two fashions: 1) An expert-generated concept map is used as an overview or framework before more detailed information is presented, or 2) students are asked to generate maps as a reflective activity at the end of a unit. Though both of these activities utilize concept maps, the theory behind why each promotes student learning is different.

For expert-generated maps presented before instruction, the concept map relates back to Ausubel's idea of an advance organizer [11]. An advance organizer is anything that provides a broad but simple overview of information to come that is understandable to novices and relates new information to prior knowledge. When used before more detailed instruction, advance organizers have been found to have a small but positive effect on student learning and retention [12]. Advance organizers can take a variety of forms from simple text to more complex visual overviews, but concept maps have been found to be particularly powerful advance organizers that promote student learning, particularly if there are anchoring concepts that the student already understands [9], [13].

For student-generated maps, the activity cannot be conducted until after the student learns the material, and so it cannot serve as an advance organizer. Instead the concept maps serve as a reflective activity, allowing students to identify and focus on the big ideas from the prior instruction. If conducted when the past instruction is still fresh in students' minds, it can help students connect the concepts they have just learned in a way that can lead to knowledge restructuring and improving knowledge retention [14].

2.3 Concept Maps and Assessment:

In addition to promoting learning, concept maps are also sometimes used as a student assessment tool. These will necessarily be based on the student-generated concept maps as described above, and are usually "scored" in one of two fashions [15]. These methods are generally labeled as "traditional" methods or "holistic" methods.

The traditional methods used to assess student maps assign points to concepts, links, hierarchy depth, and cross linking and simply tally up these points for a final score [16]. This method does not focus on one correct solution because there may be many experts who develop many equally valid concept maps; instead, this method focuses on the students developing an expert-like map in terms of the level of detail and complexity. While this method has a strength in its flexibility with student learning, it has a weakness in that the scores do nothing to help the students or instructor identify specific misconceptions or areas for improvement.

Alternatively, the holistic methods use a rubric to measure not only the complexity of the map but also the correctness of the links presented in the map [17], [18]. The results of such a holistic assessment address the weakness of the traditional method, in that correctness measures can offer feedback on specific conceptual weaknesses in the instruction.

Overall, both the traditional and holistic concept map assessment methods have been shown to be valid and reliable methods of assessment that correlate with each other and with other learning assessments such as multiple choice tests [19].

3. Research Questions and Methods:

3.1 Gaps in the Research and Research Questions:

Despite extensive research available on concept mapping, some key gaps in the literature still exist, and this work seeks to contribute to some of these areas.

First, although learning gains arising from using expert-generated concept maps as advance organizers have been well established (as discussed in the literature review), little has been done to illuminate the process by which these occur. Presumably, the expert-generated map is internalized and retained by the student in the long term, which helps scaffold the acquisition and retention of more detailed instruction. However, the internalization of this map by the student has not been directly tested, leading to the first research question.

RQ1: Do students internalize expert-generated concept maps as their own and recreate them to represent their own knowledge structures in the long term?

A related question deals with the ability of the expert-generated concept map to promote an understanding of the explicitly outlined relationships. Again, though there is a gain in generalized understanding, previous studies have not connected this back to the explicitly outlined connections that are highlighted. This leads to the second research question.

RQ2: Are students presented with expert-generated concept maps on a regular basis more likely to understand the relationships between key concepts explicitly connected in those maps?

Though the assessment of concept maps can include measures of "correctness" in the links, no one has of yet tested the correlation between the presence or absence of specific links and an outside measure of the understanding of that relationship. This leads to the third research question.

RQ 3: What is the correlation between individual links drawn in student-generated concept maps and meaningful understanding of the relationship between the linked topics?

3.2 Study Population:

To answer some of the above research questions, data was collected from students in strength of materials courses at three different universities during the first few weeks of the semester. Though students were enrolled in strength of materials, students were asked questions related to the subject matter taught in statics, which the students would have taken previously. This was purposefully done to examine the long-term retention of the content. Students were also asked to self-report their instructor from statics.

Instructor A at University A began each lecture in statics by presenting a concept map of concepts relevant to that day's lecture, highlighting how the new information would fit into previous content. This serves as an experimental group with regular exposure to concept maps as advance organizers. Instructors at Universities B and C did not use concept maps as advance organizers and serve as a control group for comparison.

Table 1: Overview of Research Participants

University	Statics Instructor	Expert Map Exposure	Number of Valid Consenting Participants
University A	Instructor A	Yes	9
University B	Instructor B	No	16
University C	Instructor C	No	36
	Instructor D	No	9

3.3 Data Collection Procedures:

An overview of research questions, data sources, and analysis methods is presented in Table 2. All data was collected in a single class session in the first few weeks of the semester with common instruments and a common concept map training video. The concept map prompt and relationship questions are presented in Appendix A.

