Promoting Conceptual Understanding via Adaptive Concept Maps

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ABSTRACT

The purpose of this study is to explore the feasibility and effectiveness of a scalable concept map based navigation system for a digital textbook. A literature review has been conducted to identify possible methods to promote conceptual understanding in the context of a digital textbook, and these hypothesized solutions will be evaluated through a prototype tool. The primary method that has been selected for this study to promote conceptual understanding in textbooks is the concept map. When concept maps are used as advance organizers or navigation aids for hypermedia documents, they have been shown to promote conceptual understanding. Issues with scalability exist, however. When maps become too large or complicated, a phenomenon labeled "map-shock" occurs. Map-shock is a result of cognitive overload that nullifies the positive effects the concept map has on learning. In order to eliminate map-shock, one needs to manage the cognitive load imposed on the learner. This project proposes using information visualization techniques leveraged from the computer science domain to develop an interactive concept map based navigation system that will retain the positive effects of concept maps, and also present the visuals in a way that does not cognitively overload the user.

This study seeks to answer the research question: "*How can a large-scale concept map visualization tools be realized in a way that promotes conceptual understanding and manages cognitive load?*" To answer the research question, a prototype tool, labeled the "Adaptive Map tool", was developed and populated with engineering statics content. This prototype contains content that is similar to the material in a traditional statics textbook, but the information is accessed through the proposed adaptive concept map visualization. The tool was then given to students in engineering statics class to be used as a supplemental textbook. The effects of the Adaptive Map tool were evaluated through a multiple case study approach that allowed researchers to understand how this tool fit into the larger learning context of a class. Results indicated that some students did integrate the Adaptive Map tool into the learning process, and furthermore that the tool did promote meaningful learning behaviors that lead to better conceptual understanding of the material.

Dedication

To my wife, for her unconditional support of my passions and my work.

Acknowledgments

This dissertation was not a solitary endeavor; there were many people who helped me in big and small ways who deserve recognition for their contributions to this work and to my development as a teacher and researcher.

First I would like to thank my advisor, Dr. Christopher Williams. He has been both my greatest supporter in this work and my role model as an emerging academic. I chose a path for my research that diverged from his in a major way, but he willingly and without question supported me in my quest to answer the questions that I was passionate about.

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1 Introduction and Motivation

1.1 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 (National Academy of Engineering, 2004, 2005). In an increasingly global and competitive marketplace, the workforce requires engineers to be innovative in the work they do (National Research Council, 2003).

Innovation, or in other words being able to solve problems in novel ways, requires conceptual understanding of the relevant content material (Rittle-Johnson, Siegler, & Alibali, 2001). Research has shown, however, that many students have a number of significant misconceptions in a variety of core engineering subjects (Streveler, Litzinger, Miller, & Steif, 2008).

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. To move the field of engineering education forward, these tools should be grounded in the science of how people learn (Jamieson & Lohmann, 2012).

One engineering education tool that is in need of an update is the textbook. For out-of-the-classroom activities, students often look to their textbooks as a primary source of expert guidance. In traditional textbooks, this guidance is given in the form of information presented in a linear, static fashion that does not match contemporary theories about how people learn or how experts think about content knowledge. Despite this mismatch with contemporary learning theories, textbooks still serve a major role in the practiced learning process, and serve as a content repository of trusted expert knowledge that can be accessed whenever and wherever the student needs guidance.

In contrast to paper-based textbooks, digital content has an inherent design flexibility that allows for a more personalized and effective presentation of the information (Fletcher, Schaffhauser, & Levin, 2012). It is not the digital medium itself, though, that improves the effectiveness of instruction (Russell, 1999), so a digital version of the status quo will not improve the quality of instruction. To build a more effective tool, a learning theory driven design is preferable. This design starts with design goals set from the review of the engineering education literature. After setting the design goals, the new digital medium simply offers more freedom and flexibility in the actual implementation of that design.

Because digital textbooks are becoming more and more prevalent in practice (Schuetze, 2011) and because of the previously discussed need for engineering graduates with deeper understanding of the material, it is imperative that the engineering education research community reexamine how digital content is presented, using what we know about how people learn to guide the redesign within the newly expanded design space afforded to us through the digital medium. The traditional notion of a textbook is in need of change, and the transition from a paper to digital medium makes now an opportune time to reexamine the textbook.

The overall purpose of this proposed research is to help students develop conceptual understanding through digital content in an out-of-the-classroom learning context. The proposed way to accomplish this is through an innovative visualization tool for digital content repositories.

1.2 Conceptual Underpinnings

To fulfill this purpose the author draws from a number of different theories and methodologies (Section 2.1). First, to understand the goals of the proposed tool, the author draws from the literature on conceptual understanding, and meaningful learning. Second, to understand existing tools that are used to promote conceptual understanding, the author draws 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 author draws from information visualization literature as a guide to possible solutions to the map-shock problem, allowing concept maps to be scaled up as instructional tools without losing their effectiveness.

The intertwined concepts of conceptual understanding (Section 2.2.1), and meaningful learning (Section 2.2.2) guide the theoretical (and physical) development of the proposed tool. Conceptual understanding is an important part of being an effective engineering problem solver (Rittle-Johnson et al., 2001), but students have often been shown to lack conceptual understanding in a variety of core engineering concepts (Streveler et al., 2008). Students instead often focus on the acquisition of rote procedural knowledge, leading to more inflexible cognitive structures. In order to develop conceptual understanding, the student needs to engage in meaningful learning activities (Ausubel, 1968; Novak, 2002). Since textbooks serve as collection of expert knowledge, the tool being developed should promote meaningful reception learning so that students are more likely to develop a conceptual understanding through using the textbook.

The primary tool that Ausubel developed to promote meaningful reception learning was the advance organizer (Ausubel, 1968). An advance organizer (Section 2.3.1) 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 (Novak & Cañas, 2008). Expert-generated concept maps (Section 2.3.2) 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 (Nesbit & Adesope, 2006).

The usefulness of expert-generated concept maps as advance organizers is currently limited to small scale activities, however, because of map-shock (Section 2.4.1). Map-shock (Blankenship & Dansereau, 2000) is the cognitive and affective reaction to large-scale concept maps that prevents meaningful learning from occurring. Although there are prescribed ways to prevent map-shock, these existing solutions are not ideal solutions to the problem. Cognitive load theory (Section 2.4.2) offers deeper insight into map-shock phenomenon. Map-shock is a specific incarnation of cognitive overload as described by cognitive load theory (Paas, Renkl, & Sweller, 2004). 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.

As a way to manage cognitive load, information visualization techniques have been utilized in the design of the adaptive map tool. Information visualization (Section 2.5) 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 (Card, Mackinlay, & Shneiderman, 1999).

1.3 Research Questions

The proposed research is focused on overcoming the problem of map-shock that plagues large-scale concept maps. The primary research question reflects this goal of finding a solution to the map-shock problem. If this barrier can be overcome, it is believed that large-scale concept maps could be used to promote students' conceptual understanding in content repositories. This could open the door for a new, and more effective, type of digital content repository.

Primary Research Question

How can large-scale concept map visualization tools be realized in a way that promotes conceptual understanding and manages cognitive load?

The author hypothesizes that the solution to the map-shock problem can be achieved by synthesizing information visualization design guidelines and existing concept map design guidelines. If the synthesized guidelines are used to guide the development of a tool, this should lead to a large-scale concept map visualization tool that both promotes conceptual understanding and manages cognitive load for the user (Figure 1.1). The primary research question will be answered through a two phase process.

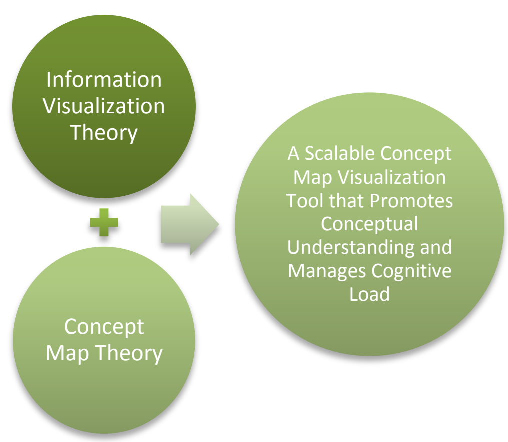


Figure 1.1 The Synthesis of the Concept Map and Information Visualization Literature.

i. The first phase was the development of a proof-of-concept tool built according to the research hypothesis.

ii. The proof-of-concept tool was then given to students in a naturalistic setting and a qualitative, multiple case study research methodology was used to address the research question empirically.

In order to ensure that the primary research question is answered fully, and in order to better define the problem space, the primary research question has been broken down into four sub-research questions. Together, the answers to these four questions should provide a thorough and informative answer to the primary research question.

Sub-Research Question 1: **How are students engaging in learning activities with the proposed tool? How does this differ from the learning behaviors students engage in with traditional textbooks?**
Sub-Research Question 2: **How do these observed learning behaviors promote or hinder the formation of conceptual understanding?**
Sub-Research Question 3: **Are students experiencing cognitive overload during any of the observed learning behaviors, and if so how is this affecting the learning process?**
Sub-Research Question 4: **What factors contribute to students adopting or not adopting the proposed tool for learning activities?**

Table 1.1 outlines the research problems, the approaches the author is taking to overcome the research problems, and the expected outcomes. The first row in the table outlines the primary problem, approach and outcome. The supporting problems, approaches and outcomes that are expected to follow the primary outcome are outlined in the rows below.

Table 1.1 Research Problems, Approaches, and Outcomes.

<table>
<tr><th>Problem</th><th>Approach</th><th>Outcome</th></tr>
<tr><td>Map-shock prevents large-scale concept maps from promoting conceptual understanding.</td><td>Information visualization techniques will be used to build an interactive concept map visualization that is designed to manage cognitive load.</td><td>Concept maps become scalable and can highlight relationships across an entire course or even between courses. This allows concept maps to serve as the primary organization and navigation system for a content repository.</td></tr>
<tr><td>Engineering students have significant misconceptions in a number of core engineering mechanics courses.</td><td rowspan="2">Expert-generated concept maps have been shown to promote conceptual understanding, and can be used in the context of a content repository.</td><td>Students develop greater conceptual understanding in engineering mechanics courses.</td></tr>
<tr><td>Textbooks are a widely used educational tool in engineering, but they receive little attention from engineering education researchers.</td><td>Textbooks become more effective learning tools, allowing more effective out-of-the-classroom learning to occur.</td></tr>
</table>

1.4 An Overview of the Adaptive Map Tool

As stated in Section 1.3, this research uses a proof-of-concept instructional tool as a primary means of answering the research questions. A detailed description of the process used to develop this tool and then a detailed overview of the tool itself are presented in Chapter 3 of this dissertation, but a basic description of the proof-of-concept tool will be useful for discussion in the coming chapters

The Adaptive Map tool seeks to fill the role of the course textbook, pulling together trusted, expert-generated explanations of the content material into a central location that students can use outside of class. The tool was deployed in an engineering statics classroom and was populated with engineering statics content for this particular study, though the tool should work with a variety of engineering courses.

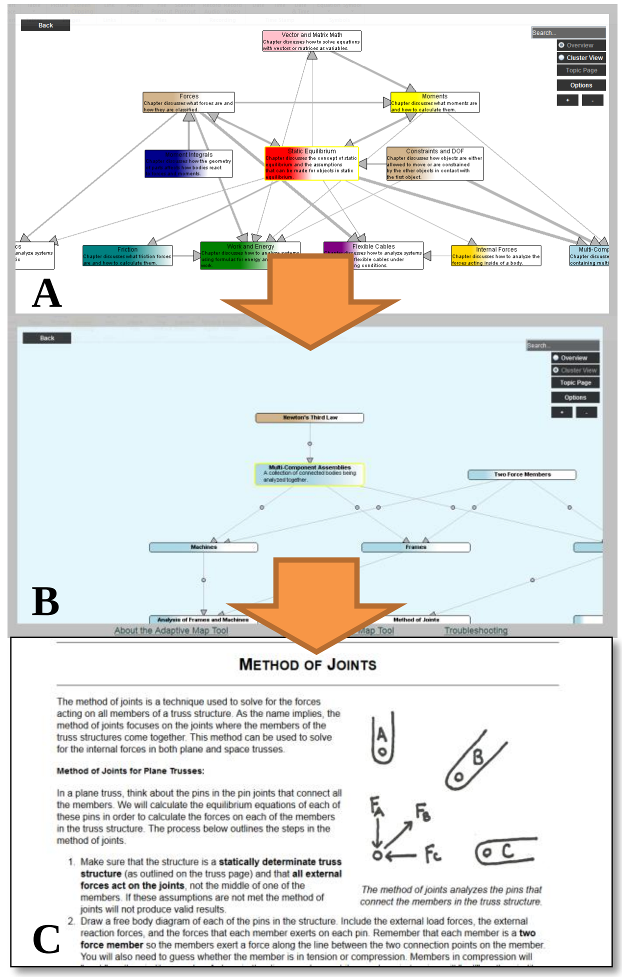


Figure 1.2: The Adaptive Map Tool

The Adaptive Map tool presents the material at multiple levels of abstraction, ranging from a broad overview of all subjects in a concept map layout (Figure 1.2A), to a concept map layout for an individual chapter (Figure 1.2B), to the presentation of single topic (Figure 1.2C). With the exception of the most detailed view, the information is laid out in a concept map format to serve as an advance organizer. The visual presentation of this concept map layout is controlled by the user's level of abstraction (how zoomed in or out they are) and the topic they are focused on with the tool. Using this user selected information; software presents a visual of the most relevant topics to the current focus at an appropriate level of detail for the current level of abstraction. To help the student maintain a sense of context while navigating, the tool also presents smooth transition animations when the user is changing either their focus topic or the level of zoom. Overall, the system allows users to navigate the content information in the textbook in a way that is similar to how people navigate geographical information in online map application such as Google Maps™.

