AC 2012-4578: TOWARDS AN "ADAPTIVE CONCEPT MAP": CREATING AN EXPERT-GENERATED CONCEPT MAP OF AN ENGINEERING STATICS CURRICULUM

Mr. Jacob Preston Moore, Virginia Tech

Jacob Moore is a Ph.D. candidate in the Department of Engineering Education at Virginia Tech.

Dr. Robert Scott Pierce, Sweet Briar College

Robert Scott Pierce is an Associate Professor of physics and engineering at Sweet Briar College in Sweet Briar, Va. He received his Ph.D. in mechanical engineering from Georgia Tech in 1993. Prior to his teaching career, he spent 13 years in industry designing automated equipment.

Dr. Christopher B. Williams, Virginia Tech

Towards an "Adaptive Concept Map": Creating an Expert-Generated Concept Map of an Engineering Statics Curriculum

Abstract

Concept maps are graphical representations of cognitive knowledge structures. Although they were originally developed as a way to follow and understand changes in student knowledge, they have proven to be effective instructional tools. Concept maps consist of labeled nodes that represent concepts, or perceived regularities or patterns, and links that are labeled to indicate the relationships between the nodes. Current work with concept maps is limited to small maps that cover only sections of a class or the entire class at a high level of abstraction. Due to problems in interpreting concept maps with numerous nodes and links, maps of larger domains are limited in the detail the can represent. The authors are exploring the use of interactive digital tools as a way to present large-scale concept maps that organize information and show connections across the curriculum without overwhelming the user visually. As an exemplar, the authors have chosen the content in an engineering statics course. If successful, the concept mapping tool could be used to cognitively link information between courses in engineering mechanics and then across the entire engineering curriculum. As the first step in this process, the authors set out to capture an expert's knowledge of engineering statics in the form of a course-wide concept map. This paper details the process of capturing expert knowledge of a course and organizing this information into a concept map that accurately represents the information taught in the course.

1. Introduction and Motivation

Concept maps are node-link diagrams that are designed to visually mimic a person's cognitive schemas. They have been widely and effectively used as instructional tools in engineering classrooms (Sections 2.1 and 2.2). Concept maps highlight the relationships between information that the students learn, and help promote a more cohesive view of the content that is being learned.

Large scale maps, maps that could be used to outline and link all the information taught in an entire course or even an entire curriculum, have the potential to be extremely powerful learning aids because of the cohesiveness of knowledge they would promote. Interpreting large-scale concept maps is difficult however, due to the user's cognitive limitations (Section 2.3). These cognitive limitations lead to problems learning with large-scale concept maps. The authors are currently exploring ways to mitigate the problems associated with interpreting large-scale concept maps using interactive digital technologies. Doing so will unlock the potential of large-scale concept maps as learning tools and enable the creation of concept maps that connect information throughout an entire engineering curriculum (Section 2.4).

As a first step in achieving this research goal, the authors must first create a large-scale concept map. Current concept map generation processes were found to be an insufficient guide as they are inherently designed to limit the scope of the concept map in order to avoid the difficulties found in interpreting large maps. As such, the purpose of this work is to present a process that guides the generation of large-scale (e.g., course-wide) concept maps.

In Section 2, the theory of concept maps, their educational impact, and their creation process are reviewed. The authors' approach for presenting large-scale concept maps is presented in Section 3. The approach is detailed through its use in creating a concept map for an engineering statics course. In Section 4, preliminary validation of the process is presented in the form of feedback from an expert review. Closure is offered in Section 5. The authors' hope is that others wishing to create concepts maps of entire courses may benefit from the process presented in this paper.

2. Background

2.1 What Are Concept Maps?

Concept maps were first developed in 1972 by Joseph Novak and his colleagues as a way to visualize what students did and did not know [1]. Novak and Cañas present an outline of information on concept mapping, in the form of a concept map, in Figure 1 [1]. The nodes in a concept map are labeled with concepts, a set of regularities observed by the person, while the links are labeled to represent the relationships between the concepts. Taken as a whole, the concept map should represent the extent and the organization of knowledge that a person possesses.

