AC 2012-4792: ADVANCING PERSONALIZED ENGINEERING LEARNING VIA AN ADAPTIVE CONCEPT MAP

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Abstract

Concept maps are effective interventions in providing students with a holistic understanding of a domain while also allowing understanding of relationships among parts and across the engineering curricula. Yet when the domain of application is large, concept maps become overburdened with too much information and complexity. A function of the individual learners' cognitive load abilities, this phenomenon (termed "map shock") results in student disengagement and reduction of expected learning gains. This limitation prevents the creation of concept maps that provide a unified framework for engineering knowledge across courses and curricula.

To address these limitations, the authors apply theoretical research on adaptive expertise, concept maps, and information visualization to design, develop and assess a cyberlearning tool that advances personalized learning and helps students develop deep and broad conceptual knowledge. The proposed visualization tool, the "adaptive concept map," overcomes the problem of map shock by providing the user control over the quantity and level of detail of information displayed, thus providing a means for navigating content in a manner that is adaptable to their personal cognitive load needs. In this paper, the authors present the progress that has been made in this project thus far. Specifically, the development of a course-wide concept map for an entire Statics course and a description of the software development process are presented.

1. Motivation

The continued success and growth of our economy depends on technological advancement, which requires a workforce that can be innovative and creative [1] and able to work in dynamic environments [2]. The need to prepare innovative engineers has led to research on adaptive expertise [2, 3], which focuses on the need for students to be on a trajectory where they are both efficient (knowing something well and able to solve things fast) and innovative (able to apply knowledge to novel situations) [3]. To start students on a trajectory of adaptive expertise, we need to ensure they have a certain amount of domain knowledge and that this knowledge is remembered in such a way that allows for flexible application. This is an acute need in early engineering courses especially (e.g., Statics), as students will apply information learned in foundational courses to a wide variety of problems in higher level courses, and later as professionals.

A critical component in students' transition to adaptive expertise is their engagement in meaningful reception learning [4] via on-demand information. In the learning process, students search through content repositories (e.g., textbooks, lecture notes, videos, web-based materials, etc.) to fill gaps in their knowledge and to search for the information needed to solve problems. This need is filled to some extent by textbooks, but their linear layout presents a limitation: they are unable to highlight the highly interconnected nature of the information being presented. Everything is presented in a lockstep fashion: every idea building on the last and everything neatly categorized in a specific chapter and section. This layout does not resemble adaptive experts' interconnected cognitive schemas, which do not match the neat linear and/or hierarchical pattern presented in the book. In addition, the textbooks' static nature presents another limitation: as students enter new domains with varying levels of proficiency, the text cannot adapt to their personalized learning needs.

To facilitate adaptive expertise development, the authors focus on highlighting the structure of the information being taught in addition to the content being taught. Specifically, the authors are currently researching an innovative cyberlearning tool that facilitates the visualization of content repositories and promotes meaningful learning and thus, adaptive expertise.

To accomplish this objective, the authors look to research on concept maps as a way to present students with information and associated conceptual connections (Section 2.1). Concept maps, a graphical tool for representing cognitive structures through a series of interlinked concept nodes, provide a means of visually representing the organization of domain knowledge. While these maps have been shown to have positive effects on meaningful learning [5], their successful widespread implementation as a content repository has been limited to small scale maps (i.e., maps that cover only a single course unit or several concepts at a high-level of abstraction). As the number of conceptual nodes increases, the map becomes too complex for the learner to cognitively process, leading to confusion and eventual disengagement. This phenomenon, termed "map shock" [6], occurs at different levels for individual learners according to their cognitive load abilities (Section 2.2). Thus, existing approaches to implementing expert-generated concept maps as content repositories are limited by: (i) an inability to effectively convey a large quantity of information and (ii) an inability to adapt the presentation of information for each learner's individual cognitive needs.