1.5 Significance of Dissertation

As stated in the ASEE Phase 1 report…

> *"Engineering education innovation is about designing effective learning environments. It requires, at the least, engineering and education expertise working in continual cycles of educational practice and research."* (Jamieson & Lohmann, 2009, p. 6)

In other words, engineering education research should, in the end, serve to improve engineering education practice. For this reason, it is important to examine how this project benefits both the research community and the practice of engineering education. These benefits are:

Benefits for the Engineering Education Research Community:

First, this research brings together both research and researchers from the fields of engineering education and information visualization. These two fields currently do not have strong research ties, but there is a potential for collaboration between these fields that goes far beyond the work presented in this dissertation.

Second, this research will contribute to the research communities' knowledge of the theories on conceptual understanding, advance organizers, concept maps, cognitive load theory, and information visualization.

Finally, in addition to providing an in depth view of how students use the Adaptive Map tool, this research provides an in depth view on how some students use regular textbooks. How students use traditional textbooks is also a gap in the literature and this aspect of the research opens up the door for future inquiries into how students use and learn from textbooks.

Benefits for Engineering Education Practice:

The prototype tool was developed for engineering statics (discussed in more detail in Chapter 3). Because the tool has been shown to promote conceptual understanding in some circumstances (discussed in more detail in Chapter 7), it can immediately be disseminated to engineering statics instructors across the nation. Since engineering statics is a foundational course for many engineering majors, and because the content is relatively stable from college to college, the tool can have an immediate and large impact without expansion or modification of the prototype and with relatively little effort on the part of instructors who choose to use the tool.

The Adaptive Map tool can also easily be expanded to other engineering subjects. The software and content have been kept separate to ensure that future developers would not need specialized programing expertise in order to develop textbooks for other subjects. In addition, all software needed to run and host a separate version of the tool is freely available, and the only required hardware cost is a desktop computer to use as a server. So far the tool has only been tested in the context of engineering statics, but there is nothing in the literature to suggest that tool would not work in the context of other courses.

Finally, if enough subject areas are developed, the tool will be able to highlight connections between courses, promoting a unified set of knowledge structures for engineering students. As is discussed in Chapter 2, connections serve as a central element in the development of conceptual understanding. So far the tool only covers one course, but the design is easily expandable to cover additional subjects. With the eventual goal of building a single knowledge representation to cover an entire four year engineering curriculum, students would be able to see how each course, and each topic fits into the grand scheme of their degree.

1.6 Summary of the Rest of the Chapters

In the following chapters this dissertation will cover the theoretical basis and the methodology for the study. Chapter 2 reviews the literature relevant to the development of the Adaptive Map tool. Chapter 3 discusses the development process for the adaptive map prototype. Chapter 4 discusses the data collection and analysis procedures that will be used to evaluate answer the research questions. Chapter 5 discusses the observed behaviors and results for each research participant. Chapter 6 identifies cross participant themes and compares and contrasts participant experiences. Finally, Chapter 7 relates the findings back to the original research questions and theoretical framework. Table 1.2 serves as a roadmap for the rest of the dissertation. It outlines the phase of the research that each chapter represents and the goals for each of the chapters.

Table 1.2 Dissertation Roadmap

	Research Phase	Chapter	Goals
Intro	Problem Identification and Hypothesis Formation	**Chapter 1** Introduction and Motivation	• Frame the context of the problem • Identify a need • Identify research questions • Identify research hypothesis
Background	Information Gathering	**Chapter 2** Literature Review and Theoretical Basis	• Synthesize literature relevant to problem • Critically analyze existing systems • Provide evidence to support research hypothesis • Provide evidence to support validation procedures
Research Methods	Developing Hypothesis Validation Procedure	**Chapter 3** Prototype Development	• Expand and clarify research hypothesis • Identify scope of prototype development • Identify prototype development procedures • Identify prototype validation procedures
		Chapter 4 Data Collection Methods	• Identify evaluation setting • Identify research metrics • Identify data collection procedures • Link research metrics to theoretical basis
Data Analysis	Hypothesis Validation	**Chapter 5** Within Case Analysis	• Report observed participant behaviors • Identify behaviors relevant to research questions
		Chapter 6 Cross Case Analysis	• Identify cross participant themes • Compare and Contrast student experiences and behaviors
Conclusions	Identifying Implications of Findings	**Chapter 7** Conclusions	• Relate identified themes to back to the theoretical basis • Evaluate the effectiveness of the prototype tool • Evaluate research hypothesis • Identify project limitations • Identify areas for future research

2 Literature Review and Theoretical Basis

2.1 Overview of the Relevant Theories

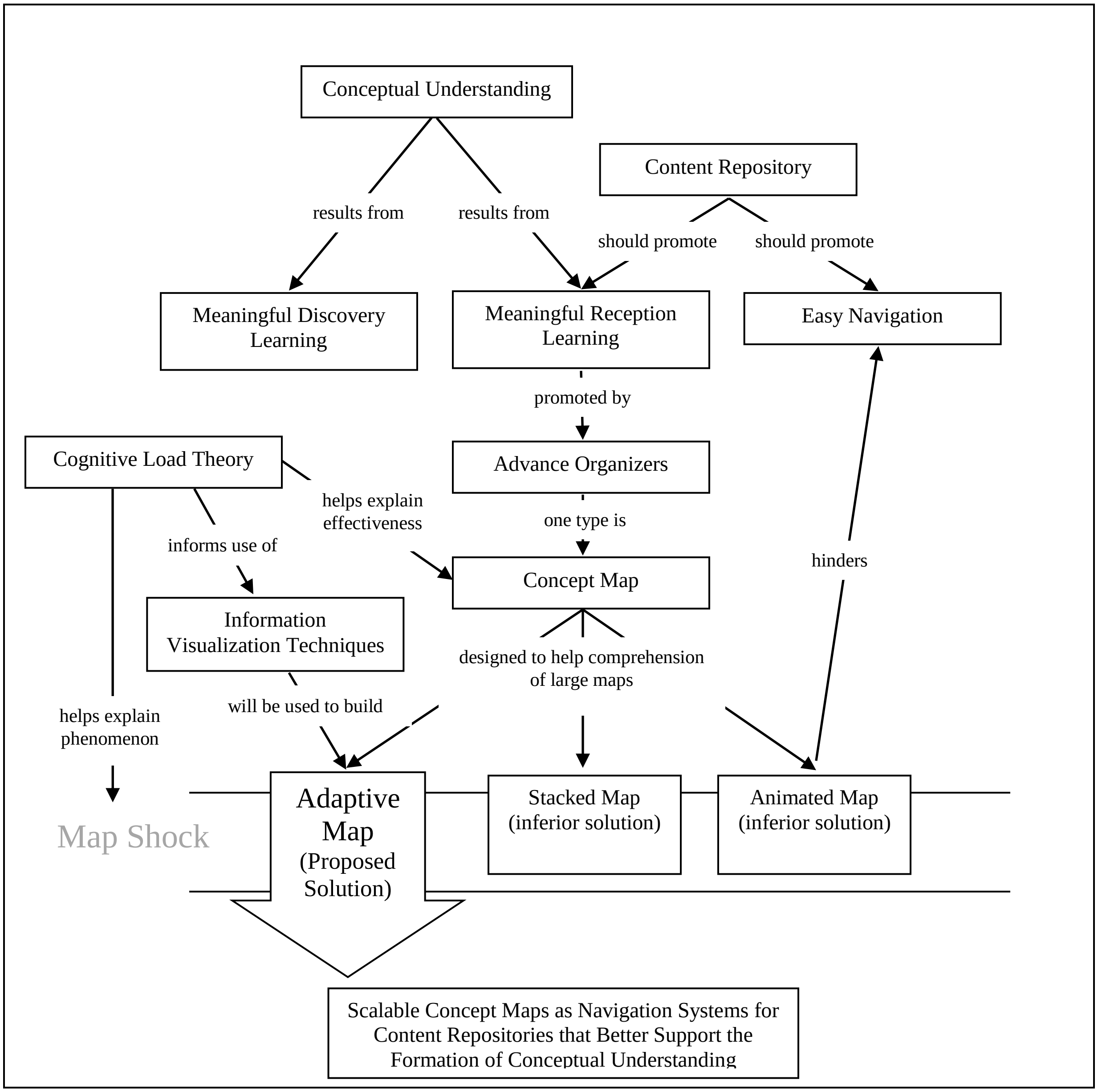


Figure 2.1: The Theoretical Framework

All of the theoretical building blocks and their relationships are outlined in the concept map in Figure 2.1. This concept map serves as an advance organizer in the form of an expert generated concept map for Chapter 2 of the dissertation, providing an example of one of the key concepts.

As discussed in Chapter 1, the proposed research project draws from a number of different theories and methodologies. The overarching goal of the proposed tool is described through the conceptual understanding and meaningful learning discussed in Section 2.2. The literature on advance organizers and expert-generated concept maps as advance organizers, discussed in Section 2.3, shows the existing tools that are currently being used to develop students' conceptual understanding. The phenomenon of map-shock, the primary barrier to the widespread adoption of expert-generated concept maps is discussed along with existing methods to combat map-shock in section 2.4.1. The map shock phenomenon is then examined trough Cognitive Load Theory in Section 2.4.2. Finally, information visualization and the reasons it may offer a solution to the research problem are described in Section 2.5.

2.2 Conceptual Understanding and Meaningful Learning

The ideas of conceptual understanding and meaningful learning are woven together to form the goal of the developed instructional tool. The author starts by examining conceptual understanding; discussing what it is, why it is important for engineering students, how it is developed, and how it is assessed. The development of conceptual understanding serves as the ultimate goal of the instructional tool that is the focus of this research. Literature on meaningful learning, in particular literature on meaningful reception learning, is addressed because of its particular significance towards developing conceptual understanding within the context of content repositories. The tool seeks to help students develop conceptual understanding by promoting meaningful reception learning.

2.2.1 Conceptual Understanding

The development of knowledge is the central goal of education, but the term 'knowledge' can be used to mean many things. In the context of problem solving, there is a common distinction between two types of knowledge: conceptual understanding and procedural skill (Greeno, Riley, & Gelman, 1984; Piaget, 1978; Rittle-Johnson et al., 2001).

Procedural skill is defined as

> *…the ability to execute action sequences to solve problems. This type of knowledge is tied to specific problem types and therefore not widely generalizable.* (Rittle-Johnson et al., 2001, p. 346).

In contrast to procedural skill, there is conceptual understanding. Conceptual understanding is defined as

> *…implicit or explicit understanding of the principles that govern a domain and of the interrelations between units of knowledge in a domain. This knowledge is flexible and not tied to specific problem types and therefore generalizable.* (Rittle-Johnson et al., 2001, p. 346)

While both procedural and conceptual knowledge can be used to help solve problems, only those with conceptual understanding can express 'why' and 'how' decisions are made in the problem solving process (Piaget, 1978). Those with conceptual understanding have deeper knowledge of the domain, leading to more effective problem solving, particularly with unfamiliar problem types (Davenport, Yaron, Koedinger, & Klahr, 2008; Karagoz & Cakir, 2011; Leppavirta, Kettunen, & Sihvola, 2011; Rittle-Johnson et al., 2001).

Being innovative, or in other words being able to effectively solve novel problems, has been and increasingly will be a key attribute of a successful engineer in the future (National Academy of Engineering, 2004; National Research Council, 2003). Because innovation is important for engineers and because innovation requires conceptual understanding, it is imperative for engineering students to develop conceptual understanding of their domain material.

Despite the importance of conceptual understanding, many university level engineering students still have misconceptions in a variety of core engineering subjects even after they complete courses that cover those topics (Clement, 1982; Halloun & Hestenes, 1985; Montfort, Brown, & Pollock, 2009; Olds, Streveler, Miller, & Nelson, 2004; Reif & Allen, 1992; Scott, Peter, & Harlow, 2012; Streveler et al., 2008). As shown in the dates in the citations above, misconceptions have been an ongoing problem within engineering education at least three decades. Because of the readily apparent need for engineering students to better develop conceptual understanding in a variety of subjects, the central goal of this research is to find a way to help students develop conceptual understanding within the context of content repositories – an already widely used learning tool in engineering education.

An expanded definition of conceptual understanding pulled from the mathematics education literature states:

> *"Conceptual understanding refers to an integrated and functional grasp of mathematical ideas. Students with conceptual understanding know more than isolated facts and methods. They understand why a mathematical idea is important and the kinds of contexts in which is it useful. They have organized their knowledge into a coherent whole, which enables them to learn new ideas by connecting those ideas to what they already know."* (Mathematics Learning Study Committee; National Research Council, 2001, p. 140).

Here the quotation is specifically looking at the conceptual understanding of mathematics, but the idea can be applied to engineering concepts as well. The idea of ‘connections’ is a central element to the concept of conceptual understanding. These connections refer to the mental connections in the knowledge structures or cognitive schemas that the learner is building while they learn the domain information. Learning can occur by either accumulating isolated facts or by integrating information into a coherent whole, but, as the definition above suggests, only those learners who create a coherent and connected cognitive schema will be able to possess conceptual understanding (Ambrose, 2010; Glaser, 1984; Mathematics Learning Study Committee; National Research Council, 2001; McCormick, 1997; Nickerson, 1985; Prawat, 1989).