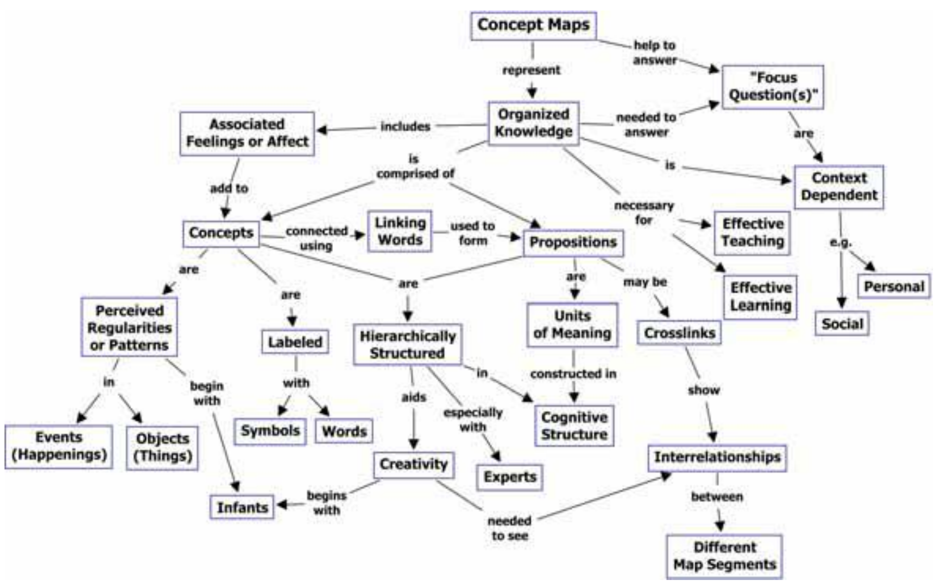

Figure 1
A concept map about concept mapping [1]

2.2 How Do Concept Maps Aid Learning?

Concept maps can fill one of two instructional roles: (i) students can either be assigned to create a concept map of their knowledge as a reflective learning exercise after instruction, or (ii) students can be given an "expert-generated concept map" before instruction which serves as an "advance organizer" [2] – a type of scaffolding tool. In both of these applications, concept maps have been shown to facilitate meaningful learning across a wide variety of settings, grade levels, and content areas [3].

To use concept mapping as a reflective learning activity, students are first given instruction in the form or readings, lectures, or other activities. Following the instructional unit, the students are asked to reflect upon the content and to create a concept map of the information they learned. The process of creating the concept map of the content is a meta-cognitive activity that improves the understanding and the retention of the information learned [4].

To use concept maps as advance organizers, an expert creates a concept map of their content knowledge for a particular instructional unit. To create an effective concept map advance organizer, the following should be true [2]:

- The concept map should be presented before and/or during the instructional unit.
- The concept map should be constructed at a high level of abstraction, focusing on the main ideas from the unit and avoiding small details.
- The concept map should avoid technical jargon, speaking to those who do not already know the content domain.
- The concept map should provide anchor concepts: concepts that the learner should already know that the learner can relate the novel ideas to.

When created with the above in mind, concept maps can serve as powerful advance organizers, leading to better understanding and retention of information [5].

In engineering mechanics courses such as statics, dynamics and mechanics of materials, research has shown promise for using concept maps as advance organizers [6], [7]. Although no research has been performed specifically in the context of engineering mechanics courses, one would expect concept mapping to be an effective reflective learning activity in such courses, as they have been successfully used in similar courses such as physics [8].

2.3 How Are Concept Maps Created?

The process of creating concept maps, as outlined by Joseph Novak, is as follows [1].

1. When creating an expert-generated concept map, locate an expert. This is someone who is very familiar with the content and is an expert problem solver in the domain.
2. Set the limit and context for a concept map by having a focus question. This is a single question that the knowledge represented by the concept map should answer.

3. Write down all the concepts related to the question using either a concept mapping software, or using adhesive notes. Generally, 15-25 concepts are recommended.
4. Organize the concepts by moving them around and drawing links between nodes that indicate the relationship between the two concepts.

As is evident in the above process, current methods limit the scope of the concept map. The established process works well to create concept maps for smaller instructional units, but a single focus question with 15-25 concepts is insufficient to capture the curriculum of an entire course.

The limitation on scope is imposed due to limitations in the size of a concept map that can be effectively interpreted by a learner. The problems learners experience in interpreting large scale concept maps have been labeled "map-shock" [9]. Map-shock is a cognitive and affective reaction that a learner has to the presentation of an overly large and complex concept map. This reaction leads to the incomplete processing of the concept map reducing its effectiveness as an advance organizer.