These are significant limitations, as large maps have the potential to provide a unified framework for engineering knowledge. Many engineering principles and ideas build upon one another, but students may not see how the ideas are related. By directly addressing relationships between different concepts and ideas, an effective large-scale map can help learners organize the large amounts of knowledge they receive on regular basis into well-organized cognitive schemas. This will help learners integrate concepts across an entire course and even a curriculum, thus providing a more cohesive and flexible body of knowledge will help students move towards a more adaptive expertise. While other methods have been shown to reduce the effects of map shock, they are a one-size-fits-all solution to a personalized problem of cognitive load.

In their current research project, the authors draw on theoretical insights from research on adaptive expertise, concept maps, and information visualization to build a cyberlearning visualization tool to help engineering students develop conceptual knowledge. Specifically, this tool, termed the "adaptive concept map," is a content repository visualization tool that enables the viewing of a large quantity of information via user control over the maps imposed cognitive load (Section 3). In this paper, the authors present the theoretical underpinnings of the adaptive map paradigm (Section 2) and present the progress made thus far in the development of the adaptive map tool (Section 4).

2. Background

2.1 Concept Maps

Across a variety of settings, grade levels and content areas, studying or creating concept maps have shown positive effects on learning [5]. A concept map is a type of a node-link diagram that has labeled nodes to represent concepts or ideas relevant to the topic that the map represents. Links that represent the relationships between the concepts or ideas are included and are often, but not always, labeled to indicate the nature of the relationship. Concept maps have been used both as an assessment tool to evaluate students' conceptual understanding and as a learning tool to guide their creation of cognitive schema [7].

One particular tool that has been used for navigation of content repositories is the expert-generated concept map [8-10]. Expert-generated concept maps fit under the larger label of an "advanced organizer," and serve as a framework, presented to the learner at the beginning of an instructional unit, onto which the learner builds the rest of the information. Ausubel advocated the use of advance organizers to promote meaningful reception learning [4]. Fitting with what is known about preparation for future learning and time to learn, such tools promote meaningful learning for three reasons:

- (i) the advanced organizer mobilizes anchoring ideas the learner already understands and brings them into working memory so that they can easily be connected to the new information,
- (ii) advance organizers present an optimal cognitive framework that the learners can mimic,
- (iii) and with a framework presented, it should prevent learners from resorting to rote memorization [11].

Ausubel and his colleagues conducted a number of experiments showing that advance organizers did in fact promote the learning and retention of information [12-15].

Expert-generated concept maps can be used to guide students through large stores of information, such as in a content repository. In the past two decades there have been numerous studies on concept maps [5]. Studying expert-generated maps has been shown to improve learning when presented with a text [16], when used as an advanced organizer in the classroom [17], when used as an organizer presented concurrently with classroom instruction [18], and as a navigation tool for a hypermedia learning environment [8-10].

2.2 Concept Map Limitations: Map Shock, Cognitive Overload, and Lack of Personalization

Map Shock

A limitation of concept maps as content repositories is found when trying to represent a large quantity of information. Large scale maps, maps that could bring together all of the information in a course or a series of courses, quickly become too complex to be processed by the learner and the maps no longer present the same advantages that smaller maps have. In a phenomena labeled "map shock," the learners become overloaded by the complexity of the display and either become lost in the material or disengage because of the complexity [6]. In small experimental setups, covering a couple hours up to a couple weeks, expert-generated maps provide benefits to learning, but when they are scaled up to a full course setting they lose those benefits. This proves to be a significant limitation because the large and complex cognitive schema that should be built up in a full scale course cannot be summarized with a traditional knowledge/concept map without the learner encountering "map shock."

Two approaches to combat map shock have been presented in the literature: "stacked maps" and "animated maps." Though these approaches to presenting a large quantity of information in a map visualization have both been shown to reduce map shock, their effectiveness as a navigational tool for a content repository is limited. A stacked map involves the simple solution of breaking the map down into several smaller maps; however, Wiegmann and co-authors found that the optimal presentation, either one big map or several smaller maps, depended upon the learner's ability to integrate disparate visual information (i.e., their spatial ability) [19]. Fundamentally, the ideal setup for one person is not necessarily the best setup for everyone. The division of a large map into smaller maps also obscures relationships between concepts on separate maps. Animated maps animate the active construction of the map with audio narration to guide the learners through large, complex maps [6, 20]. While they have been shown to reduce map shock, the animations impose a linear format on the map, thus making the animated maps poor navigational tools.

