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Promoting Conceptual Understanding in Engineering Statics Through the Use of Adaptive Concept Maps

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PROMOTING CONCEPTUAL UNDERSTANDING IN ENGINEERING STATICS THROUGH THE USE OF ADAPTIVE CONCEPT MAPS

Abstract:

In this paper, the authors discuss their continuing work on a NSF TUES Phase 1 project in which they are exploring the feasibility and effectiveness of a scalable concept map as an organizational tool for a digital textbook. This tool, termed the Adaptive Map, is designed to promote students' conceptual understanding by using an expert-generated concept map as an advance organizer. Because large concept maps become visually cluttered and are therefore less effective as learning tools, information visualization techniques have been employed to visualize the digital concept map content. These techniques structure the visual organization of the map for the content based on the users' current focus, which provides them context for detailed content information while also managing the cognitive load imposed on the learner. The authors are exploring the tool's effect on conceptual understanding and cognitive load. To measure the tool's effect on conceptual understanding, researchers are using verbal explanation sessions, and the Statics Concept Inventory. To measure cognitive load, researchers used self-reported values of mental effort during the data collection sessions, which were designed to ensure that students needed to explore content using the Adaptive Map or their regular textbook. Preliminary results indicate that if students are given an opportunity to adapt to the radically different format of the Adaptive Map, they prefer the Adaptive Map tool to their traditional paper textbook. The data also seems to suggest that the students studying with the Adaptive Map tool tend to focus more on conceptual knowledge, where students studying with the traditional paper textbook tend to focus more on procedural knowledge.

1. Motivation:

Within the engineering education community, there have been recent calls to radically redesign the higher education system to better prepare students for the future workplace [1, 2]. In an increasingly global and competitive marketplace, the workforce requires engineers to be both innovative and creative in the work they do [3]. In order to develop students as adaptive experts in their domain areas [4], students need to develop a conceptual understanding of the knowledge in their chosen domain [5]. Research has shown, however, that many students still have significant misconceptions in a variety of core engineering subjects [6].

Since time in the classroom is only part of the learning experience that students encounter, it is important to develop educational tools that promote conceptual understanding both inside and outside the classroom. One particular tool that is widely used outside the classroom, but is often criticized by engineering education researchers, is the textbook. Textbooks are a familiar tool to most students today, as they have used throughout their K-12 education and on into college. The textbook can serve as a type of content repository, gathering relevant expert-generated domain knowledge together into an organized and central source for a user. The students can then use this information for problem solving or other active learning experiences, where the textbook serves as a just-in-time way to learn the information.

Often viewed as a staple of the obsolete "sage on the stage" teaching style, the conventional textbook is seen as tool that presents information in a lockstep, linear fashion. Experts on the other hand have highly interconnected cognitive schemas that do not match the way information is presented in these textbooks. Digital textbooks do not need to be linear tools in the way that paper textbooks are though; they can be constructed to more closely match the way knowledge is stored in memory and therefore promote more effective learning strategies. The traditional notion of a textbook is in need of change, and this change should be guided by what we know about how people learn.

The overall purpose of this proposed research is to help students develop conceptual understanding, which will lead to more adaptive graduates. The proposed way to accomplish this is through an innovative visualization tool to better organize and present the information in digital textbooks. The purpose of this paper is to discuss the ongoing efforts to do this. In Section 2 of this paper, the authors discuss the theoretical basis behind the design of the Adaptive Map tool, in Section 3 the authors provide an overview of how the Adaptive Map tool works, and in Section 4 the authors discuss preliminary results of an evaluation of the tool's usage and effect on conceptual understanding.

2. Theoretical Basis:

To design an effective visualization tool to better organize and present the information in digital textbooks, the authors draw from a number of different theories and methodologies. First, to understand the goals of the proposed tool, the authors draw from the literature on adaptive expertise, conceptual understanding, and meaningful learning. Second, to understand existing tools that are used to promote conceptual understanding, the authors draw from literature on advance organizers and, in particular, concept and knowledge maps as advance organizers. To understand problems with the existing tools, the author critically examines the map-shock phenomenon and draws from literature on cognitive load theory to better characterize map-shock. Finally, the authors draw from information visualization literature as a guide to possible solutions to the map-shock problem, which would allow concept maps to be scaled up as instructional tools without losing their effectiveness.