2.4 What are the Potential Uses for an Expert-Generated Course-Wide Concept Map?

Because large and complex concept maps can induce map-shock for viewers, they are not directly useful as advance organizers. Though expert-generated course-wide concept maps are too large and unwieldy to be useful advance organizers, they do have potential uses as pedagogical tools.

The first potential use of course-wide concept maps is to use the concept map as a lesson or curriculum planning tool. By mapping all course concepts and their interrelationships, the instructor gains insights into the order in which information should be presented and can quickly identify any conceptual gaps that may be present in their instructional plan. Research has shown that instructors who were introduced to concept mapping as part of the lesson planning process have found the strategy helpful and have continued to use the strategy in lesson planning [10], [11]. Additionally, instructors in highly interconnected courses, such as statics, dynamics and mechanics of materials, can use course-wide concept maps to clarify and negotiate the content covered in each course. The instructors can directly examine how information in each course flows into the next, ensuring there are no gaps in knowledge between the prerequisite and post requisite courses.

Another potential use for course-wide concept maps is as an expert-generated map that could aid with scaffolding a student's cognitive framing of the curriculum. In order to mitigate learning-losses associated with map-shock, the authors are currently researching the use of an interactive digital system designed to manage concept map presentation in a manner that follows information visualization best practices. This tool, termed the "adaptive concept map," is a software prototype that adjusts a digital display in order to provide user control over the amount of information displayed in a concept map at any one time.

By managing the amount of information displayed, the course-wide concept map could be used as a cohesive advance organizer that promotes conceptual understanding for an entire course. This adaptive map tool could be used as a navigation system for digital course textbook, and should promote conceptual understanding of the material across the entire course, just as static maps have enhanced learning for smaller digital texts [12–14].

3. Course-Wide Concept Map Creation Process

3.1 The General Process

The general process developed by the authors to capture the knowledge of an expert in the form of a course-wide concept map is as follows:

1. Locate an expert. This is someone who is very familiar with the content and is an expert problem solver in the domain.
2. Use existing textbooks and course syllabi to brainstorm concepts that are covered in the course. Record these concepts using either a concept mapping software, or by writing the concepts down on small adhesive notes.
3. To facilitate the organization of the concept map, first group the concepts by placing the concepts into groups that are traditionally taught together. Form labels for these groups and definitions of what does and does not belong in each group. Continue grouping and adjusting group labels until all concepts are placed in a group.
4. Check for repeated or extraneous concepts in each group. Remove these concepts.
5. Within each of the groups, organize the concepts in a concept map by drawing links that indicate the relationships between the nodes in the group.
6. After concept maps have been made for each group, draw in the cross links (links between concepts in different groups).
7. Revise and refine the concept map through discussion with other experts and students learning the material.

The above steps are applicable to any engineering course, and should result in a concept map of that course. The strategy presented here differs from the process presented in Section 2.3 in two major ways. First, the new process uses a bottom-up concept generation strategy where existing materials are used to guide brainstorming, rather than using a top-down focus question approach. Second, in order to deal with the large number of concepts, all concepts are grouped as an intermediate step towards structuring the concept map. Details on the new process, the motivation behind each step and examples on each part of the process are discussed in Section 3.2.

3.2 The Process Exemplar of Engineering Statics

In this section, the authors present an example of using the general process described in Section 3.1. Specifically, the authors present the creation of a concept map for an Engineering Statics course.

Step 1:Expert Consultation

The process of creating a concept map of engineering statics was intended to capture the knowledge of an expert in the domain of engineering statics. The researchers selected an expert in the domain by seeking a faculty member who had been teaching engineering statics for many semesters. It was assumed that the experience of teaching a course in engineering statics many times would lead to well-developed cognitive schemas that are a trademark of expertise. To ready the expert for the whole process, the researchers first explained what concept maps were and how they can be used (as is described in Section 2) so that the expert would understand what was being asked of him.

Step 2: Concept Brainstorming

Researchers decided to model the new concept map development process on the existing process for developing work activity affinity diagrams [15]. Work activity affinity diagrams (WAADs) are implemented by user interface designers in computer science to organize the large quantities user data, collected through surveys, interviews and observations, into coherent themes. These diagrams can then be used by the software developers as a tool for improving the interface design. Where the raw user data is too disorganized and unwieldy to be an effective guide for the developers, the WAAD is an effective guide because it is more organized and manageable. The process for developing these WAADs matches the current task because work activity affinity diagrams take the form of large node-link diagrams, much like the desired course-wide concept map.