Table 2: Research Questions, Data Sources, and Analysis Methods

Research Questions	Data Sources	Analysis Methods
Do students internalize expert-generated concept maps as their own and recreate them to represent their own knowledge structures in the long term?	Student- and instructor-generated concept maps	Statistical comparison: experimental and control measures of student-to-instructor concept map similarity scores
Are students presented with expert-generated concept maps on a regular basis more likely to understand the relationships between key concepts explicitly connected in those maps?	Open-response conceptual questions	Statistical comparison: experimental and control scores on conceptual questions
What is the correlation between individual links drawn in student-generated concept maps and meaningful understanding of the relationship between the linked topics?		Correlation between presence or absence of specific links in concept map to scores on specific items in the conceptual questions

To answer the first research question, students in all groups were asked to create concept maps of topics related to engineering structures. This subject area was chosen because of the equitable coverage of the subject between universities. A common set of concepts related to this subject were agreed upon by the instructors and given as the starting point for concept map construction. In this way, the students were only responsible for organizing and linking the topics, not coming up with the topics themselves. This was done to make the comparison of maps a more objective process. No link labels were used, again for the objectivity of comparison, though directed links were used where students were asked to draw the arrow from the topic they would teach first to the topic they would teach second. In addition to the student maps, each statics instructor was also asked to create a concept map using the same concepts and process.

To examine the student adoption of presented expert maps, each student's map was compared to their instructor's map. For Instructor A, this was the same map used as an advance organizer during that section of the course. The hypothesis is that students with regular exposure to the advance organizer concept map in class would create maps more similar to their instructors than students without regular exposure to the advance organizer maps.

To measure map similarity, the researchers totaled up the number of links the student and instructor had in common (half points for links with reversed arrows) and divided by the number of links in the instructor map. In this way, the researchers obtained a measure of the percentage of links in common. These similarity measures were then compared with appropriate statistical methods to look for any significant differences.

To answer the second and third research questions, students were asked to answer a set of six conceptual open-response questions related to the topics in the concept map. Each of these questions was mapped to a specific link, effectively serving to test the student's understanding of that relationship. Student responses to these questions were graded for correctness by a single researcher blind to the student group.

To specifically address the second research question, scores from each group were compared with appropriate statistical tests to determine any significant differences. The hypothesis is that students with regular exposure to the concept map advance organizer would better understand the relationships between concepts, since the concept maps highlighted these relationships.

To specifically address the third research question, individual responses to each question were mapped back to the presence or absence of that link in the student map. In this way, the researchers could correlate the link in the concept map to a second independent measure of the understanding of that relationship, with the hypothesis that link presence and correct answers would be highly correlated.

4. Results and Discussion:

4.1 Student to Instructor Concept Map Similarity Scores:

Once the data was collected, the similarity score between a student's map and their respective instructor's map was calculated as described above. Some examples of high and low similarity maps are shown in Figure 1.

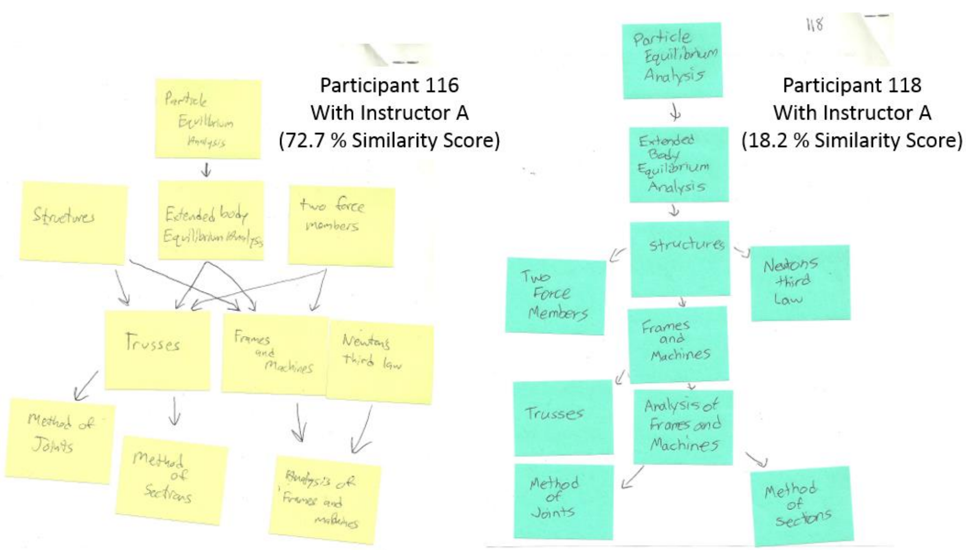

Figure 2: Examples of student concept maps with high and low similarity scores (compared to Instructor A's map presented in Figure 1)

A summary of all of the calculated similarity scores is presented in Table 3 below.

Table 3: Overview of Research Participants

University	Statics Instructor	Expert Map Exposure	Mean Similarity Score	Similarity Score Standard Deviation	Median Similarity Score
University A	A	Yes	39.9%	17.1%	45.5%
University B	B	No	31.1%	21.2%	25.0%
University C	C	No	33.8%	15.1%	33.3%
	D	No	29.6%	9.5%	33.3%

The original hypothesis was that regular exposure to an expert-generated map (as with Instructor A) would lead to students largely recreating that map as their own, thus having higher similarity scores. To test this hypothesis, similarity scores from Group A were compared to the similarity scores from Groups B-D using a Mann-Whitney U Test (also sometimes called a Wilcoxon Rank Sum Test). This non-parametric test was used because the similarity scores proved to be non-normally distributed according to a Chi-Square Goodness of Fit Test at the 95% confidence level.