Adaptive expertise [4] is a type of expertise that can be developed in which the expert demonstrates both efficiency and flexibility in problem solving. This flexibility in problem solving is an extremely valuable skill as an engineer and therefore engineering universities and colleges should work to develop adaptive expertise in their students. What separates adaptive experts from routine experts (the opposite of an adaptive expert) is conceptual understanding [5]. Finally, in order to develop conceptual understanding, the student needs to experience meaningful learning activities [7]. Since textbooks serve as collection of expert knowledge, the tool being developed should promote meaningful reception learning in order to develop adaptive expertise in the students while still filling its role as a source of information.

The primary tool that Ausubel developed to promote meaningful reception learning was the advance organizer [7]. An advance organizer is a short overview presented at a higher level of abstraction, generality, and inclusiveness given before the detailed presentation of an instructional unit. Advance organizers can take a variety of different forms, but one tool that can serve as a powerful advance organizer is the expert-generated concept map [8]. Expert-generated concept maps are node-link diagrams designed to visually mimic the cognitive structures of the expert. Research has shown that in a variety of settings and domain areas, expert-generated concept maps have a positive effect on learning and retention [9].

The usefulness of expert-generated concept maps as advance organizers is currently limited to small scale activities, however, because of a phenomenon labeled "map-shock". Map-shock [10] is the cognitive and affective reaction to large-scale concept maps that prevents meaningful learning from occurring. Cognitive load theory suggests that the map-shock phenomenon is caused by a learner experiencing cognitive overload due to the plethora of information on view [11]. In order to utilize expert-generated concept maps with large scale instructional units, such as an entire course or the textbook for an entire course, cognitive load needs to be effectively managed.

Although there are prescribed ways to prevent map-shock; existing solutions such as stacked maps [12] and animated maps [10] are not ideal solutions to the problem [13]. As a way to manage cognitive load, information visualization techniques are being utilized by the researchers to the Adaptive Map tool. Information visualization is the field of computer science that deals with displaying abstract data, often large amounts of abstract data, in a way that allows the user to gain insight into the data in accurate and efficient ways [14]. For more information on the theoretical framework of this research and its integration of information visualization theory, consult the author's previous work [13].

3. The Adaptive Map Tool

The Adaptive Map tool uses a large-scale concept map with semantic zooming techniques, where the scope of the material being covered determines the level of detail presented in the visualization. By having the software present only the most relevant information to the user's current focus, the software is helping to manage the cognitive load imposed on the user.

As the information visualization literature suggests, the Adaptive Map tool opens by presenting users with an overview of all of the information in the textbook covered at a high level of abstraction. Beginning with an overview helps users to develop a better sense of the data in the visualization [15]. At this overview level the topics are grouped into clusters of highly related ideas, similar to chapters in a traditional book. Each cluster is represented as a node in the node-link diagram, and the links between the nodes represent direct relationships between the topics in each of the clusters. These links are directed and generally flowing from prerequisite topics to post-requisite topics. The weight of the linking lines is directly correlated to the number of the direct connections between topics in those two clusters. An image of the overview can be seen in Figure 1.