Because the use of a single focus question was insufficient for identifying the scope of engineering statics with any degree of specificity, researchers did not use a focus question. An alternate approach was based on the development process for WAADs where developers use large stores of user feedback to generate nodes for the WAAD. For the course-wide concept map development process, researchers also adopted a bottom-up approach, referencing existing materials during brainstorming to ensure that all concepts covered in a typical engineering statics course were present in the concept map. A researcher worked with the expert and existing materials in the form of course syllabi from two universities and four existing engineering statics textbooks [16–19] to help define the content included in the concept map of engineering statics.

To generate a list of concepts, the nodes in the concept map, researchers read through the existing materials and listing all potential concepts on adhesive notes. A concept, as defined by Joseph Novak, is "a perceived regularity in events or objects, or records of events or objects, designated by a label" [1]. This definition allows for both very specific concepts (such as a space truss) and very broad concepts (such as engineering statics). To ensure that concept map was as detailed as possible, the expert was told to take the narrowest possible definition of the concept, assuming no concept was explicitly contained within another concept. The concept generation phase of the map development was intended to be a brainstorming process. The focus was on the generation of as many concepts as possible in order to ensure complete coverage of the course content. This resulted in more than 100 separate concepts that were taught in the course.

Steps 3 and 4: *Concept Grouping*

After each concept was written on the adhesive notes, the notes were placed on a white board for organization. The first step in the organization process was to cluster the concepts into groups of concepts that are usually taught together. Just over ten groups were formed, labeled “chapter groups” by researchers. During the grouping process, repeated concepts and extraneous concepts were eliminated, subsuming concepts (concepts that could be broken into two or more sub concepts) were broken up, and missing concepts that were identified were added. The concept grouping process involved dialog between the researcher and the expert which was aided by manipulation of the concept notes on the white board. During the grouping process, the nature of the links between the concepts was intentionally ignored. The researchers focused solely on identifying concepts that “go together”.

The dialog was intended to draw out the expert’s reasoning behind the groups and why each concept was in the specified group. By making the expert articulate his ideas, this helped clarify the groupings and the boundaries of those groupings. The “Friction” chapter group developed by the researchers is shown in Figure 2 with all the concepts in the group.

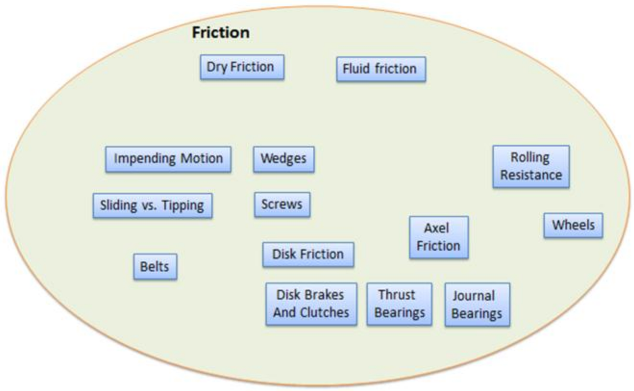

Figure 2
The concepts assigned to the friction chapter group

Step 5: *Linking within Groups*

Once the chapter groups were formed, the researchers considered each group independently in order to identify the nature of the links between concepts within a group. First, the concepts in a group were examined for hierarchical relationships. These hierarchical relationships are characterized by a higher-level concept, for which an understanding or application leads to a lower-level concept. For example, in the “Forces” chapter group the concept of a force is a higher-level concept, the understanding of which leads to the lower-level concepts of point forces and distributed forces. Identification of these hierarchical arrangements of concepts was an important first step to assigning links between them.