Another important aspect of this definition is the ability to understand ‘why.’ Conceptual understanding is something more than just factual knowledge or procedural knowledge. It complements factual and procedural knowledge that is often the focus of classroom assessments. Conceptual knowledge allows the learner to understand why a fact or procedure is important, why the fact or procedure is relevant, and why the procedure is applicable in some contexts but not in others. It has also been found that conceptual knowledge and procedural knowledge aid the acquisition of one another: conceptual knowledge aiding the learning of procedural knowledge and procedural knowledge aiding the learning of conceptual knowledge (Rittle-Johnson, Siegler, & Alibali, 2001). In other words, developing conceptual understanding, understanding the ‘why’ of the information, along with developing procedural knowledge, can help an individual be better prepared for future learning.

2.2.2 Meaningful Learning

The idea of meaningful learning is addressed because of the relevance of the literature of meaningful reception learning. Meaningful learning relates to conceptual understanding in that students must engage in meaningful learning activities to form conceptual understanding (Novak, 2002).

David Ausubel's (1963, 1968) theory of meaningful learning proposed that there are two key characteristics of learning experiences that affect how newly learned information is stored, retrieved, and used. The most influential factor is how the new information is processed by the learner. According to Ausubel, the type of processing for any learning experience lies somewhere between the two extremes of purely rote learning and purely meaningful learning. In rote learning, the learner only minimally processes the information, the information is stored in a more or less verbatim form, there is no deeper understanding of the information, and the information is not integrated with other information the learner knows. In meaningful learning, the information is deeply processed and this results in a deep understanding of the information. This deep processing fully integrates the new information into the learner's existing cognitive schemas. Relating this to a more widely used educational concept, Bloom's taxonomy (Anderson et al., 2000; Bloom, 1956), rote learning leads to fulfillment of the instructional goals at the 'knowledge' level objectives while meaningful learning leads to the fulfillment of the 'intellectual abilities and skills' level objectives (comprehension, application, analysis, synthesis, and evaluation) (Ausubel & Robinson, 1969).

Like the conceptual understanding literature, the meaningful learning literature stresses the importance of connections for learning. Ausubel himself stressed the importance of ‘assimilating’ new information into existing cognitive frameworks (Ausubel, 1968). Learning without connecting information to existing frameworks is rote learning while learning that involves connecting new information to existing student knowledge is meaningful learning.

A second characteristic that Ausubel identified to classify learning experiences is the way in which information is presented to the learner, which fits somewhere between the two extremes of pure discovery learning and pure reception learning (Ausubel, 1963, 1968). Pure discovery learning results from active experimentation with no expert guidance. Learners form and test hypotheses based solely on their own experiences. Pure reception learning results from an expert presenting the information to the learner in more or less final form with no experimentation on the part of the learner. Most school learning experiences fall somewhere in the middle with some expert guidance and some active experimentation (though more traditional programs lean further towards the reception learning side). Ausubel states that although the two factors in learning can affect one another, they are in fact separate metrics for learning experiences (Ausubel, 1968). It is possible to have meaningful and rote processing for both reception and discovery learning experiences. Of the two factors, how the information was processed is far more important for learning than how the information was presented. These two characteristics of learning experiences can be represented as axes on a graph. This 2-D space can then be used to classify different learning experiences. In Figure 2.2, a visual of this space is shown with areas that some learning activities typically occupy.

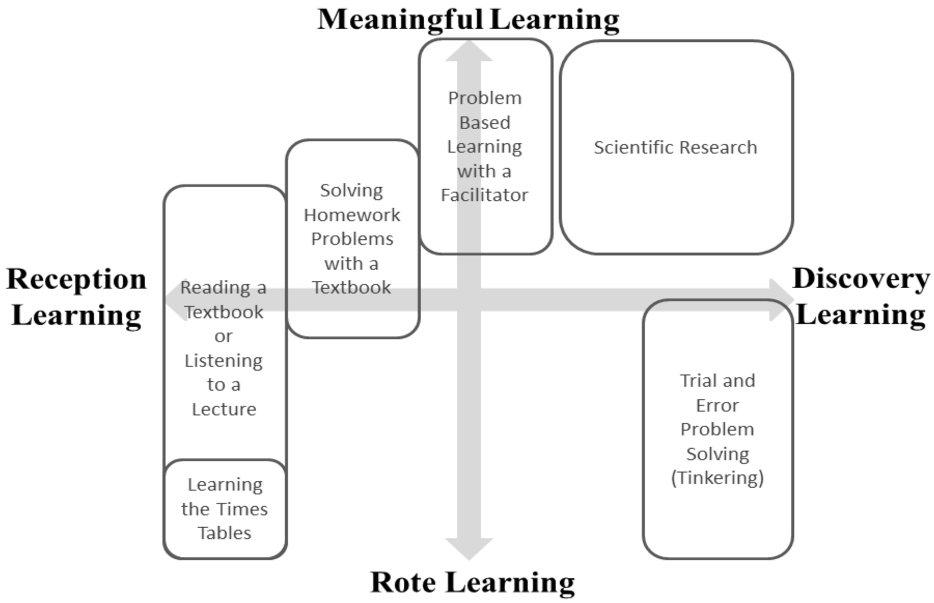


Figure 2.2:
Ausubel's Learning Experience Characteristic Axes. Based on a Diagram in (Novak 2010)

Ausubel's work is particularly relevant to the design of a content repository because of his focus on meaningful reception learning. The content repository is a representation of domain experts' knowledge, and its role is that of a reception learning tool (it presents expert knowledge in more or less final form). Unlike most studies on developing conceptual understanding, which use discovery or guided discovery learning techniques, Ausubel focused on how to promote meaningful reception learning. Specifically, Ausubel worked to format texts in a way to promote meaningful learning as much as possible. The tool he developed to promote meaningful learning from texts, which should help develop conceptual understanding in the context of the content repository, was the advance organizer.

2.3 Concept Maps as Advance Organizers

2.3.1 Advance Organizers

Ausubel's advance organizers were designed to help students connect what they were learning to what they already knew. In Ausubel's own words:

> *The principle function of the organizer is to bridge the gap between what the learner already knows and what he needs to know before he can successfully learn the task at hand.* (Ausubel, 1968, p. 148)

They fulfilled that function by giving the learner an overview of information that is going to be presented at the beginning of the reading. This helps the learner build a basic cognitive framework; a skeleton for the information to be learned. By helping the learner to move from broad, general, but correct, cognitive frameworks to more detailed cognitive frameworks, the advance organizer pushes students to engage in meaningful rather than rote learning. The learner will add to and clarify their cognitive framework, rather than building the detailed cognitive framework from scratch as they are reading the text.

To validate advance organizers, Ausubel and his colleagues did numerous studies with university students and found that the advance organizers improved both meaningful learning and the retention of the information (Ausubel, 1960; Ausubel & Fitzgerald, 1961, 1962; Ausubel & Youssef, 1963). A later meta-analysis of 152 studies on advance organizers "…found a small, but facilitative effect on learning and retention" (Luiten, Ames, & Ackerson, 1980, p. 217).

Some guidelines set forth by Ausubel (1968) for creating advance organizers are described below.

- The advance organizer should be written at a high level of abstraction and generality, including the big ideas and how they are related but leaving out detailed information on the concepts.
- The advance organizer should be written in a language that is easily understood by people that are unfamiliar with the domain. Technical jargon should either be defined when it is first used or avoided altogether. The advance organizer will be read before the rest of the passage and it will be read by novices.
- If possible, provide anchor concepts. Include ideas that the learner should already know and then show how other central ideas are related to those ideas. This can help mobilize prior knowledge so that meaningful learning can occur.

These guidelines address more intent than format for the advance organizer. Ausubel developed purely textual organizers in the form of expository and comparative organizers, but graphical advance organizers have been developed as well. The most prominent tool available for creating graphical advance organizers is the concept map.

2.3.2 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 (Novak & Cañas, 2008). Concept maps are node-link diagrams designed to visualize the cognitive schemata of either experts or students. This was originally used as an assessment tool based on Ausubel's models of learning (1963, 1968), but was quickly found to promote meaningful learning as well (Novak, 2010).

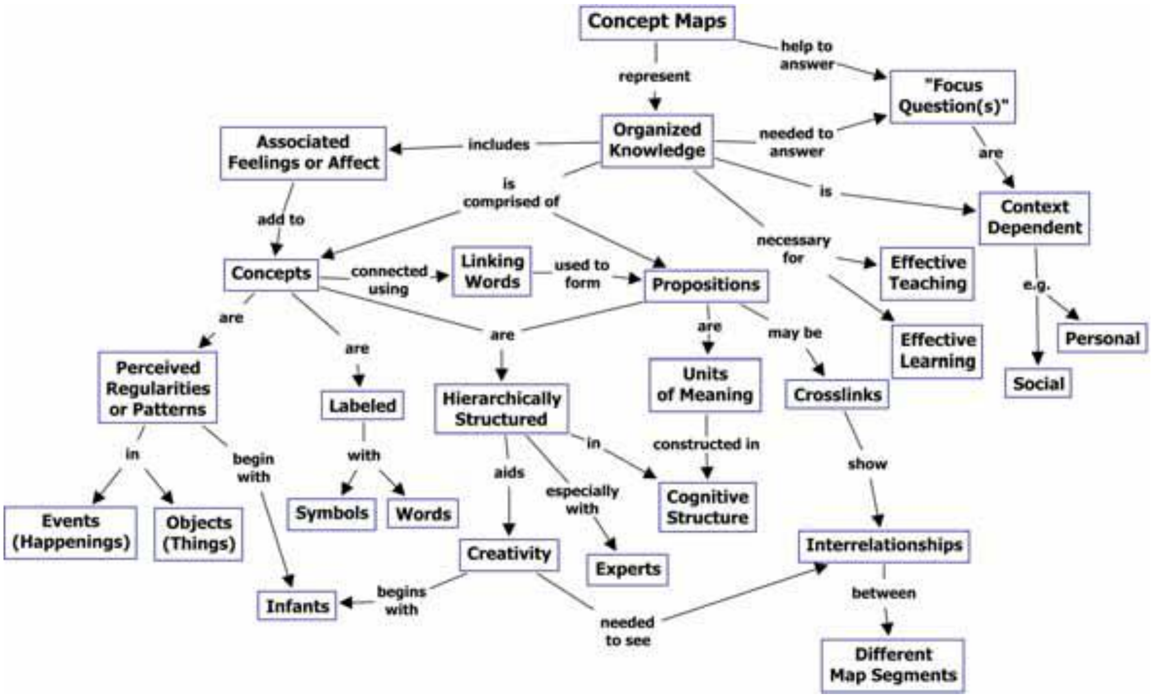


Figure 2.3: A Concept Map About Concept Mapping (Novak and Cañas 2008)

An example of a concept map taken from (Novak & Cañas, 2008) is shown in Figure 2.3 above. Concept maps are a form of node-link diagrams designed to mimic the cognitive schemas of a person. The nodes are labeled with concepts, a set of regularities observed by the person, while the links are labeled to represent the relationship between the concepts. A proposition, which is two concepts connected by a single link, serves as a statement that the person understands. For example, from Figure 2.3 the reader can assume that the author of the concept map understands that concept maps represent organized knowledge and that concept maps help to answer focus questions.

A subset of concept maps are known as knowledge maps (O'Donnell, Dansereau, & Hall, 2002). The official difference for knowledge maps is that they use a common, limited set of link labels to simplify the diagram for easier understanding. Rather than the linking words shown in Figure 2.3 they would simply have single letters or different link colors with a legend to indicate the link type. Another unofficial difference is that the concept map research community has focused on having students build concept maps of their own knowledge as learning activities, while the knowledge map research community has focused on students studying expert-generated maps.

Because of the focus of this research project, much of the literature comes from the knowledge map research community, though the term concept map will be used to refer to both concept and knowledge maps since concept map is the more inclusive term. There are also many different variations for formatting concept maps, more than one claiming to be the optimal setup, but for the purposes of my literature review a broad definition of concept maps as node-link diagrams that are built to mimic a person's cognitive structures was used.

Over the past two decades, there have been numerous studies looking at concept maps as learning tools, and across a variety of settings, grade levels, and content areas, concept mapping has been shown to be an effective learning tool (Nesbit & Adesope, 2006). Concept maps can be generated by students, partially generated by students, or generated by experts. Although having students generate their own maps has been shown to be more effective as a learning activity than studying expert-generated maps (Lim, Lee, & Grabowski, 2009), it requires expert guidance, which eliminates it as a possibility for asynchronous learning. Though less effective, studying expert-generated maps has been shown to have significant positive effect in promoting learning and recall and does not require guidance from the instructor (Nesbit & Adesope, 2006). In fact, concept maps can serve as powerful advance organizers, particularly if the map contains information the student already knows which can serve as an anchor (Novak, 2010). Studying expert-generated maps has been shown to improve learning when presented with a text (Wachter, 1993), when used as an advanced organizer in the classroom (Willerman & Mac Harg, 1991), when used as an organizer presented concurrently with classroom instruction (Salata, 1999), and as a navigation tool for a hypermedia learning environment (Chang, Sung, & Chiou, 2003; Coffey, 2005; R. Shaw, 2010).