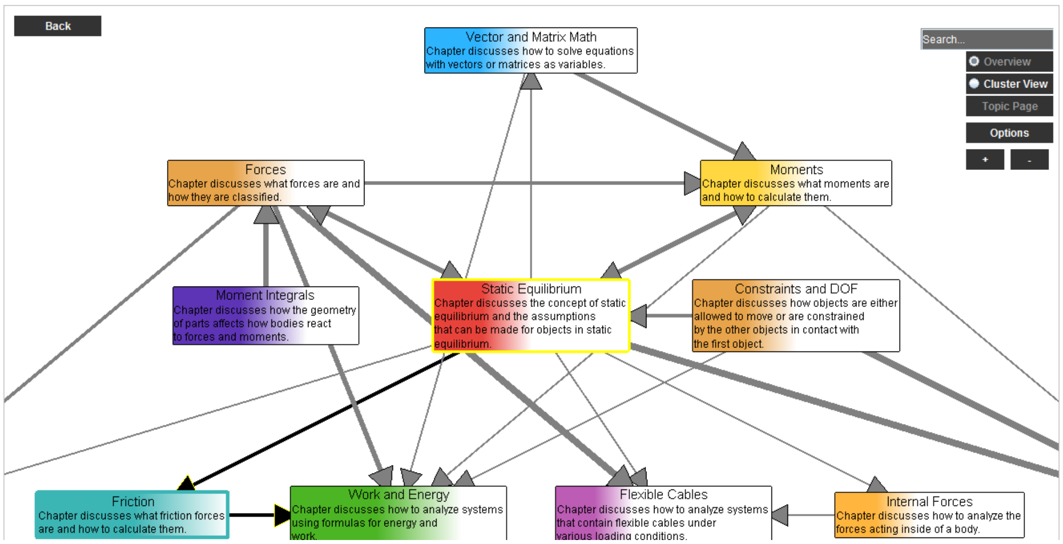

Figure 1: The Adaptive Map Overview

The user at any level can pan by either clicking on cluster nodes to center them on the screen, or by clicking, holding and dragging the background. The user can also zoom in or out using scroll wheel, or by using the + and – buttons on the screen.

If the user zooms in to any one of the clusters in the overview, the cluster node will decompose into topic nodes, via an animation, to provide the user more details on that cluster. These highly interlinked topic nodes are amalgamated in the overview to help manage the load imposed on the user. Each cluster contains several topics, where a topic was defined as the smallest teachable lesson. Information on how the topics and clusters were identified can be found in previous literature [16]. At this level, the topics are represented by individual nodes in the concept map and the relationships between the topics are represented by links. A sample screenshot of the "Static Equilibrium" cluster is shown in Figure 2 (The content currently developed is for an engineering statics course).

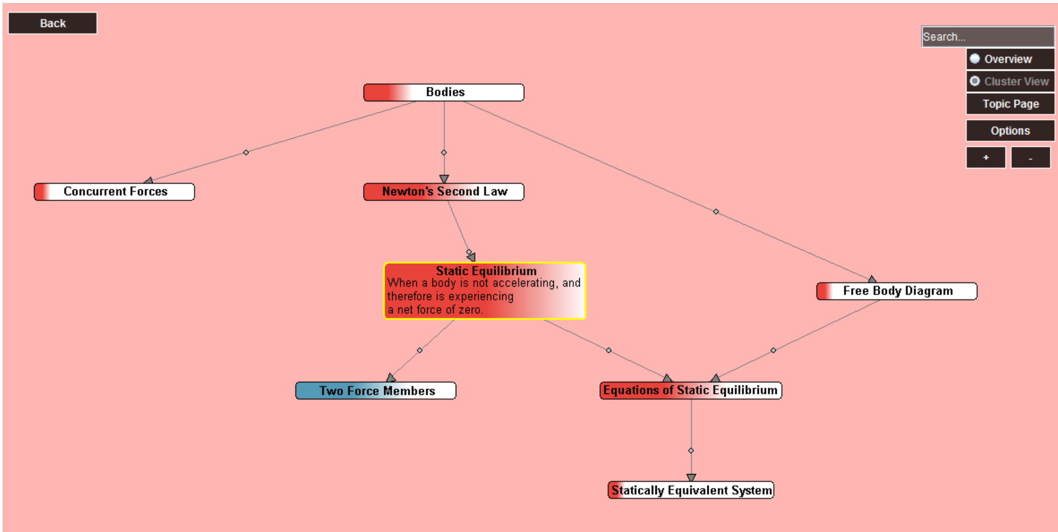

Figure 2: The Cluster View

The concept map represented in Figure 2 is organized according to an automatic graph layout algorithm called Graphviz [17]. The algorithm works to minimize link lengths and minimize link crossings, which have been shown to increase the comprehension of concept maps [12, 18-19]. The background color of the screen, and all the topics within the cluster (Figure 2), match the color of the cluster node in the overview (Figure 1), to indicate a relationship between the cluster node and its underlying topics.