Cognitive Load

Research of learning theory literature relevant to content repositories leads to the authors' hypothesis that map shock in concept map navigation systems can be explained by Cognitive Load Theory (CLT) [21, 22]. CLT begins with the assumption that people have a limited capacity to store information in their working memory, a well-established theory [23, 24]. This capacity determines the maximum amount of information people can process at one time. If a learner is asked to process more information than they are able to fit into their working memory (i.e., when presented a large and complex map), then the learner becomes cognitively overloaded and learning is hindered. Also, if the learner is not given enough information to process, they become disinterested and learning is hindered. There is an optimal amount of information that should be presented at any one time to have the most effective processing, and therefore most effective learning.

CLT also identifies the types of load that can be placed on the learner into three categories: intrinsic, germane and extraneous [25]. Intrinsic load results from the natural complexity of the information to be processed. There is some amount of effort that must be put forth to read, listen, or to solve a problem, no matter how simple. Intrinsic load is important in the problem solving process, where the intrinsic load can be fairly high; but the nature of reception learning (the focus of the proposed research) should keep intrinsic load relatively low. Germane load results from the effort of learning. It is the load imparted on the learner while they process new information and integrate it into their cognitive schemas. Obviously, germane loading should be promoted by the use of the content repository, but not to a degree that it overloads the learner. The last type of load is extraneous load which is a result of cognitive processing from unrelated events such as poorly worded problems, poorly designed instruction, or the presentation of irrelevant information. Since extraneous loads do not contribute to problem solving or to learning, they are considered wasted cognitive load and should be reduced as much as possible for effective instruction. These three types of load are additive in nature. A high load in any one category will leave less processing ability available for the other two types of processing.

Lack of Personalization

Given that cognitive load is responsible for map shock, an ideal concept map would promote a reasonable level of germane loading while limiting intrinsic and extraneous loading. While this may seem trivial, it is complicated by the fact that the type and amount of load that is placed on the learner depends heavily upon their prior knowledge. One type of learner may prefer larger maps, while another type may prefer several smaller maps [19]. Fundamentally, what may lead to a germane load in one learner may be extraneous to a learner who has different prior knowledge.

Since cognitive load depends heavily upon the prior knowledge and other learner characteristics, the methods used to combat map shock must take into account these learner characteristics. Other methods to combat map shock, such as animating the map or dividing the map into several smaller maps, may show map shock reduction because they move the tool closer to presenting the average of the ideal load for the class. However this is not ideal, as they are a static, one-size-fits-all solution to a personalized problem. As students' prior knowledge changes, as they shift their focus, as their motivation changes, the map should adapt to their needs as a learner. The ideal approach would be to adapt the map according to the individual cognitive load needs that are specific to each learner.

As noted in Section 1, alleviating these limitations through the design of a proper visualization tool that enables the viewing of a large quantity of information and personalizes information visualization according to the learner's cognitive load needs will help learners integrate concepts across an entire course and even a curriculum, thus providing a more cohesive and flexible body of knowledge and will help students move towards a more adaptive expertise.

3. Proposed Approach: The Adaptive Concept Map

To achieve the research objective of improving reception learning tools in order to better prepare students for the transition to conceptual understanding of domain knowledge and adaptive expertise (Section 1), and to address the limitations of existing approaches (Section 2.2), the authors propose the creation of an adaptive concept map – a content repository cyberlearning tool that enables the viewing of a large quantity of information and personalizes the information visualization according to individual learners' cognitive load.