Results from the Mann-Whitney Test did not find significant differences at the 95% confidence level (P=.06), though with the experimental group having the largest average and median similarity scores, significant differences may show up with larger sample sizes.

4.2 Relationship Question Results:

Next, the correctness of the answers to the relationship questions was compared between groups. A summary of the results of the relationship questions can be seen in Table 4. Again, responses to each of the six short answer questions was graded simply as correct or incorrect by a researcher blind to group assignment.

Table 4: Overview of Research Participants

University	Statics Instructor	Expert Map Exposure	Average Relationship Question Score (out of 6)	Relationship Score Standard Deviation	Median Relationship Question Score (out of 6)
University A	A	Yes	1.89	1.19	2
University B	B	No	1.47	1.33	1
University C	C	No	0.92	0.92	1
	D	No	1.11	0.87	1

The original hypothesis here was that students with regular exposure to expert-generated concept maps that highlight the relationships between ideas (as with Instructor A) would lead to higher scores on the relationship questions. To test this hypothesis, relationship scores from Group A were compared to the relationship scores from Groups B-D using a Mann-Whitney U Test. This non-parametric test was again used because the relationship scores also proved to be non-normally distributed according to a Chi-Square Goodness of Fit Test at the 95% confidence level.

Results from the Mann-Whitney test for this comparison did find a significant difference (P=.029), indicating that the students with regular exposure to the expert-generated concept maps had a better understanding of the relationships between topics than their peers without exposure to concept maps.

4.3 Link to Relationship Question Correlation:

To test the correlation between specific links in student concept maps and the questions designed to test the given relationship, we used the Phi Coefficient Test. This is designed to test the correlation between two Boolean values. In this case, we were testing the relationship between the presence or absence of a specific link and a correct or incorrect answer to the corresponding relationship question.

Overall, each of the six questions was mapped to one of five specific links, and each of those six correlations was tested. Of the six possible correlations, none was found to be significant at the 95% confidence level. Based on this result, the researchers found no evidence linking the presence or absence of given links to the correctness of answers directly related to those linked concepts.

5. Conclusions:

Overall, results of the study were mixed, with exposure to expert-generated concept maps showing a significant positive impact on the overall scores on conceptual relationship questions and a positive, though not significant, impact on map similarity. This indicates that the students with exposure to expert-generated maps may have internalized them and definitely understood the relationships between key concepts better.

However, the researchers were unable to map specific links to specific questions, indicating that the presence or absence of any particular link may have little relationship to the understanding of key conceptual relationships.

Past research has shown a clear positive impact on student learning for using expert-generated concept maps as advance organizers, and this study backs up that claim, but questions as to the intermediate phases of the learning process still remain. Additionally this research shows the difficulty in linking specific map structures to specific bits of student understanding, indicating that student concept map assessment should take a big picture view, as alternative concept map assessment methods already do, rather than focusing on the specific structures.

6. Limitations and Future Work:

Though this work shows some promising results, the study has some limitations as well. The most prominent limitations were probably class size and differing instructors between groups. The small class size for the experimental group allows flexibility in teaching methods, but it also limits the ability to identify statistically significant results. Additionally, instructors and students understandably varied from university to university and from section to section. Differences between instructors beyond the use or non-use of concept maps will invariably have an effect on the research measures, but the use of multiple control groups was designed to maximize the chance to identify the unique characteristics of the experimental group. In the end, the researchers worked to make best use of the participating class sections while also not purposefully compromising instruction for any participating students.

With some promising results apparent, the researchers hope to further this research with larger multi-section courses where sample sizes will be larger and instructor-to-instructor variability can be eliminated as a confounding variable. The researchers hope to re-investigate the similarity between instructor and student maps, as this result was inconclusive, and to more holistically examine the relationship between conceptual understanding and concept map structure as individual links do not seem to correlate with specific bits of conceptual understanding.

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Appendix A:

Concept Map Generation Prompt

Use the back of this page to create a concept map of the following topics as shown in the video tutorial:

- Trusses
- Frames and Machines
- Rigid Body Equilibrium Analysis
- Method of Joints
- Structures
- Method of Sections
- Analysis of Frames and Machines
- Newton's Third Law
- Two Force Members
- Particle Equilibrium Analysis

Relationship Questions:

1. How are two force members relevant to trusses?

2. When using the method of joints, what type of analysis or equations can we use?

3. How are frames and machines related to engineering structures?

4. Why are the weights of members in a truss assumed to be negligible or act on the ends of the members?

5. How is the method of sections similar to the analysis of frames and machines?

6. What is the relationship between Newton's third law and the analysis of frames and machines?