After the concepts in a chapter group were arranged hierarchically, the concepts within the group were considered in pairs in order to identify those concept pairs that have a direct linking relationship. Each linked pair was designated by connecting the concepts with an arrow, starting at the “source concept” and ending at the “destination concept.” The source concept was generally defined as the concept that would logically be taught first in the pair. As each link was identified, the nature of the link between the two concepts was described. Through this process the researchers found that all of the concepts in the map could be linked using one of six general linking relationships:

- ALT - Destination concept is an *alternate* representation or model of the source concept (a non-directional link).
- APP - Source concept is *applied* in the destination concept.
- CON - Source is a *concept* that is required in order to define destination.
- DRV - Destination concept is mathematically *derived* from the source concept.
- MTH - Destination concept is a *method* used in a situation described in the source concept.
- SUB – Destination concept is a *subset* of the source concept.

By assigning one of these linking relationships to each link within a chapter group, a concept map for each chapter group was generated. The "Friction" chapter group from Figure 2 is further developed by linking concepts within the group (shown in Figure 3).

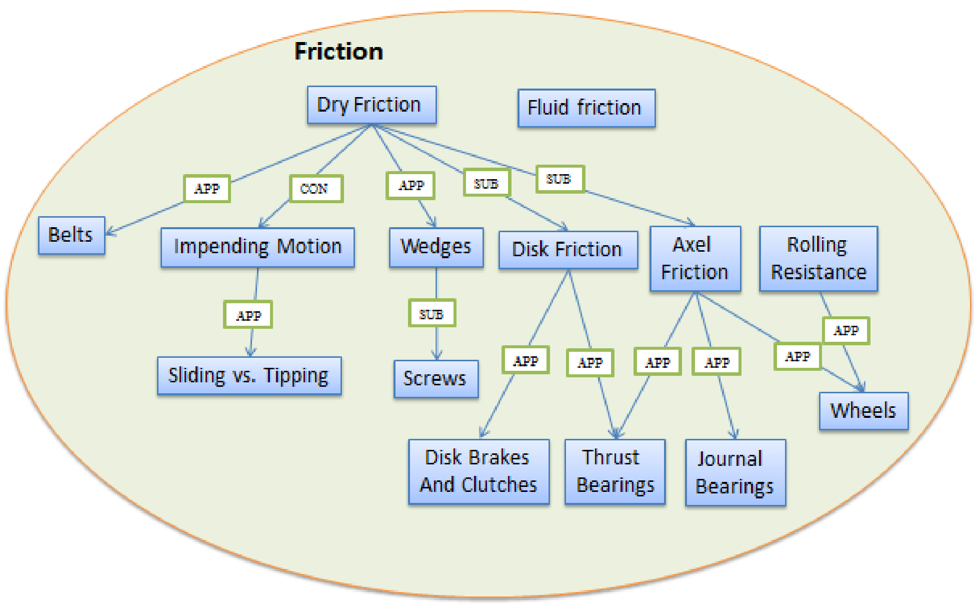

Figure 3
Relationships between the friction chapter concepts added

Step 6: Linking across Groups

Next, each chapter group was inspected in order to identify links that are external to the group. These are links between concepts in different concept groups. For example, the concept of a "point force" that is contained in the "forces" chapter group is linked to the concept of "cables with point loading" that is contained in the "flexible cables" chapter group. As each external link was identified, it was assigned one of the six linking relations described above. As seen in

Figure 4, the crosslinks that connect concepts in different chapter groups (the white boxes represent links to concepts in chapter groups displayed elsewhere on the concept map) are added.

The collection of all chapter groups along with their internal and external linking relationships constitutes a complete concept map for engineering statics. It is possible to display the entire map in a single graphic by including all chapter groups and connecting all of the external links. Such a graphic, while complete, would be of limited use as a teaching tool due to the problem of map-shock discussed in Section 2.3.