The design goal for the adaptive concept map is to enable the learner to control the amount and type of presented information in a task-centric fashion, as follows:

- At the start, learners will be presented with an overview of the content space to provide context and orientation. This overview will use carefully designed visual representations of the content to present the entire collection, but at a high level of abstraction. At this level, the concept map will not display detailed content, but rather encode the information visually so that learners can gain a larger perspective of overall coverage and relationships. These visual encodings can be designed according to principles of the human visual perception system, thus reducing intrinsic load required to "read" the information [26].
- Then, learners will be provided with powerful interactive controls that enable them to "zoom in" on information of interest and filter out undesired information. These interactive controls enable learners to focus the concept map on their current learning needs, thus reducing extraneous load required to process irrelevant information.

- Finally, learners will be able to directly access desired detailed content by simply selecting its node in the concept map.

At its lowest level of detail, the tool will help the student visualize connections across the entire course (and later, curriculum); at its highest, the tool will display the content pertaining to a single concept of the domain being explored. The provided controls will enable users to "zoom-in and out" of the adaptive concept map, adjusting the information visualization, and thus the imposed cognitive load, in order to adapt the concept map to their personalized cognitive needs. In effect, the tool is somewhat similar to a digital map visualization software such as Google Maps (www.maps.google.com), where controls are provided to "zoom in and out" of the map in their search for information at various levels of detail. A preliminary prototype of the software is shown in Figure 1.

4. Progress Thus Far

4.1. Statics Concept Map Exemplar

While the adaptive map tool is being developed in a manner so as to easily integrate and present information in any domain (Section 4.2.), the authors' focus in this project is in its implementation in the context of a Statics course. Statics is chosen as an application exemplar because it represents a central node in the conceptual content of every engineering domain. In addition to the potential for broad impact, Statics is chosen as an exemplar because recent research has shown that students have several misconceptions about its content even after completing a Statics course [27]. As the course is a foundational course that many other courses build off of, such as dynamics and mechanics of materials, conceptual understanding is particularly important. Additionally, the domain has a valid and reliable evaluation tool that is capable of assessing students' conceptual understanding in the Statics Concept Inventory [27]. Since conceptual understanding should be a result of meaningful learning, the concept inventory should also be a valid measure of meaningful learning. Furthermore, as a result of the creation