2.4 Map-Shock and Cognitive Load Theory

2.4.1 Map-Shock and Existing Solutions

Why have maps not been used more broadly in education? One reason may be a phenomenon called 'map-shock' (Blankenship & Dansereau, 2000). 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. The learners become overloaded by the complexity of the display and either become lost in the material or disengage because of the complexity (Blankenship & Dansereau, 2000). An example of a 900+ node concept map in Figure 2.4 from Gaines and M. L. G. Shaw (1995) shows a display almost certain to induce map-shock. In small experimental setups, covering a few hours up to a few weeks, expert-

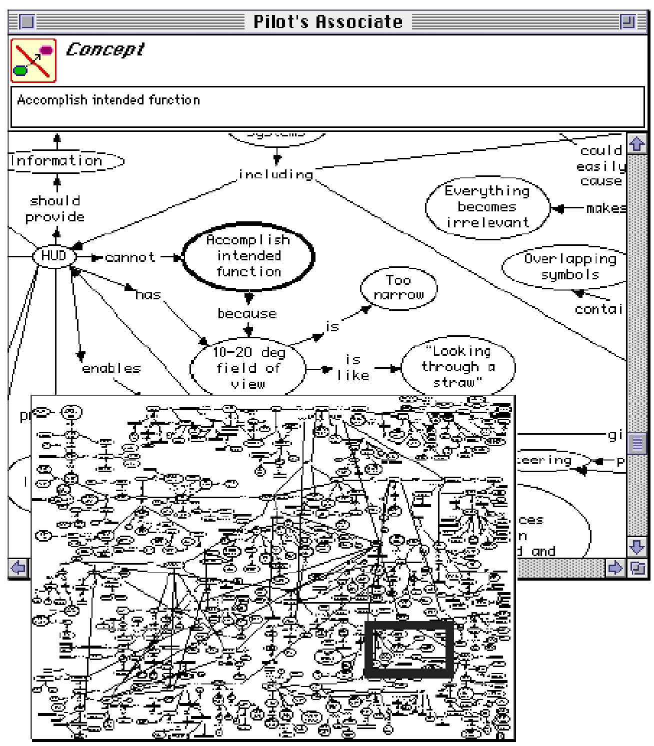


Figure 2.4:
A 900+ node concept map from (Gains and M.L.G Shaw, 1995)

generated maps provide benefits to learning, but they lose those benefits when they are scaled up to a full course setting (Blankenship & Dansereau, 2000). This loss of benefits for large scale maps proves to be an impediment to widespread use because the large and complex cognitive schema that should be built up in a full scale course cannot be summarized with a traditional concept map without the learner encountering map-shock.

How is map-shock being combated? There are two approaches to present a large quantity of information while combating map shock that have been shown to be somewhat effective: stacked maps and animated maps. Though these approaches have both been shown to reduce map-shock, their effectiveness as navigational tools for content repositories is limited.

A stacked map involves the simple solution of breaking the map down into several smaller maps. A stacked map can be made by having one overview map with other more detailed maps embedded into the overview map (Alpert, 2005; Cañas et al., 2005; Chang, Sung, & Chiou, 2003) or by splitting one large concept map into a series of maps presented sequentially (Wiegmann, Dansereau, McCagg, Rewey, & Pitre, 1992). However, Wiegmann et al. (1992) 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). 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, minimizing the amount and effectiveness of the crosslinking that is an important part of concept mapping.

Another strategy that has been used to reduce map shock, termed animated maps, actively constructs the map with audio narration (Adesope, 2006; Blankenship & Dansereau, 2000). This guides learners through large, complex maps and has been shown to reduce map shock (Adesope, 2006; Blankenship & Dansereau, 2000). Unfortunately, the animations impose a linear format on the map. Learners are no longer free to navigate the map for themselves, and thus the tool impedes searching the map for specific information. Because the animation takes navigational control away from the learner, animated maps are neither useful as a navigational tool nor are they personalized for an individual learners' needs.

2.4.2 Cognitive Load Theory

A review of learning theory literature relevant to content repositories leads the author to propose a hypothesis that map shock in concept or knowledge map navigation systems can be explained by cognitive load theory (Paas et al., 2004; Sweller, 1988, 2005). Cognitive load theory is an information processing theory that is based on the dual store model of human information processing. In the dual store model of the human cognitive system, the three areas where information is stored and processed are: the sensory register, working memory, and long-term memory (Ormrod, 2008).

- The sensory register holds information from the senses for a short time.
- Working memory holds current thoughts pulling information that is attended to from the sensory register and recalling information stored in long-term memory.
- Long-term memory stores knowledge that is not currently being processed for later recall.

Cognitive load theory focuses on working memory as the most critical part of the architecture for learning. The theory begins with the well-established assumption that people have a limited capacity to store information in their working memory (Baddeley, 1994; Miller, 1956). This limited capacity is the bottleneck in the human information processing system, and this 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 with 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 ideal amount of information that should be presented at any one time to have the most effective processing and therefore the most effective learning.

Looking at the specifics of map-shock, we can see that it is a specific incarnation of cognitive overload. Map-shock results in incomplete processing of the map (Blankenship & Dansereau, 2000), which matches the main effect of cognitive overload. The affective reactions that are also associated with map-shock (Blankenship & Dansereau, 2000) can also be attributed to cognitive overload (Kirsh, 2000). In addition to these similarities, managing cognitive load by presenting a reasonable amount of information in a well-organized map has also been widely presented as an essential prerequisite for effective processing of the map (Adesope, 2006; Alpert, 2005; Cañas et al., 2005; Wiegmann et al., 1992).

Cognitive load theory differentiates the types of load that can be placed on the learner into three categories: intrinsic, germane, and extraneous (Sweller, 2005). 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. The load imposed by a task depends upon experience, wherein certain tasks can become more automatic; as an example, think about driving a car for the first time and then driving it after several years of experience. Looking specifically at the context of this project, the intrinsic load of reading text, watching a video, or looking at a worked example is fairly low. The intrinsic load imposed by problem solving activities, however, is high, (Sweller, 1988) and this is an activity often coupled with textbook use.

Germane load is the load imparted on the learner through schema creation or schema automation. Germane loading can be considered the effort put forth to learn from the situation at hand. Obviously, germane loading should be promoted by the content repository but not to a degree that it that overloads the user or in a way that hinders navigation.

Extraneous load is the last type of load, which is loading that does not directly result from completing a task or learning. Since extraneous loads do not contribute to problem solving tasks or to learning, they are often considered wasted cognitive load. Extraneous cognitive load results from poorly worded problems, poorly designed instruction, or other scenarios where people are forced to process and filter through information that is irrelevant to them and their current situation. In general, extraneous loads should be avoided, particularly for novices who may have higher intrinsic and germane loads imparted on them by novel situations and information.

These three types of load are additive in nature. Intrinsic, germane, and extraneous loading all fill the limited capacity of working memory, and it is the cumulative load that leads to cognitive overload or underload for the user. A high load in any one category will leave less processing capacity available for the other two types of processing.

An ideal content repository would promote a reasonable level of germane loading, leaving some capacity for intrinsic loading imposed by problem solving activities and reducing extraneous load as much as possible. 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. What promotes germane loading in a novice user of a system may impose an extraneous load on a more experienced user for the same system. For this reason, the ideal setup for a content repository is going to be both personal and dynamic. The concept map literature agrees with this learner dependency by showing that while one set of learners preferred larger maps, another set preferred several smaller maps (Dansereau, 2005; Wiegmann, Dansereau, et al., 1992).

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 these are static, one-size-fits-all solutions to a personalized problem. The ideal approach would be to adapt the map according to the individual cognitive load needs that are specific to each learner. As students' prior knowledge changes, as they shift their focus, as their motivation changes, the map should adapt to their needs as a learner, presenting the information that is most pertinent to them and their current situation. To achieve this goal of a more ideal map for the learner's current situation, the author looks to leverage theories from the field of information visualization.

2.5 Information Visualization

The final piece of theory that is woven into the literature review to help overcome the problem of map shock is the field of information visualization.

> *Information Visualization is the use of computer-supported interactive visual representations of abstract data to amplify cognition* (Card, Mackinlay, & Shneiderman, 1999).

An expert-generated concept map is a visual representation of an expert's abstract cognitive structures designed to help develop understanding and is therefore an information visualization by definition.

A key goal of the information visualization field is to build tools for usability. Users of any system should be able to efficiently navigate large amounts of information and develop insights from that information faster and more accurately with the aid of an information visualization tool. Information visualization researchers do not promote limiting the data set to enhance usability as the concept map research community does (Novak & Cañas, 2008), but instead promote finding ways to present large data sets in a usable form (Ware, 2004). This would allow for scalability in concept mapping without sacrificing understanding on the part of the learner. A properly designed information visualization tool of a large-scale concept map should prevent map-shock by managing cognitive load, and this is why the information visualization literature is particularly helpful as a design guide for the adaptive concept map.

Within the information visualization literature, there are many studies that deal specifically with node-link diagrams (as reviewed in Herman, Melançon, & Marshall, 2000). Called graphs in the information visualization community, node-link diagrams lend themselves particularly well to information organized in network or hierarchical structures such as cognitive schemas. This is confirmation of the idea that concept maps can serve particularly well as advance organizers. This literature also serves as the focus within information visualization for guidance on designing the adaptive concept map tool.

2.6 Summary of Theoretical Claims

Table 2.1, summarizes the claims made in the course of the literature review and theoretical basis of each of those claims.

Table 2.1 Summary of Theoretical Claims

Claim	Theoretical Basis
Meaningful reception learning can be used to develop conceptual understanding in students within the context of a textbook.	Meaningful leads to the development of conceptual understanding (Novak, 2002).
Advance organizers can be used to promote meaningful reception learning.	Advance organizers have a small but significant impact on meaningful reception learning (Luiten et al., 1980).
Expert-generated concept maps can be used to promote meaningful reception learning as an advance organizer.	Concept maps can serve as powerful advance organizers (Novak, 2010).
Map-shock prevents large-scale concept maps from effectively used as advance organizers.	Map-shock is a cognitive and affective reaction to large and complex maps that prevents the learner from fully processing the map (Blankenship & Dansereau, 2000).
Map-shock is a specific instance of cognitive overload, and therefore managing cognitive load is the key to preventing map-shock.	The symptoms of cognitive overload match the symptoms of map-shock (Sweller, 2005).
Information visualization techniques can be used to develop an interactive concept map based visual that will effectively manage cognitive load and promote meaningful reception learning, leading to the development of conceptual understanding in students.	This hypothesis is to be tested in this research.

3 Prototype Development Methodology

3.1 Overview of the Prototype Development Process

In order to answer the research questions identified in Section 1.3, a prototype instructional tool was developed and evaluated according to the research hypothesis. This instructional tool, the Adaptive Map tool, serves as a visualization and navigation tool for a digital content repository as discussed in Chapter 1. Work done by both educational researchers working on concept maps, and computer scientists working with node-link diagrams, helped inform the design of the adaptive map tool. Because these two research communities are in such disparate fields, they first needed to be integrated into one coherent set of design guidelines before they could be used.

In order make future content development easier, the tool was developed in a modular fashion, keeping content and software separate wherever possible. This design should create a low barrier for adoption by minimizing the training needed to be able to develop content. Because of the modular fashion of the adaptive map tool, the prototype development process was divided into two parallel development processes: software development and content development. The software serves as the incarnation of the research hypothesis, but the tool cannot be evaluated without the creation of quality content to be used within the software. For this reason, both elements of the prototype development process were vitally important to the success of the project. The rest of this chapter is divided into four sections:

- Section 3.2 discusses the content development process.
- Section 3.3 discusses the software development process.

- Section 3.4 provides a walkthrough of the developed tool from the perspective of both a student and a content developer.
- Section 3.5 discusses the methods and results of the formative assessment used to help guide the development of the Adaptive Map tool.

3.2 The Content Development Process

3.2.1 Statics as an Exemplar Content Domain

The proposed tool will represent, and eventually link together, numerous engineering domains, but in order to build a prototype a starting point needed to be chosen. A single course was chosen as the appropriate scale for the project because it is the smallest domain that will be likely to run into problems with map-shock. If a concept map with embedded content were made for just a portion of Statics, the concept map may not induce map-shock in the first place, and if map-shock is not encountered, the interactive visualization is not needed. Creating content for an entire course was a considerable undertaking, but this scale was necessary to test the research hypotheses.

Statics was chosen as a preliminary exemplar for a number of reasons.

- First; statics is a common course to most engineering students regardless of local curriculum or engineering major. As such, the results of this research should be directly applicable to statics courses at other universities, and the prototype has as broad an impact as possible if successful and disseminated.
- Additionally, because the course is a foundational course that many other courses build upon, such as dynamics and mechanics of materials, conceptual understanding is particularly important. The concepts introduced in statics are developed and built upon in a variety of other core engineering courses.
- The concepts taught within statics are also highly interconnected (as opposed to a survey course in which the ideas have only sparse connections), which lends itself well to concept mapping.
- Finally, despite the importance of the material, there are still a number of misconceptions that some students retain even after a course in statics (Steif & Dantzler, 2005; Streveler et al., 2008).

3.2.2 Developing a New Large-Scale Concept Map Generation Procedure

The existing procedure for creating concept maps (Novak & Cañas, 2008) consisted of four steps 1) Locate an expert, 2) Set the limit and context of the concept map by formulating a focus question that the information in the concept map should answer, 3) write down all the concepts related to the focus question, and 4) organize the concepts by moving them around and drawing in links to indicate the relationships between concepts. This procedure was identified as being inadequate for the researcher's needs for two primary reasons: first it is difficult to come up with a single focus question to span the breadth of information covered in even a single course, and second simply moving around and drawing in links for close to a hundred nodes is an unmanageably complex activity. The existing procedure was designed for concept maps of approximately 15-25 nodes and, like concept maps themselves, the procedure did not scale up well.