At the Cluster View, any topic that is directly related to the focus topic (the one currently selected with the yellow border) from other clusters is also drawn in. In this case, the “Two Force Member” topic is directly related to the “Static Equilibrium” topic, though the “Two Force Member” topic is part of another cluster. These cross-cluster relationships are amalgamated into the links seen in the overview. More details on the topics and their relationships can be found by hovering over the nodes or links in these views. This design decision follows the “details on demand” part of the information visualization mantra [20].

If one zooms-in further to a topic node, one will view the Topic Page associated with that topic. Topic Pages contain the “smallest teachable lesson” and can contain content explanations, images, videos, and worked example problems. A screenshot of a portion of the “Static Equilibrium” Topic Page is shown in Figure 3.

Figure 3: The Topic Page

Through these three levels of zoom (Overview, Cluster View, and Topic Pages), learners can explore topics, and the relationships between topics, contained in the Adaptive Map. The interface provides controls that allow the user to manipulate the amount of information on-screen. This prevents too much information from being presented at any one time, and allows the users explore the information through smooth transitions that preserve a sense of context in the information [21].

4. Preliminary Results

To assess the effectiveness of the Adaptive Map tool, participants were solicited from two sections of a Statics course at Virginia Tech. The two sections shared a common instructor, common assignments, and common overall course structure. To test the effectiveness the Adaptive Map tool, the Adaptive Map was introduced to one of the two sections near the beginning of the semester (experimental group), while the other was not introduced to the Adaptive Map tool (control group). Volunteers were solicited from the two sections to assist in evaluation of the Adaptive Map tool.

A total of thirteen participants participated in the study to evaluate the effectiveness of the Adaptive Map tool. Of these thirteen participants, seven were members of the experimental group (had access to the Adaptive Map and the traditional paper textbook) and six were of the control group (had access to only the traditional paper textbook). A variety of measures were used to evaluate the participants' conceptual understanding and cognitive load from the either the Adaptive Map or a traditional textbook ([22]) during experimental sessions.

4.1 Adaptive Map Usage

Within the experimental group of seven participants, six of the participants reported using the Adaptive Map tool on a regular basis outside of the research sessions (on average at least once a week). Self-reported reasons for using the Adaptive Map included looking up information to solve homework problems, studying for exams, and catching up after missing class. The majority of the Adaptive Map participants (5/7) reported using the Adaptive Map as much (2/7) or more (3/7) than their regular course text (which they were also required to have for the course). The one participant who did not use the Adaptive Map outside of the research session reported little to no use of either the Adaptive Map or the paper textbook, and instead relied on detailed notes taken during lecture. These results indicate that the tool was adopted as a learning tool by participants in the research group.

More than one hundred and fifty students were introduced to the tool during volunteer solicitation efforts though, most not participating in data collection efforts. Website analytics were used to track the number of users that logged onto the Adaptive Map website. The plot of the number of site visits is shown in Figure 4.