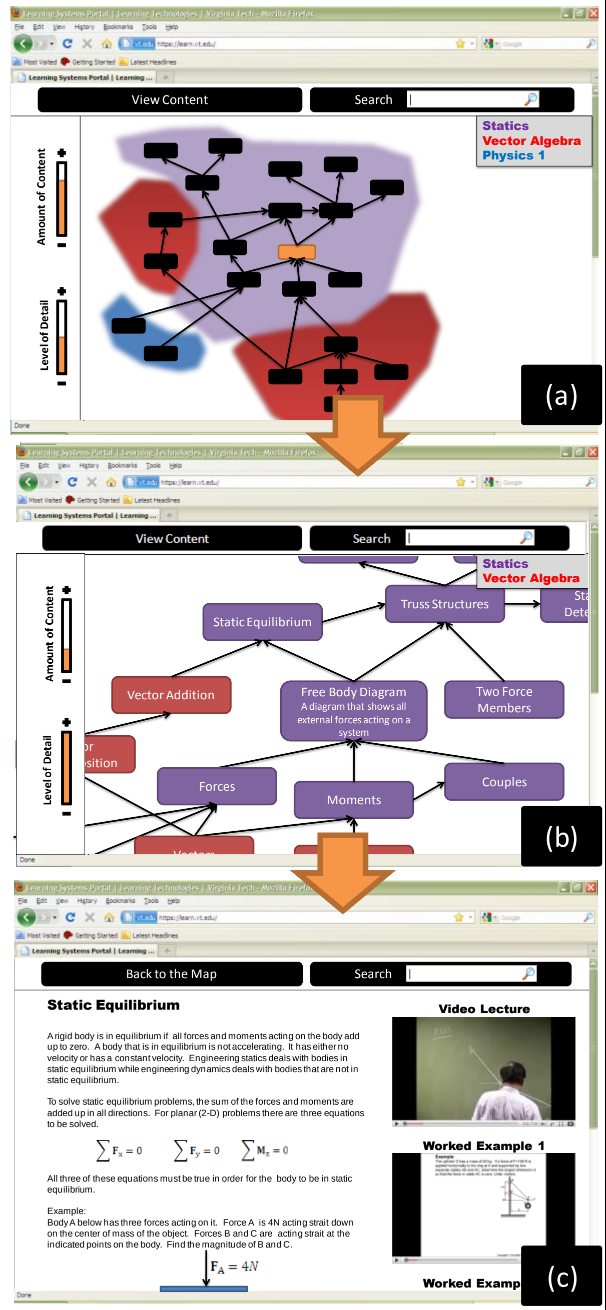

Figure 1. Prototype Views of the Adaptive Concept Map Cyberlearning Tool

of the Statics Concept Inventory, the domain has a clearly defined set of concepts that will assist in the creation of an expert-generated concept map [28].

In the efforts to create a large-scale concept map that represents the content knowledge of an entire Statics course, the authors first needed to identify a suitable systematic process. 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 to 15-25 concepts in order to avoid the difficulties found in interpreting large maps [7]. As such, the authors developed a new process for capturing the knowledge of an expert for the creation of a course-wide concept map [29]:

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 covered in the course. Record these concepts using either a concept mapping software, or by writing the concepts down on 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 complete concept map of engineering statics developed by the researchers is too large to be displayed in the paper. A modified visualization is provided in Figure 2. The most current version of the course wide concept map for engineering statics can be accessed at: http://filebox.vt.edu/users/moorej7/statics_concept_map.pdf

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. 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.