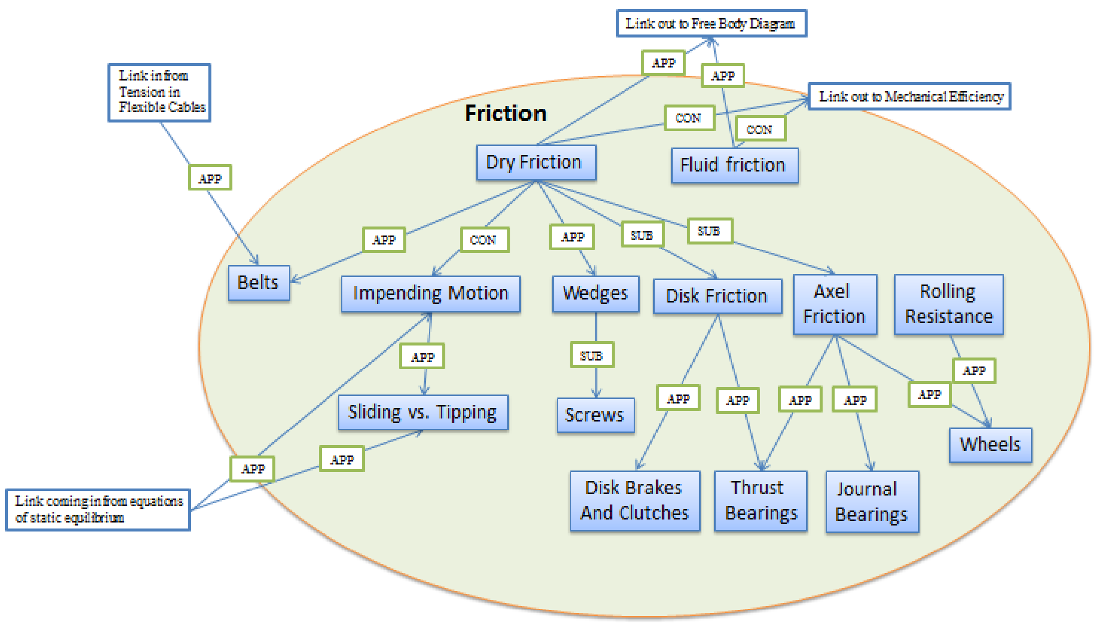

Figure 4
Relationships to concepts in other chapter groups added

Step 7: Revise and Refine

After the crosslinking of the concepts was complete, the first draft of the concept map was deemed to be complete. Using the concept map to develop and create instruction (in the form of instructional web pages to be used in the adaptive map; Section 2.4) has led to many revisions of the map. Just as in product design, there is no one "correct" concept map for any given subject, and continuous revision and improvement are possible. The concept map created with the above process was a starting point. Feedback from the use of the concept map as either an instructional design tool or as a learning tool for students should be used to further refine the concept map.

The complete concept map of engineering statics developed by the researchers is too large to be displayed in the paper. The most current version of the course-wide concept map for engineering statics can be viewed at the following website:
http://filebox.vt.edu/users/moorej7/statics_concept_map.pdf

4. Concept Map Validation

In order to validate the course wide concept map, the map was reviewed by a secondary experienced statics instructor that was external to the original concept map creation process. This external expert was given instruction on what concept maps are and how they are constructed (similar to the instruction given to the original statics expert, Section 3.2 - Step 1). The external expert was then given a copy of the complete concept map of engineering statics and asked to review the map for completeness and for accuracy and to record any changes or additions they would recommend. After the external evaluator had sufficient time to review the map individually, the external evaluator met with one of the researchers. The researcher and the external evaluator went through the evaluators notes, discussing each of the notes the evaluator prepared.

The evaluator did not suggest any major revisions, indicating that the course-wide concept map developed was largely complete and accurate in the eyes of the outside expert. The evaluator did suggest the modification of several links, the subtraction of three concepts, and the addition of two more concepts. With a map of more that ninety concepts however, this is a high ratio of agreement between the experts.

Future evaluation with students in an instructional environment is needed to validate the course-wide concept map as an effective learning tool; however, map-shock will prevent the course-wide concept map from being effective in its current state. The authors intend to validate the course-wide concept map in conjunction with the adaptive map prototype. By using the adaptive map software to view and interact with the statics concept map developed here, students should be able to use the statics concept map effectively as an advance organizer. Only once the software is developed to mitigate map-shock can the course-wide concept map be effectively validated as an instructional tool.

5. Closure

In this paper, the authors present a process for developing concept maps for an entire engineering course. In addition, the authors validated its use in the creation of a map for an engineering statics course. Course-wide concept maps have the potential to serve as useful tools for both instructional design and as learning tools for students, though more research is needed to explore their full potential.

The outlined process of developing the course-wide concept map contributes to the field of engineering education by enabling course-wide concept maps to be created for other engineering courses. By building a set of course-wide concept maps and connecting these maps, instructors and students alike can examine how knowledge in higher-level courses builds upon foundational courses. This can lead to a more holistic view of the knowledge that students are learning in their engineering courses.