As discussed in Section 3.2.1, the exemplar content domain was engineering statics, which covers far more than 15-25 topics. The scale of the content area being examined meant that existing methods for creating concept maps (Novak & Cañas, 2008) were inadequate. A new, modified method was developed for the purpose of creating the large-scale concept map that served as the content base of the Adaptive Map tool. This newly developed large-scale concept map generation procedure is outlined below and was disseminated to the engineering education community so that others may develop their own large-scale concept maps (Moore, Pierce, & Williams, 2012). A summarized version of the process is as follows:

1. Locate an expert. This is someone who is very familiar with the content and is an expert in the domain area. This is the expert whose knowledge it is you are trying to capture.

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 categorize 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 new concept map generation procedure deliberately departed from the existing procedure in the following ways. First the focus question was eliminated from the procedure. The purpose of the focus question was to limit the scope of the concept map and to allow for much larger concept maps, it was preferable to eliminate this step. This step was instead replaced with using existing materials (existing textbooks and course syllabi) to seed the concept generation step in the procedure.

Second, the step that instructions developers to simply "rearrange the concepts and draw in links" was expanded into a number of steps. This new expanded method was modeled on the steps to create a Work Activity Affinity Diagram (Hartson & Pyla, 2012). Work Activity Affinity Diagrams (WAADs), are used by user interface designers and are used to analyze large stores of user feedback. Because they take the form of large scale node link diagrams, their development process serves as a useful analog for the desired procedure. The intermediate steps of grouping the concepts, organizing the concepts within the groups, and then finally linking the concepts across groups was borrowed from the WAAD generation procedure to replace the single "rearrange the concepts and draw in links" step.

The final change was the addition of the revise and refine step. It was found that there was no clear finished concept map, and that the concept map continued to evolve beyond the end result of Step 6. These changes were usually the result of grappling with the concepts through discussion with both the expert who understood the concepts well, or with students who were novices struggling to understand the information for the first time.

3.2.3 Developing the Engineering Statics Concept Map

This section details how the generalized procedure discussed in Section 3.2.2, was implemented to capture the knowledge of an experienced statics instructor. Because visualization algorithms are only useful if the data being visualized are relevant to the user (Munzner, 2009), it was essential that the expert's knowledge structures be accurately captured in the concept map of engineering statics. Details on the practice of implementing the seven step large-scale concept map generation technique are provided below.

1. *Expert Consultation:* 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 author first explained what concept maps were and how they can be used (as is described in Section 2.3) so that the expert would understand what was being asked of him.
2. *Use Existing Materials to Brainstorm Concepts:* The expert and the author had collected course syllabi from two institutions, and collected four familiar course texts (McGill & King, 1989; Meriam & Kraige, 2007; Riley, Sturges, & Morris, 1995; Riley & Sturges, 1996) to help seed the ideation process. Skimming through these materials, the author and the expert generated a list of 166 potential

concepts to be addressed in the statics concept map. Each of these concepts was written on a Post-It® note and posted on a white board. This phase of the process, like many brainstorming processes, was focused on generating large quantities of concepts and quality of the concepts was not addressed until later stages.

3. *Grouping Concepts:* Once the concept generation procedure was complete, the expert and the author worked collaboratively group the concepts into related sets. Bounding boxes and title were drawn onto the white board and the Post-It® notes were placed into these boxes. The process of defining what fit into each category and the definition of each category evolved through discussion during the grouping process. The process of grouping concepts was complete when there was agreement on what did and did not belong in each group and when all concepts had been placed into a group. A total of fourteen different groups (termed clusters) had been created in the end, ranging from just two concepts in a group up to thirteen concepts in a cluster. An example of the concepts in the friction cluster is shown in Figure 3.1.

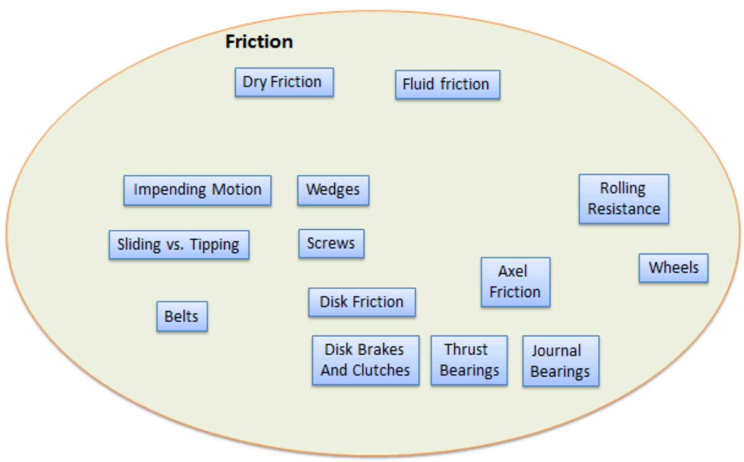


Figure 3.1: The Friction Cluster Concepts

4. *Concept Weeding:* During the process of grouping concepts, many of the concepts were eliminated because they were either repeated, or because it was decided that they were not independently teachable (for example, it was decided that it was easier to just have a single unit on dry friction rather than discussing static and dynamic friction separately). The criteria of the "smallest independently teachable idea" was used as a criteria for determine the level of detail the concepts should adhere to since each of these concepts later would have an independent content page associated with it. Each of the eliminated concepts was removed from the white board upon being identified. The grouping procedure also helped the expert and author identify number of gaps, or missing concepts and these concepts were written on Post-It® notes and added to the board in the appropriate

cluster. Of the original 166 concepts, a total of 96 concepts remained after weeding (which continued to a smaller extent until step 6).

5. *Inter-Cluster Linking:* After all the concepts were placed in, the author and expert worked to create concept maps out of the concepts within each group. Concepts within each group were organized and links describing the relationships between these concepts were drawn in. The concepts were organized into a directed layered graph structure, putting more basic and prerequisite information at the top and having directed links that generally flowed downward to the more advanced concepts that built upon the more basic ones. Initially, labels for the links were written in as needed, but as more labels went up, a set of six general labels (described below) were used to label all of the links.

    - 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.

    A representation of the organized group of friction concepts (shown in Figure 3.1) is shown in Figure 3.2.

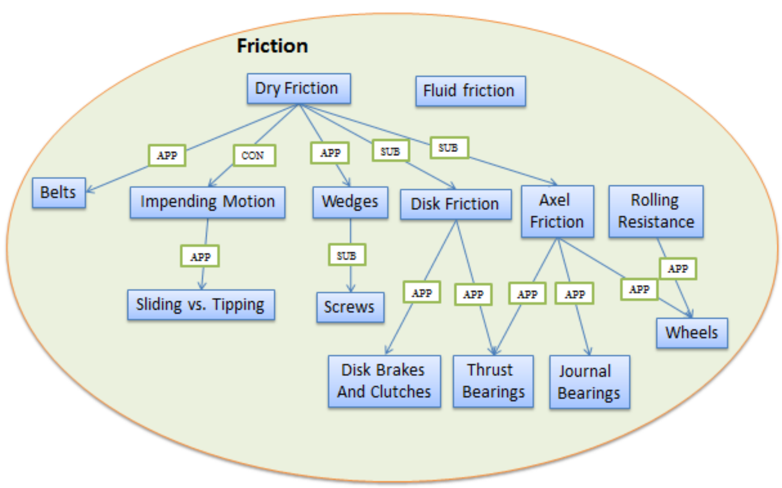


Figure 3.2: The Friction Cluster Concept Map

6. *Cross-Cluster Concept Linking:* After the topics in each cluster were organized into concept maps, cross-cluster links were added. These were links connected concepts that were in different clusters. The same set of six link labels was used

for cross cluster connections as was used for inter-cluster links. Because of the difficulty in organizing and following the complicated and web of long cross-cluster links, these links were represented by drawing in white boxes just outside of the cluster. Each of these white boxes just outside of the cluster was labeled with and represented a topic within another cluster. The link was drawn in connecting the concept within the cluster to the white box representing an out of cluster concept. A corresponding white box and link was drawn in near the connected concept in the other cluster. This representation helped represent cross-cluster links without cluttering the concept map to where it was incomprehensible. An example of the Friction cluster seen in Figure 3.2 shown with added cross-cluster links is seen in Figure 3.3.

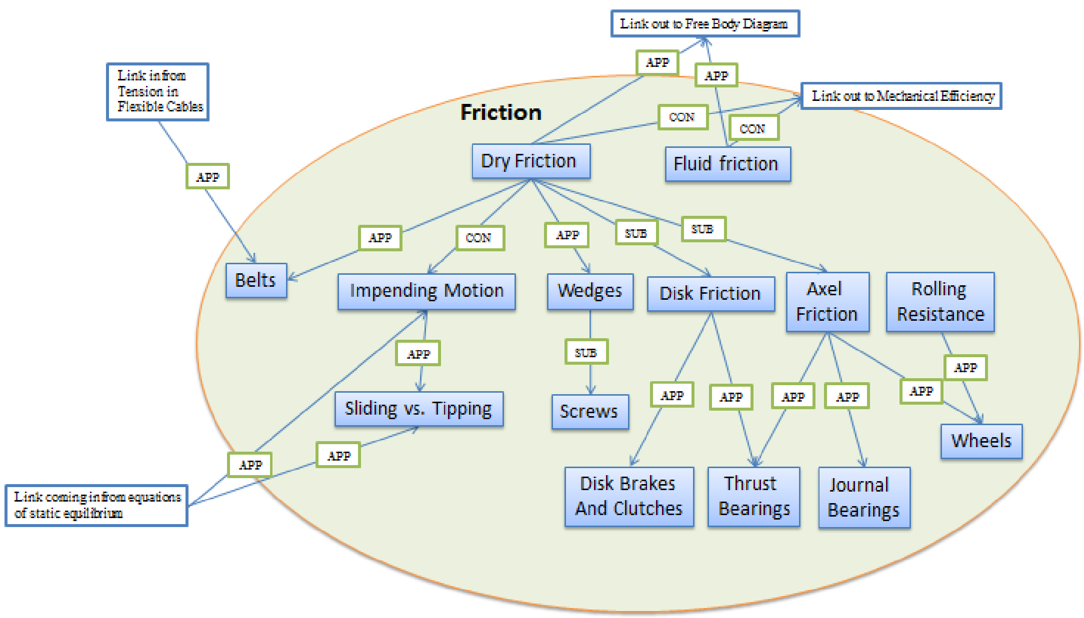


Figure 3.3: The Friction Cluster with Cross-Cluster Links Shown

7. *Revise and Refine:* After the cross-cluster linking 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 content (in the form of instructional web pages to be used in the adaptive map; Section 3.2.5) 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 both experts and students has been used to further develop the concept map.

3.2.4 Building the Content Pages

After creating the concept map that would serve as the backbone of the adaptive map tool, the next step was to create topic pages that would flesh out each topic node with explanations and examples. These topic pages are HTML webpages that could host text, images, videos, and interactive elements. For the purposes of this research, only text and images were used. This was designed help to limit the differences between the content in the Adaptive Map and a paper textbook, and reduce confounding variables in later comparisons of the Adaptive Map tool and paper textbooks.

The process began by identifying existing websites to link to for each topic node. This allowed content to be quickly populated and for pilot testing to be conducted earlier, as developing new topic pages was a very time consuming process. These external websites, deemed the best freely available website to explain each of the prescribed topics, were selected by the content expert (the same expert who helped develop the original concept map). The selections were reviewed by the author and then added to the live hosted Adaptive Map tool.

As time allowed, links to external websites were replaced with custom developed topic pages. These in-house webpages allowed for more control over the content, more consistency in terms and conventions (since the external links drew from a wide variety of sources), and better alignment with the targeted concepts. All in-house topic pages were developed by the author, with a review conducted by the content expert on the first set of eight pages to help guide the design and creation of these pages.

By the time students in the formal prototype evaluation used the Adaptive Map tool in statics, original content accounted for about 80% of the material they covered in class. This included everything they covered on the first three course exams and a small amount of the material covered in the last course exam. All topics covered in the observation sessions as part of the prototype evaluation had in-house developed topic pages.

3.3 The Software Development Process

The prototype Adaptive Map Tool is an engineering education innovation. As such the development of such a tool should be grounded in the engineering education literature (Jamieson & Lohmann, 2012), and should have well defined educational objectives (Dick, Carey, & Carey, 2008). The software development process, discussed in the literature (Moore, Pascal, Williams, & North, 2013) and outlined below, began with the development of a set of firm goals (Section 3.3.4) that were grounded in the literature on both concept maps (Section 3.3.2) and information visualization (Section 3.3.3). Only after a set of goals that was grounded in the literature was developed, did the researchers move on to implement software (Section 3.3.5) that would put these goals into practice.

3.3.1Developing the Software Goals

The first step of the software development process was to identify the goals of the software. The overarching goal of the software was to interpret the content and display a meaningful and manageable visualization for the user. The visualization must be useful to the user at multiple levels of abstraction, ranging from the display of an individual topic, to a view containing multiple topics, to a view containing all topics in the course. Other than the individual topic level, the visualization should be a concept map of the topics, showing individual ideas and highlighting how they are related. All of these concept map visuals should be presented in a way that promotes meaningful learning and effectively manages cognitive load for the user, and all of this should be done by the software. Content developers should not have to worry about the concept map formatting. Both research on concept maps and research in information visualization provide several guidelines on how the maps should be constructed to best accomplish this, and the following sections are devoted to identifying the guidelines and integrating them into one set of subgoals.