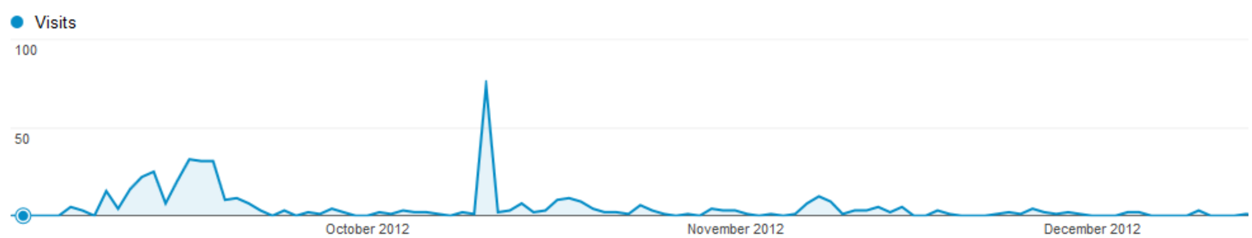

Figure 4: Website Analytics, User Visits Over the Semester

Figure 4 shows that there are two periods of intense activity, but other than those two periods there was fairly minimal usage. These two periods correspond to an evaluation of the tool conducted by an outside course (the first spread out spike in usage) and an in-class demonstration of the tool (the second, sudden spike in usage). Outside of these two windows, usage seems to be primarily limited to the research group. This may indicate a barrier to adoption, where students in the research group were forced to become familiar with the tool through research sessions and then began using the tool outside of the research sessions.

Results for the control group showed that usage of the textbook was reported to be more frequent than usage of the Adaptive Map (paper textbook usage averaged about twice a week). The overwhelming reason for using the textbook, however was to look up homework problems. More than half of the participants in the control group (3/5) reported using their textbooks exclusively for looking up homework problems, and relying on course notes for all other aspects. If this type of usage is neglected (the Adaptive Map did not have any assigned homework problems in it), the Adaptive Map tool showed a far higher usage rate among the research participants.

4.2 Conceptual Understanding

Measuring the tool's effect on conceptual understanding was primarily evaluated through a series of two explanation tasks, where students were asked to study a certain set of topics and then explain those topics to a researcher. The researcher asked probing questions along the way to help draw out the student's understanding of the topics of interest. This method, based on the CRESST Performance Assessment Model [23], serves as a way to explore the student's understanding of specific topics. The first of these two tasks was a review of material already covered in class and the second session was on a section that the students had not covered in class. Observation notes were taken by the researcher on how the students prepared and the explanation sessions were recoded and transcribed for analysis.

It is still too early in the analysis of the transcripts to say if the Adaptive Map students exhibited higher levels of conceptual understanding, but initial coding has revealed trends in what students focus on in their explanations. All transcripts have been segmented and coded according to three broad codes: conceptual, procedural, and prior knowledge. The coding criteria for each of these codes is shown in Table 1.

Table 1: Broad Code Definitions

Title	Description	Inclusion Criteria	Exclusion Criteria	Example
Conceptual	Discussion of conceptual content within the prescribed content area .	Any segment that explains any concepts: How they are defined, how to classify them, how to categorize them, or how they are related to procedures or other concepts.	The segment does not explain any concepts: How they are defined, how to classify them, how to categorize them, or how they are related to procedures or other concepts. Any segment that does not describe anything within the prescribed topic area.	"There's a plane truss which is framework composed of members joined at their ends."
Procedural	Discussion of procedural content within the prescribed content area.	Any segment that explains, or partially explains how to use a predefined procedure or equation.	The segment does not explain or partially explain how to use a predefined procedure or equation. Any segment that does not describe anything within the prescribed topic area.	"P: And like I just showed you, it is first easiest to like break up the free body diagram in all specific members. And then draw the forces applied to each one. And see which one you need to use."
Prior Knowledge	Discussion of prior knowledge related to the topic area.	Any segment that relates to any information outside of the prescribed topic area.	Any segment that does not relate to any information outside of the prescribed topic area.	"I: Okay, why do they have to be collinear? P: Because, when they have the forces going the opposite direction you have a distance between them and you have a moment."

The average percentages of the transcript devoted to each type of discussion (as a percentage of total character count) is shown in Figure 5 for the review session (engineering structures) and in Figure 6 for the new material session (fluid statics). In addition to the two groups, an experienced statics instructor was given the same explanation tasks as the student. The expert used the same textbook as the textbook group to prepare for the explanation tasks. Analysis of his transcripts are also included in Figures 5 and 6.