The concept map of the domain of engineering statics contributes to the field of engineering education by helping better understand the concepts taught in engineering statics and how they are interrelated. By explicitly outlining the concepts to be taught and their relationships to one another, the concept map can help instructors and students alike form a more cohesive understanding of the body of knowledge taught in the engineering statics.

To build upon this work in the future, the authors will implement the adaptive map tool described in Section 2.4 to present the course-wide concept map of engineering statics as an advance organizer that does not induce map shock. The researchers will then evaluate the cyber-infrastructure system as a learning tool in an educational setting. This forthcoming research should help further define the potential of large-scale concept maps in engineering education.

6. Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. NSF DUE-1044790. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. The authors would also like to thank Christopher Venters for offering his expert review of the developed Statics concept map.

7. References

[1] J. D. Novak and A. J. Cañas, "The Theory Underlying Concept Maps and How to Construct and Use Them," Technical Report Cmap Tools 2006-01 Rev 01-2008, 2008.
[2] D. P. Ausubel, *Educational Psychology; a Cognitive View*. New York, NY: Holt, Rinehart and Winston, 1968.
[3] J. C. Nesbit and O. O. Adesope, "Learning With Concept and Knowledge Maps: A Meta-Analysis," *Review of Educational Research*, vol. 76, no. 3, pp. 413 -448, Fall 2006.
[4] K. Y. Lim, H. W. Lee, and B. Grabowski, "Does Concept-Mapping Strategy Work for Everyone? The Levels of Generativity and Learners' Self-Regulated Learning Skills," *British Journal of Educational Technology*, vol. 40, no. 4, pp. 606–618, 2009.
[5] J. D. Novak, *Learning, Creating, and Using Knowledge: Concept Maps as Facilitative Tools in Schools and Corporations*. New York, NY: Taylor & Francis, 2010.
[6] P. J. Cornwell, "Concept maps in the mechanical engineering curriculum," in *Proceedings of the 1996 ASEE Annual Conference*, 1996.
[7] G. W. Ellis, A. Rudnitsky, and B. Silverstein, "Using concept maps to enhance understanding in Engineering Education," *International Journal of Engineering Education*, vol. 20, pp. 1012–1021, 2004.
[8] W. J. Pankratius, "Building an organized knowledge base: Concept mapping and achievement in secondary school physics," *Journal of Research in Science Teaching*, vol. 27, no. 4, pp. 315-333, Apr. 1990.
[9] J. Blankenship and D. Dansereau, "The Effect of Animated Node-Link Displays on Information Recall," *The Journal of Experimental Education*, vol. 68, no. 4, pp. 293-308, 2000.
[10] J. D. Novak and D. B. Gowin, *Learning how to learn*. Cambridge University Press, 1984.
[11] D. J. Martin, "Concept mapping as an AID to lesson planning: A longitudinal study," *Journal of Elementary Science Education*, vol. 6, no. 2, pp. 11-30, Oct. 1994.
[12] K.-E. Chang, Y.-T. Sung, and S.-K. Chiou, "Use of Hierarchical Hyper Concept Map in Web-Based Courses," *Journal of Educational Computing Research*, vol. 27, no. 4, pp. 335-353, Feb. 2003.

[13] J. W. Coffey, “LEO: A Concept Map Based Course Visualization Tool for Instructors and Students,” in *Knowledge and Information Visualization*, vol. 3426, S.-O. Tergan and T. Keller, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2005, pp. 285-301.
[14] R.-S. Shaw, “A Study of Learning Performance of E-learning Materials Design With Knowledge Maps,” *Computers & Education*, vol. 54, no. 1, pp. 253–264, 2010.
[15] R. Hartson and P. Pyla, *The UX Book: Ensuring a Quality User Experience*. Morgan Kaufmann, 2011.
[16] D. J. McGill and W. W. King, *Engineering Mechanics: Statics*, 2nd ed. PWS Kent Publishers, 1989.
[17] J. L. Meriam and L. G. Kraige, *Engineering Mechanics: Statics*, 6th ed., vol. 1. John Wiley & Sons Inc, 2007.
[18] W. F. Riley and L. D. Sturges, *Engineering Mechanics: Statics*, 2nd ed. John Wiley & Sons Inc, 1996.
[19] W. F. Riley, L. D. Sturges, and D. H. Morris, *Statics and Mechanics of Materials: An Integrated Approach*. John Wiley & Sons Inc, 1995.