3.3.2 Guidance from Concept Map Literature

Concept map research has identified several characteristics of quality concept maps. Some of the most widely accepted guidelines are derived from the Gestalt principles of how people perceive patterns. These guidelines are symmetry, proximity, continuation, and similarity (Wiegmann et al., 1992).

Symmetry in concept maps refers to the visual uniformity of the structures in a concept map. A concept map with good symmetry displays similar structures in similar ways. As an example, Figure 3.4 A shows good symmetry as it displays both instances of the parent node with two child nodes in the same way. Figure 3.4 B displays the two parent nodes with two child nodes each in different ways, so it does not have good symmetry. Symmetry in concept maps has been shown to enhance comprehension (Wiegmann et al., 1992). If there are two instances of the same basic structure, then the display of these two structures should look the same or at least very similar.

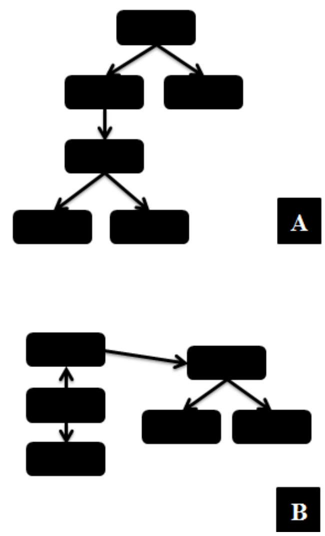


Figure 3.4
A node-link diagram with good (A) and bad (B) symmetry

Proximity refers to the closeness of related nodes. If two nodes are directly linked or otherwise related, then they should be in close proximity to one another. Concept maps that follow this guideline have been shown to be more effective than concept maps that do not (Wallace & West, 1998; Wiegmann et al., 1992). This guideline can be adhered to by finding ways to minimize link length.

Continuation refers to a common direction for directional links. The directional links should generally flow in one direction. As an example, Figure 3.4 A shows good continuation because all of the directional links generally point down while Figure 3.4 B shows poor continuation because the directional links point in several different directions. Good continuation has been shown to enhance concept map comprehension (Wiegmann et al., 1992). Additionally, it has been found that users prefer vertically oriented directionality over horizontally oriented directionality, so maps should flow either up or down (Dansereau, 2005).

Similarity refers to the use of color and shape to indicate features of the nodes and links. Features like a group of nodes, the type of node, or the type of link can be indicated with either color or shape. It was found that embellished maps, maps that used color and shape to specify features of the nodes and links, resulted in better comprehension than unembellished maps (Wallace & West, 1998). This does have a limit, though, and excessive embellishment has been shown to be detrimental to comprehension (because of the high cognitive load imposed by interpreting the many embellishments). The preferred amount of embellishment also varies greatly from user to user (Wiegmann et al., 1992).

The last advice that the concept map literature offers is to limit the amount of nodes to a reasonable level. This was already discussed with map-shock as one of the key features of the visualization. The concept map literature suggests centering the concept map on one specific focus question to limit the scope of the map. Novak, the creator of the concept map, suggests fifteen to twenty-five nodes in a concept map (Novak &

Cañas, 2008). Research has also found, however that the preferred number of nodes is highly dependent on the learner (Wiegmann et al., 1992).

3.3.3 Guidance from Information Visualization Literature

By examining the broader category of node-link diagrams (referred to as graphs in the information visualization literature), the information visualization literature also offers advice on how to construct quality concept maps. The information visualization literature is particularly helpful in its advice on dealing with large-scale node-link diagrams, since the concept map literature avoids dealing with the issue by advising against large-scale maps.

Information visualization literature discusses the Gestalt principles, confirming what the concept map literature has found. The principles of symmetry, proximity, continuation, similarity, and connectedness can all be at work when viewing a concept map (Ware, 2004), and these properties should be thought about in concept map design. These principles help users group, organize, and interpret the information that they see. All of these items were discussed in the concept map section, except for connectedness. Connectedness is the tendency to group elements that are linked visually. It is very fundamental to concept maps and node-link diagrams because this is one of the defining features of node-link diagrams. A node-link diagram without connections (links) is not a node-link diagram at all, so no comparison between connected and unconnected maps was made in the concept map literature.

An extension of the idea of symmetry is the idea of predictability. Where symmetry is the repetition of the same structures spatially, predictability is the repetition of the same structures temporally. A predictable algorithm will take the input and build the same diagram every time. An unpredictable algorithm may build a different diagram every time the program is run, even though the input is the same. Predictable algorithms should also not radically change the output if there is a small change to the input. This resistance to change provides a consistency that allows the user to become familiar with the node-link diagram, and having predictable node-link diagram building algorithms has been shown to be important for the comprehension of dynamic node-link diagrams (Herman, Delest, & Melançon, 1998; S. C. North, 1996).

While dealing with large-scale diagrams, users have trouble focusing on details while also maintaining a sense of context (Herman et al., 2000; Spence, 2007). In order to deal with the focus and context problem, there are several potential methods that could be employed. These methods involve using smooth zooming and panning features, using multiple windows, or using distorted views. One or some combination of these three methods should be used to allow detailed information to be presented while maintaining a sense of context.

Using smooth zooming and panning features is the simplest solution to the problem of achieving focus and context. This technique requires interaction on the part of the user because focus and context are not displayed at the same time. The user must navigate the information, zooming in and out, and then integrate the different information to maintain focus and context (Ware, 2004). The mental integration is made easier with the ability to rapidly zoom in or out and smooth transitions while zooming or panning (Bederson & Hollan, 1994). Two options are also available for zooming, geometric and semantic (Herman et al., 2000). Geometric zooming is the traditional notion of zooming where all the information is displayed while zoomed out, but it is just too small to read or interpret.

Semantic zooming involves adding or subtracting features dependent on the level the user is currently in. Semantic zooming has the advantage of simplifying the display for easier cognitive processing by suppressing irrelevant information, but this comes at the cost of more complex algorithms.

Using multiple windows allows the user to have a detailed view and a big picture view at the same time. At least one window should be devoted to focus while one would be devoted to the big picture. There also needs to be an indication of where the focused image is in the big picture so that the two or more views can be integrated (Card, Pirolli, & Mackinlay, 1994). This helps maintain focus and context at the same time, but multiple windows means less screen real estate is devoted to each window.

The third option for providing focus and context is using distorted views. These views provide both focus and context in one display by displaying a big picture view on the screen but distorting part of the big picture to zoom in on details. This can be done with either a single focus (Lamping, Rao, & Pirolli, 1995) or with multiple focuses (Rao & Card, 1994). An example of a single focus distorted view of a node link diagram from Lamping et al. (1995) is shown in Figure 3.5.

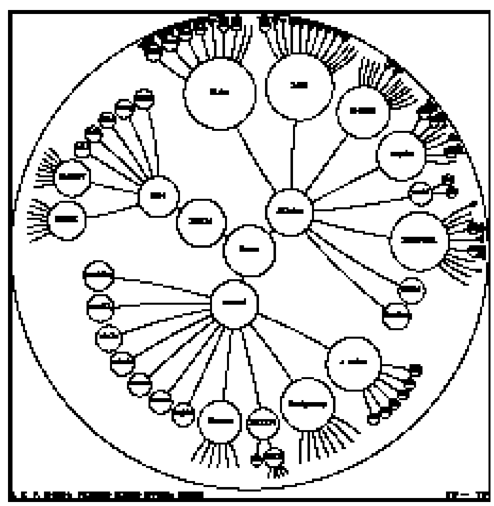


Figure 3.5
A hyperbolic display for a node-link diagram from (Lamping et al. 1995)

Another set of guidelines comes from the information visualization mantra *"overview first, zoom and filter, then details on demand"* (Shneiderman, 2010). Starting with an overview helps users form mental models of the information, highlights the relationships in the information, allows direct access to parts of the data, and encourages exploration (C. North, 2005). Starting with an overview has also been shown to improve performance in information seeking tasks (Hornbæk, Bederson, & Plaisant, 2002; C. North, 2001). Based on this evidence, starting the user with an overview of the data should improve the effectiveness of the adaptive map tool. Zooming and filtering have been discussed earlier as ways to manage large amounts of data, and details on demand is a fundamental part of the content repository since content will be embedded at the lowest level of detail. The tool should, of course, provide easy transition back and forth between the most detailed view and views with the concept map, making this transition smooth if possible.

Finally, the information visualization community has shown that reducing the number of link crossings is one of the most important aesthetic features for the comprehension of node-link diagrams (Purchase, 1997). It is fairly simple to have no link crossings for simple node-link diagrams, but as the diagrams become more complicated, it becomes difficult or even impossible to achieve a setup with no crossing links. Keeping the number of link crossings to a minimum should be a high priority though, since excessive link crossings can significantly hinder the comprehension of a concept map.

3.3.4 Design Requirements for the Software

Guidance from concept mapping literature, information visualization literature, and other project goals were integrated into one list. That list of design requirements is presented below and was used as guidance for software development.

1. The tool will act as a digital content repository with a concept map based navigation scheme. The tool must be able to display detailed information as well as concept maps of the embedded information at several levels of detail and

abstraction, and it must allow the user to easily navigate horizontally (from one topic to another) and vertically (from one level of detail to another).

2. Usability of the visualization as both a learning and navigation tool is the primary goal of the software. The information should be displayed in a way that does not cognitively overload the user.
3. The tool will automatically generate the visualizations based on metadata from the content developer. The content developer will develop content pages with metadata to inform the program what other topics a given idea is directly related to, what the nature of those relationships are, and what groups the topic belongs to. The software should interpret this information and determine how to best visualize the information automatically based on the expert-generated metadata.
4. The tool should be as modular as possible. Software and content should be kept as separate as possible so that future content can be developed without understanding the inner workings of the visualization software. This should lower the barrier to adoption for content developers.
5. The software should provide means for the user to adjust the settings. Since the ideal parameters for a concept map are learner dependent, the user should be able to change the settings to match his or her needs.
6. The concept map displays should provide good "symmetry" and "predictability." The concept map displays should display node-link structures with similar relationships in similar ways. The displays should also be consistent temporally - if the user leaves a view and then later comes back to it, it should look the same as it did the first time. Also, small changes to the content should not radically alter the output. Both of these goals can be accomplished by having consistent and structured rules for how the concept map visual is built.
7. The concept map should minimize link lengths and link crossings. This will provide good proximity for directly linked nodes and reduce the mental effort needed to interpret the links.
8. The concept map should provide good continuation. Directional links should consistently go in one general direction. This direction of flow should be vertically oriented.
9. The nodes and links should utilize color and shape as indications of different features of the nodes and links. This should be kept fairly simple, however, and the degree of color and shape variation should be able to be adjusted by the user.
10. The tool should help the user maintain a sense of context while viewing details. To accomplish this goal, smooth zooming and panning, multiple window setups, distorted views, or some combination of these methods will be employed.
11. Upon startup, the tool should display an overview of all the content available to the user.

3.3.5 Software Implementation

To implement the software design goals discussed in Section 3.3.4, the author led a number of teams of undergraduate computer science students. These teams of software developers worked to interpret and develop code that matched the software design goals.

As the first development decision, the design team decided to develop the Adaptive Map tool as a Java applet, as this approach offered many advantages. First, the native cross-platform compatibility of Java allowed the team to distribute the program to students on all major platforms, without having to write much platform-specific code. Second, prior experiences with Java and the widespread availability of free web tutorials about programming with Java allowed all team members to participate in development process quickly without learning the details of more uncommonly used programming language. Finally, using a Java applet allowed the team to host the program on one central server rather than having users install and have to update software on their personal computers. This provided all users access via web browser and the centralized location allowed for simple and efficient updates to both the software and the content.

Once the team chose the programming language, the team selected a tool to use for the visual aspect of the program. The tool needed to be able to animate many objects at the same time in a smooth and efficient manner in order maintain a sense of context for the learner (software design goal #10). Of the possibilities that were considered, the "Zoomable Visual Transformation Machine" (ZVTM) toolkit (Pietriga, 2005) was chosen. This toolkit provided a simple programming interface that allowed the team to create and animate objects without much effort. It also provided the source code for all of its objects, which allowed for easy modification that better allowed the design team to address a variety of software design goals.

To properly implement design goals 3, 6, 7 and 8, which deal with graph layout, the development team researched available graphing software. Many free graph layout algorithms have already been developed and optimized by outside researchers, and it was deemed best to not try to figuratively “reinvent the wheel” for this particular task. The first graphing toolkit the team tested was the “Hierarchical Layout Plugin”, developed by Robert Sheridan for the Institute for Systems Biology (Cline et al., 2007). This plugin worked well for getting a basic layout of nodes, but did not adequately minimize link crossings (software design goal #7). Graphviz (Ellson, Gansner, Koutsofios, North, & Woodhull, 2002) was ultimately selected as it provided a better graphing solution than the Hierarchical Layout plugin, with less link crossings overall. Graphviz also provided the ability to pre-generate the graph layout solutions beforehand so that overall layout consistency could be maintained (software design goal #6). This created an extra step for the content developer when changing the content, but this drawback was balanced by the decreased load on user’s machines. These pre-generated maps could be downloaded once upon loading the Adaptive Map and saved, rather than having user’s machines continually regenerate the new maps as the user was exploring the concept maps.

As a way to encode the concept map content, the developers decide to use an XML document. XML offered two advantages for content encoding. First, it is a fairly simple markup language. It requires little programming expertise to understand and modify XML documents. Second, by storing all of the concept map content in a single XML document, it kept the content centralized and separate from the software (software design goal #4).