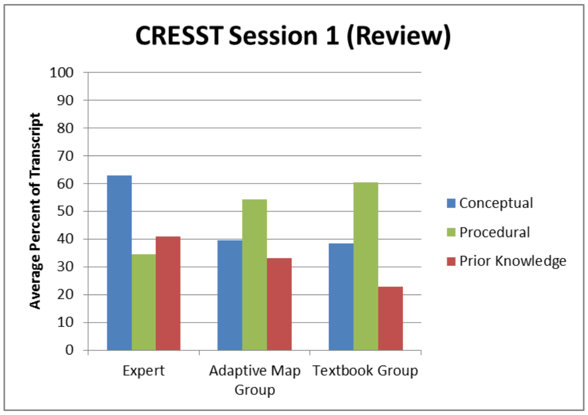

Figure 5: Session 1 Code Percentages

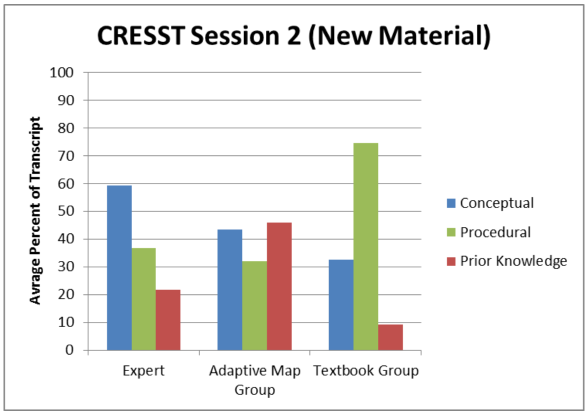

Figure 6: Session 2 Code Percentages

As can be seen in Figures 5 and 6, the experts explanations of the material were more focused on conceptual information, while students tended to focus more on procedures in their explanations of the material. Differences in the percentages between the Adaptive Map and textbook students in the review session (Figure 5) were minimal, though the Adaptive Map group did seem to be slightly more likely to reference previously learned content in their explanations. This smaller observed difference is expected, because students had both been exposed to the materials on this content in class before this session. The session where students were exposed to entirely new content (Figure 6) really highlights the differences between the Adaptive Map and the textbook though. The adaptive map groups explanations were more balanced between conceptual, procedural, and prior knowledge discussion while the textbook group was very focused on procedures and did very little to link the content to what had already been learned.

The strong procedural focus with very little linking to prior knowledge is an indication of rote learning, that will not form conceptual understanding [7]. The more balanced approach to learning, which is evidenced by the more balanced explanations of the Adaptive Map group, should lead to more effective problem solving abilities [24].

5. Closure and Future Work

Overall the Adaptive Map shows promise as a tool to promote conceptual understanding of engineering statics concepts. Analysis is ongoing to determine the effects of using the Adaptive Map tool on conceptual understanding and cognitive load.

There exist numerous opportunities to expand upon this project. Specifically, the Adaptive Map tool can be used as a basis for more broadly exploring how to build and present repositories of information in ways that can be most effectively used by students. Some immediate areas of interest on this project include:

- Social Textbooks: Exploring the potential of web-based tools as community knowledge building environments by integrating feedback, discussion, and annotation features into a web-based textbook. For this aspect of the project, there is particular interest to investigate how these features relate to feelings of ownership of the information and how this affects student motivation. Community knowledge building could also serve as an easy way to increase the scope of content covered by the tool.

- More Intuitive High Level Knowledge Representation: Representing a simple but effective overview of all the content at a high level has proven to be the most difficult visualization task. There is more work that needs to done on developing an overview of the information that is simple and understandable but that still offers clues as to what is contained at more detailed levels.

- Cross-Course Effects on Learning: The power of the Adaptive Map tool is its emphasis on connections. So far, the tool has been limited to a single course, but by developing content for related courses (e.g., Dynamics, Strength of Materials, etc.) researchers could explore how this tool could help students develop knowledge that crosses course boundaries.

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