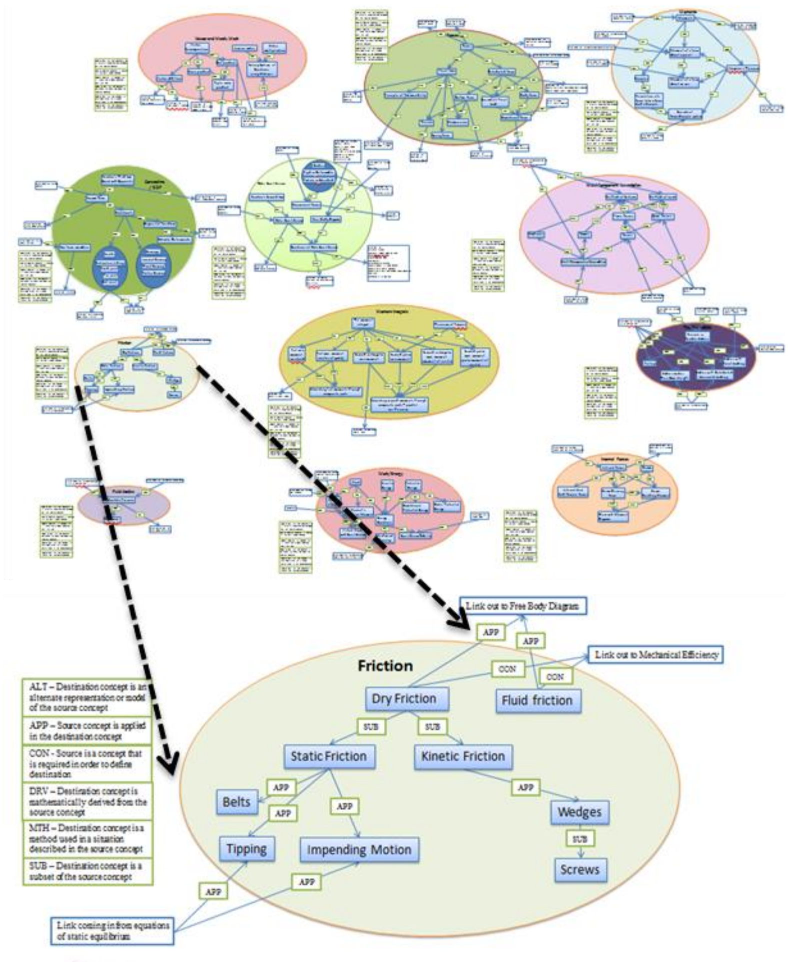

Figure 2. Condensed View of Statics Course Concept Map

<u>4.2. Adaptive Map Cyberlearning Tool</u>

The researchers have made significant progress in the development of the adaptive map software framework. The system is designed to be modular, keeping the content of the textbook separate from the software designed to visualize the content. The concept map of engineering statics is stored as an XML document, and the content pages associated with each of the nodes are written in XHTML (though the software can link to any type of document on the web). These documents are read by the visualization software, so content developers have complete control of the content through the XML and XHTML documents. Both of the content document types are simple to create and maintain, so little programming experience is needed to create and maintain the content for the adaptive map tool.

To implement the adaptive map tool, the researchers chose ZVTM (Zoomable Visualization Transformation Machine) [30]. ZVTM is a freely available user interface design toolkit implemented in Java. The toolkit was chosen because it offered a number of features that match the desired goals of the adaptive map tool. Being based on Java, the software could also be run as a Java Applet on a server, so that students would not need to install any specialized software to use the adaptive map tool.

Each individual domain concept of the overall map is being represented as a content web page. Each topic is a relatively discrete idea, corresponding to about ten to twenty minutes of lecture or a few pages of a textbook. The content pages represent the "details-on-demand," [31] and include text, images and videos of both direct instruction and worked problems (Figure 1c). Content pages are be linked by metadata (captured in the XHTML content page) and are represented as nodes in the adaptive concept map. The metadata contains the name of the topic node, a one sentence description of the node, a list of directly related concepts, data indicating the nature of each relationship, and a list of groups to which the topic belongs.

On startup, the program displays the map view at the lowest level of detail (i.e., most abstract) with a high amount of content (i.e., large number of conceptual connections), as shown in Figure 1a. At this view, the user is able to explore conceptual connections across the entire course. Its function is to serve as an advanced organizer and is designed to aid the user in integrating the new knowledge into their cognitive schemas and to help users identify gaps in their understanding. The visual connections to the content pages afford the user to be cognizant of how the new information they are learning fits into the overall structure of the curriculum, thus promoting meaningful learning. To navigate throughout the map, the user specifies a central topic, or focus, of the map by clicking on a single node. The ZVTM algorithms adjust the map display so as to focus on this selected topic. The metadata associated with that node is used to find and display the directly related nodes and the nature of the relationships between the two topics. A double-click on this node takes the user to the content webpage, which contains the highest level of detail on that topic.

As the researchers continue to improve the software, they will focus on (i) refining the concept map layout algorithm and (ii) providing more intuitive controls for the user to zoom out and view an overview of all concepts.

5. Closure and Future Work

In this paper, the authors present progress towards the realization of a creating an adaptive concept map cyberlearning tool that is capable of representing and conceptually linking together large amounts of information without inducing cognitive overload by representing the information visualization based on a learner's personalized needs. Such a tool could be used to outline and link all the information taught in an entire course or even an entire curriculum. This tool has the potential to be an extremely powerful learning aid because of the cohesiveness of knowledge it promotes.

The authors have developed a generalized approach for creating large-scale concept maps. This approach has been used to generate a concept map for an entire Statics curriculum. 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. In addition, the authors have established a software framework for the cyberlearning tool. The framework, created for dissemination via a web interface using Java, enables a user to view a large-scale concept map. Controls allow a user to dynamically adjust the focus of the map and the level of detail and amount of concepts on display. These controls allow the map visualization to be adjusted to best fit a learner's cognitive needs.

The authors look next to evaluate the developed tool's ability to promote meaningful learning. Specifically, the authors will assess the tool via two parallel measurements at two universities. Specifically, the tool will be evaluated by comparing measures of conceptual understanding and cognitive load between experimental groups (those with access to the adaptive map tool) and control groups (those without access to the adaptive map tool).

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