The XML document captures the topics, clusters, and links defined through the concept map generation procedure (Section 3.2.2), but removes any physical layout information so that the visualization software can determine the best physical presentation of the abstract information captured by the content developer (software design goal #3). To further assist in the creation and maintenance of the large XML content document, a Java graphical user interface was developed. This interface allows content developers to more quickly create, navigate, and modify the XML content document. A screenshot of the XML generator GUI is shown in Figure 3.6. After the content developer encodes their content in the form of an XML document. The content document can be easily parsed and the used by the Java Visualization software.

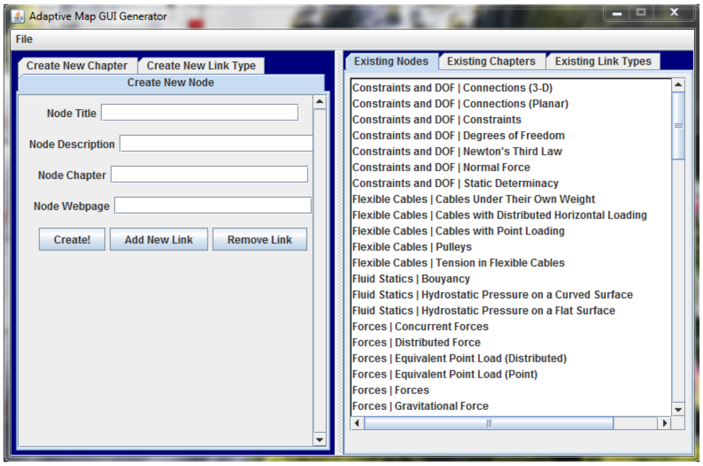


Figure 3.6: The XML Generator GUI

3.4 Walkthrough of the Adaptive Map Tool

This section provides a potential walkthrough of the adaptive map from the perspective of a student (Section 3.4.1) and from the perspective of a content developer (Section 3.4.2). These two perspectives illustrate the final design features of the Adaptive Map Tool through the lens of user experiences.

3.4.1 Student User Walkthrough

The user of the Adaptive Map software is a student in an engineering statics course halfway through the semester. She is working on a homework assignment that is due tomorrow and needs to look up information to solve the homework problems in the assignment. The assignment focuses on trusses, frames, machines, and how to analyze each of these structures.

She opens a web browser and navigates to the adaptive map tool online. She starts the tool and is presented with an overview of the course in the form of a concept map (Figure 3.7). Presenting an overview first helps users form mental models of the information, highlights the relationships in the information, allows direct access to parts of the data, and encourages exploration (C. North, 2005).

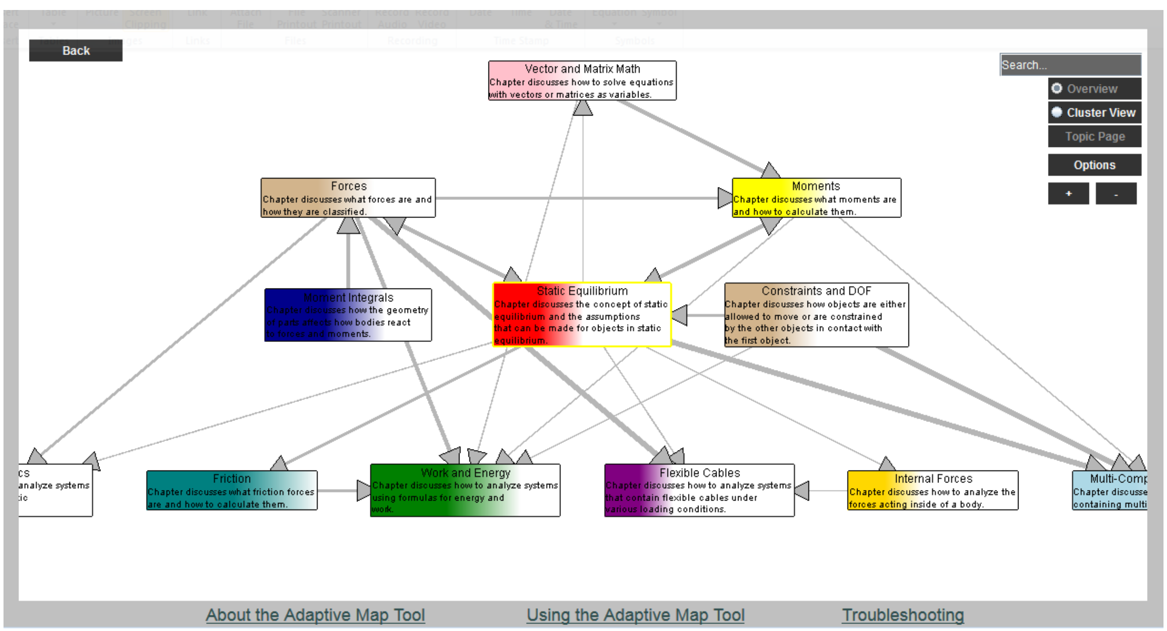


Figure 3.7: The Adaptive Map Overview

The overview diagram has several cluster nodes, each representing a number of highly related topics, similar to a chapter is a traditional textbook. The links between these clusters represent relationships between the topics within each of the clusters. The thicker the link, the more relationships between those two clusters.

Knowing that she is working with trusses, frames and machines for the homework problems, she clicks on the multi-component assembly cluster in the overview. The multi-component assembly node smoothly slides to the center of her laptop screen. This smooth, animated transition helps the user maintain their sense of context in the visualization (Bederson & Hollan, 1994).

She then flicks the scroll wheel on her mouse and she begins to zoom in on the concept map, the multi-component assembly node expanding in the center of her screen. Eventually the cluster node starts to fade and a concept map of smaller topic nodes start to appear (Figure 3.8).

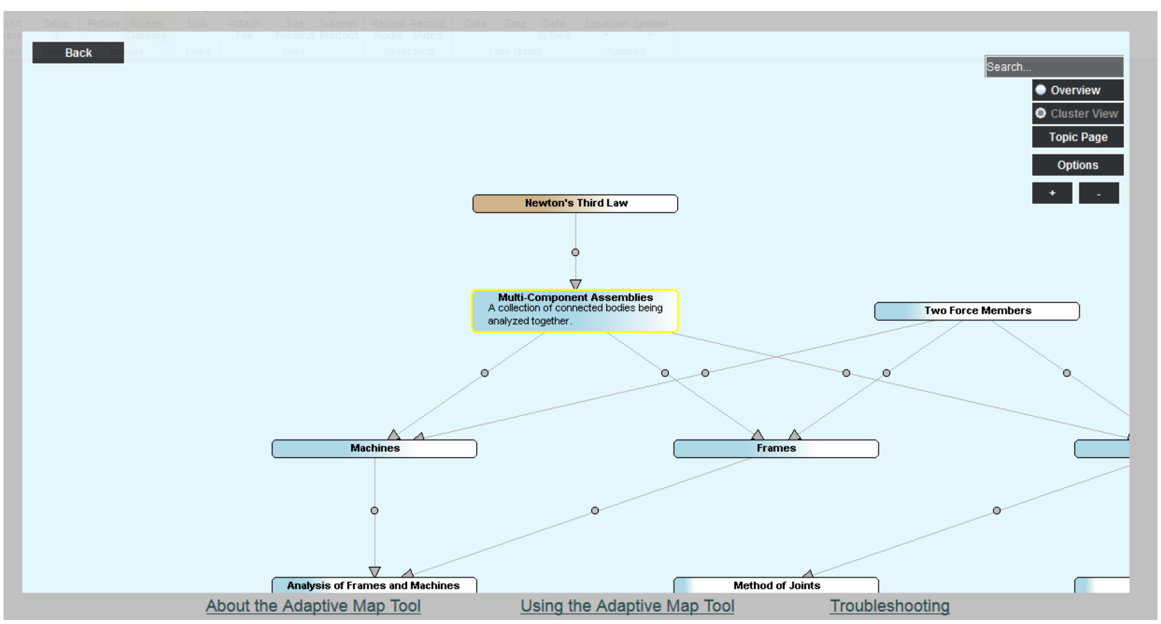


Figure 3.8: The Multi-Component Assembly Cluster View

In this view the background color changes to correspond to the cluster the user has entered. The view is centered on the Multi-Component Assemblies topic node, which was designated as the central topic for the multi-component assemblies cluster. The color of this node matches the cluster node color to provide a sense of continuity between the cluster and the topics within. Built up around the central topic node is a concept map of the topics within the multi-component assemblies cluster. These other nodes also have the same color as the multi-component assemblies cluster node.

An out of cluster connection can be seen connecting the Newton's Third Law topic (in the Constraints cluster) directly to the multi-component assemblies topic. The differing color of the topic node indicates that this is not part of the multi-component assemblies cluster. The cross-cluster link is between the "Newton's Third Law" and the "Multi-Component Assemblies" topic nodes represents one of the links that was amalgamated together in the overview.

Because the first question asks the student to apply the method of joints, the student clicks on the "Method of Joints" topic node. This recenters the screen on the "Method of Joints" topic node, with the nodes sliding smoothly from one location to the next. At the same time, the "Newton's Third Law" topic node fades away as the focus changes away from the "Multi-Component Assemblies" topic and the "Equations of Static Equilibrium" topic node flies in from off screen. A link appears between the "Equations of Static Equilibrium" and the "Method of Joints," "Method of Sections" and "Analysis of Frames and Machines" topic nodes (Figure 3.9).

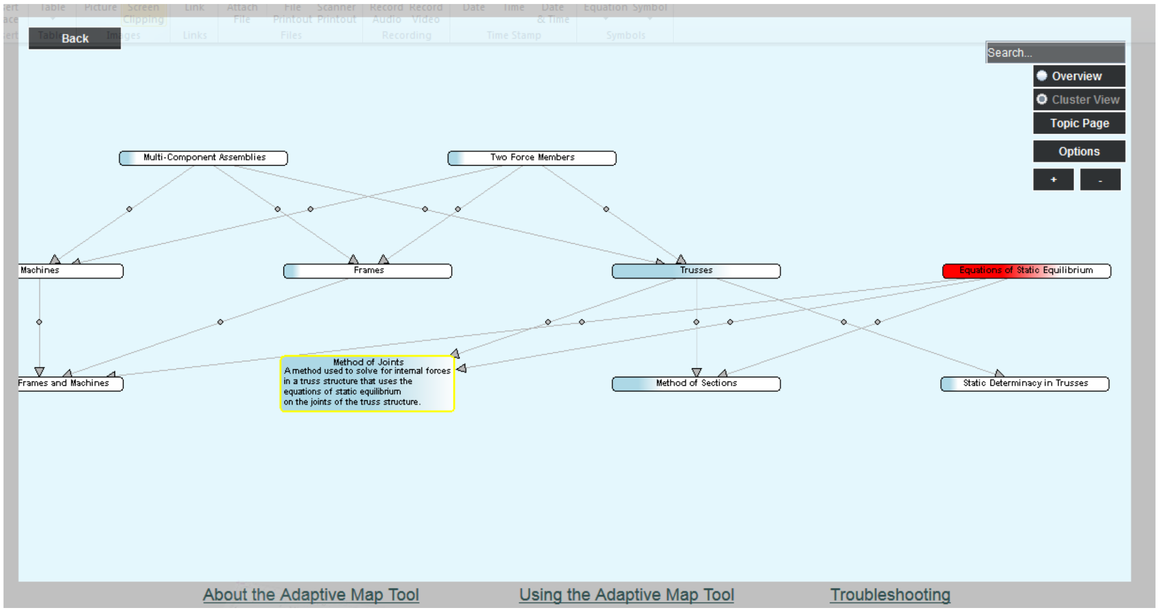
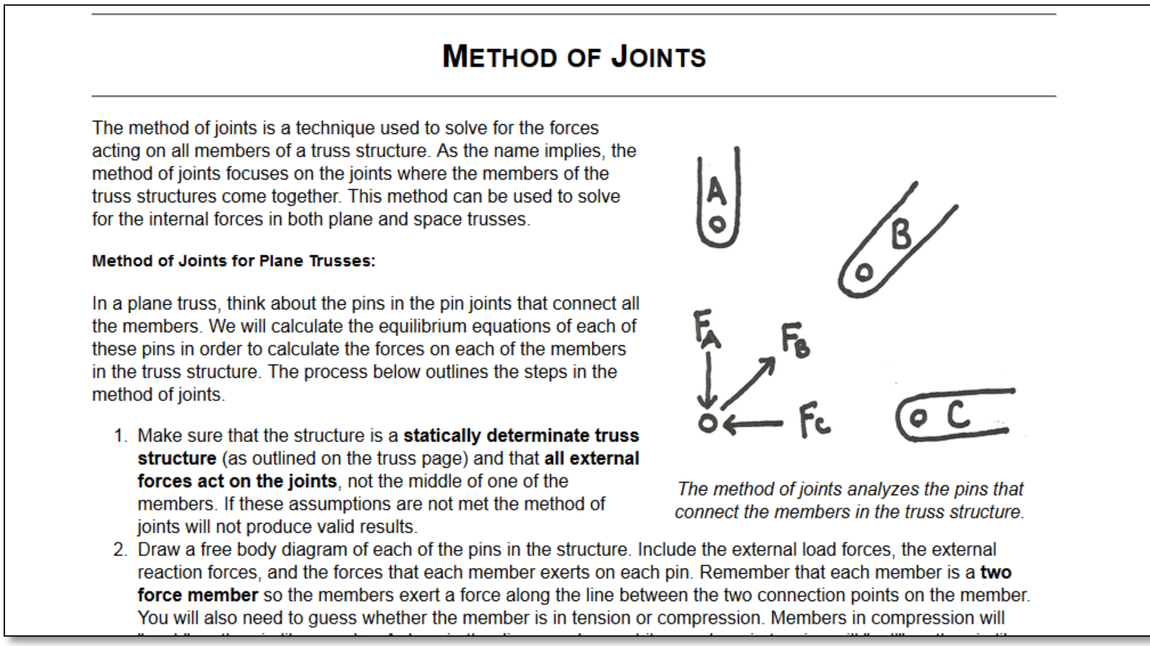


Figure 3.9: The Multi-Component Cluster Centered on the Method of Joints

The student hovers over the Method of Joints topic node to see the nature of the relationships shown. When the student does this, three letter labels appear over all the links going to or from the Method of Joints topic node. This method provides “details on demand” as suggested by the information visualization mantra (Shneiderman, 2010). The student recognizes the “APP” label as an application of the source topic in the destination concept, but the student does not recognize the “MTH” label that links the Trusses and Method of Joints topic nodes. She hovers over the small dot in the middle of this labeled link and a description of this type of link appears stating that “The destination is a method used in a situation described by the source concept.”

The student then double clicks on the Method of Joints Node to open the topic page (Figure 3.10). This page opens in another tab and the student is presented with an webpage consisting of text and images that explain the method of joints and gives some worked examples the use the method of joints. The student reads through the explanation and then uses the explanation and the worked examples to solve her first homework problem with little difficulty.



METHOD OF JOINTS

The method of joints is a technique used to solve for the forces acting on all members of a truss structure. As the name implies, the method of joints focuses on the joints where the members of the truss structures come together. This method can be used to solve for the internal forces in both plane and space trusses.

Method of Joints for Plane Trusses:

In a plane truss, think about the pins in the pin joints that connect all the members. We will calculate the equilibrium equations of each of these pins in order to calculate the forces on each of the members in the truss structure. The process below outlines the steps in the method of joints.

1. Make sure that the structure is a **statically determinate truss structure** (as outlined on the truss page) and that **all external forces act on the joints**, not the middle of one of the members. If these assumptions are not met the method of joints will not produce valid results.
2. Draw a free body diagram of each of the pins in the structure. Include the external load forces, the external reaction forces, and the forces that each member exerts on each pin. Remember that each member is a **two force member** so the members exert a force along the line between the two connection points on the member. You will also need to guess whether the member is in tension or compression. Members in compression will

The method of joints analyzes the pins that connect the members in the truss structure.

Figure 3.10: The Method of Joints Topic Page

The next problem asks the student to solve the given multi-component assembly using the appropriate method. Seeing that different methods seem to be linked to different types of Multi-Component Assemblies, decides that she need to determine what type of assembly this is. She navigates back to the Multi-Component Assemblies topic node and opens up that page. She quickly determines the given assembly is rigid and therefore eliminates a machine as an option. She is left deciding between a frame and a truss. She reads that two force members are the key to separating these two types of assemblies. She then closes the topic page and looks at the cluster view again. She sees a topic node on two force members. She clicks on this topic node and opens this page. Reading up on two force members, she determines that one member in her assembly is not a two force member which eliminates trusses as an option. She navigates to and skims the page on frames just to confirm, and then zooms back out to the map. Next she follows the link down from frames and clicks on the node titled "Analysis of Frames and Machines." She opens this page and reads about the method used to analyze frames and machines.

The student continues solving homework problems using the Adaptive Map tool to understand the topics and find worked examples to follow, following links up or down in the concept map to guide herself to the appropriate topics. When the student comes across a term in her homework that she does not know and does not see immediately, she uses the search bar to search for the appropriate topics and the concept map recenters on the most appropriate topic. By navigating through the concept map, the student slowly gains a familiarity with the concept map of the Multi-Component Assemblies cluster. Through this they learn to understand that multi-component assemblies can be broken down into trusses, frames and machines. They learn that two force members are the key to distinguishing between trusses and frames and machines, and they learn that there are separate methods used to analyze the different types of assemblies. These big picture relationships are subtly, but repeatedly emphasized to the student through the concept maps.

3.4.2 Developer User Walkthrough

The developer for the adaptive map software is an engineering dynamics instructor who wishes to create a dynamics textbook of his own. He has the summer to develop some content and wishes to use the tool in the coming fall semester. He is familiar with the adaptive map statics digital textbook, but does not have experience developing his own content.

Towards the end of the spring semester, he collaborates with another faculty member who has also taught the engineering dynamics class. Using the method outlined in Section 3.2.2, he creates a large scale concept map of the topics taught in the engineering dynamics course that contains about seventy topics in eight clusters.

Reading the developer guide that is freely available, he learns that he will need an Apache Tomcat server to host his own textbook. He hunts down an old desktop computer and installs Windows and the free Apache Tomcat, and GraphViz softwares as instructed in the developer guide. After working with the tech people at his university and getting the default Tomcat webpage successfully hosted, he

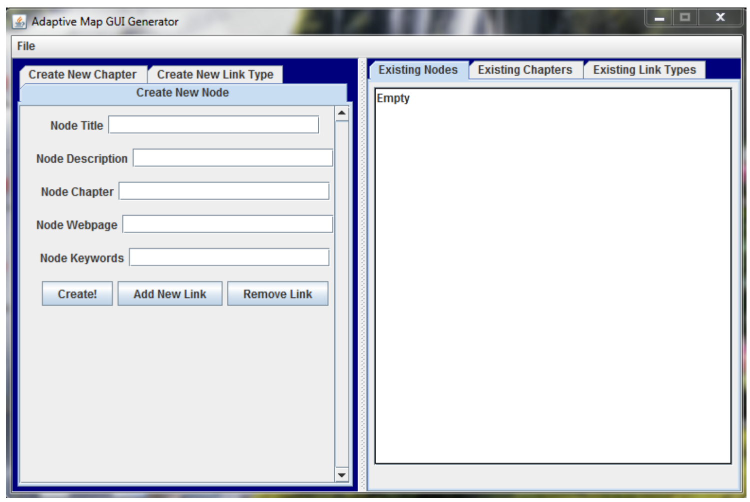


Figure 3.11: The Adaptive Map XML Generator

downloads all the files from the Adaptive Map's GitHub repository. He replaces tomcat's default webpage with the new index page that he downloaded. He also places the .jar file that is the core software in the appropriate file on the server. He visits the website, which seems to be working (except that there is no content, yet).

Now that the software is up and running, he starts to fill in content for the tool. He begins by running the Adaptive Map XML Generator that he downloaded from the GitHub Repository (Figure 3.11). He uses his concept map of engineering dynamics to create and enter information for the clusters, the link types and the topics. As he creates each, they show up in the field on the left and can be edited at any time. After transferring all the information in his concept map to the Adaptive Map XML Generator, he hits file and then save to generate the XML that represents his concept map.

Next he runs the GraphViz Data Creator, which reads the XML file he just created and creates a number of new content files (one for each cluster he defined in the nodes file). After he completes this step, he moves the XML file, and all of the files created with the GraphViz Data Creator, to the content folder on the server. He revisits his website and now his content is shown in the Adaptive Map tool. The only remaining task is to fill in the content pages, as none of them currently contain anything.

He spends most of his summer using his class notes to develop topic pages for the dynamics concept map. Each of these pages is just an HTML page, which he has some experience creating. As he is creating these topic pages, he puts them onto the server and edits the XML so that the topics link to those pages. By the time the summer comes to an end he has a complete concept map with all of the topic pages. It is still bit unfinished, but over the next few years he refines the content, adds some homework problems, adds some video lectures and generally works to improve the tool based on feedback from students that use the tool each year.

3.5 Formative Assessment

Essential to the success of the prototype, and any educational innovation for that matter, is formative assessment (Spurlin, Rajala, & Lavelle, 2008). Both the software and the content were evaluated by both experts and novices before formal evaluation to identify incorrect, misleading, or missing information in the content and help identify any usability issues with the software.

The formative assessment plan consisted of three separate elements: An expert content validation, an expert software validation, and pilot testing with engineering statics students. Each of these three separate elements pulled external evaluators into the development process and each offered a different perspectives and insights.

3.5.1 Expert Concept Map Validation

In order to validate the content, in the form of 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). 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 the author to discuss his recommended changes. 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. All of these suggestions were discussed and the author and secondary expert decided on the appropriate changes. With a map of more that ninety concepts the suggested changes were relatively small, indicating a high degree of agreement between the secondary expert and the original concept map.

3.5.2 Software Heuristic Validation

In order for the Adaptive Map tool to be useful as a learning tool, it must first be an effective information visualization. Students must be able to draw meaning from the concrete representations of abstract concepts and relationships. In order to evaluate the Adaptive Map tool as an information visualization, a heuristic analysis of the visualization was performed. For this heuristic analysis, the author used Munzner's four level information visualization framework (Munzner, 2009).

Table 3.1 Munzner's Four Level Validation Framework

Level	Primary Question	Threats to validity
Problem Level	Is the visualization attempting aid a legitimate user task?	The visualization is aiding a task the user does not need to perform. The visualization is aiding a task the user does not need help with.
Data Abstraction Level	Is the visualization presenting the appropriate data to perform the user task outlined in the problem level?	The data necessary to complete the user task is not presented. The data presented to the user is irrelevant to the user task.
Data Encoding Level	Do the visualization strategies and interaction techniques effectively communicate the data outlined in the data abstraction level?	The data is presented in a way that is difficult to understand. The data is presented in a way that makes it difficult for the user to navigate and explore the data in a meaningful way.
Algorithm Level	Do the software algorithms effectively implement the visualization strategies and interaction techniques outlined in the in the data encoding level?	The software algorithms cannot effectively execute the visualization strategies and interaction techniques.

Munzner's model breaks the information visualization development process down into four stages, with each stage dependent upon the previous stage. To validate information visualizations using Munzner's model, a developer needs to examine his or her design with respect to a number of threats to validity at each level. If the design fails to address the threats to validity at any of the four levels, the information visualization will not be an effective tool. Table 3.1 outlines Munzner's four level model for visualization design and validation.

The Adaptive Map tool was examined through the lens of Munzner's framework by both the developers and by a number of evaluators external to the project. The external evaluators consisted of 22 students enrolled in an information visualization class; these students were asked to evaluate the Adaptive Map tool according to Munzner's model as part of a class assignment. Because most students in the class were not familiar with the content in engineering statics, two additional external participants who were familiar the statics content (one professional and one student) were brought into a class to interact with the tool to aid in the evaluation. An outline of the heuristic analysis and a summary of the suggestions from external evaluators are outlined below.

The Problem Level:

At the problem level, users of the Adaptive Map tool were encouraged to use the tool as a replacement to their textbook. Common user tasks consist of looking up information to solve homework problems, studying for exams, and catching up with the information from missed classes. In all of these cases, the students are attempting to learn the content information in the textbook. As discussed in Section 2.3, concept maps in particular aid in the formation of conceptual understanding, a type of learning that usually lags behind the acquisition of procedural knowledge in mechanics courses such as engineering statics.

In general, the external evaluators agreed that the task of learning the material during out of class hours was a valid task for statics students. Because the tool is filling the role of an existing tool, that of a textbook, the user tasks were well defined, already familiar, and inherently validated through the already widespread use of textbooks in learning. Additionally, several external evaluators agreed that gaining an understanding of the concepts in a course was more difficult than learning and using procedures, helping to specifically validate the need to help students develop conceptual understanding.

The Data Abstraction Level:

At the data abstraction level, the developer had to determine if the types of data being presented were relevant to the identified user tasks. The Adaptive Map presents two primary types of data to the user, concepts and relationships. Each of the concepts and relationships has many associated characteristics, but the core data is the concepts and relationships between those concepts. Concepts and relationships were specifically chosen because this is how people store knowledge in cognitive schemas in long term memory (Ormrod, 2008). Concept maps were originally developed as a way to externalize these cognitive schemas in learners for evaluation (Novak & Cañas, 2008), and the close correlation between the data presented and the way humans remember information speaks to the validity of the data presented. Overall, the external evaluators found that concepts and relationships were relevant to learning, but there was also a call for more data types that were not present.

The first data type that evaluators found was missing was a single linear ordering of the concepts. Though the directed nature of the links provided some guidance through the content, there was desire from a large number of evaluators for a linear ordering to the concepts. Without a “first page”, evaluators were left wondering where to start. This is an artificial data, stemming not from the way the mind works or from expert understanding, but from experiences with previous textbooks. A number of different orders are valid for learning the topics, but as novices with a newfound choice on their hands (where to start and what to learn next), the evaluators were understandably uneasy. Results from the classroom-based evaluations do not show similar feelings, however, most likely because the course schedule provided the information on where to start and what to learn next. Since the linear ordering would interfere with the presentation of the relationships between ideas, the suggestion to add a linear ordering is not immediately being pursued. Developers have taken this into consideration, however, as a possible barrier to adoption.

The second data type that evaluators found was missing was user history data. The evaluators wanted a system to record what pages they visited, what had already been covered in class, and a system to record notes on the topics. Though some data was available through the back button, there was a call for more of this data to be recorded and available. Results from the formal evaluation indicate that actual students desire to have this information as well. The desire for this information may stem from a performance orientation to learning (Ames & Archer, 1988), where students measure their success by checking off what they have done, what they understand, and how they compare to their classmates. Because of this, a system of tracking user history and user performance on integrated quizzes has been included as an aspect of the future work related to the Adaptive Map Tool.

The Data Encoding Level:

At the data encoding level, the primary visualization strategy was to use a graph, in the form of a concept map, to represent the data of concepts and relationships. To navigate and interact with the graph, a semantic zooming strategy was employed to manage cognitive load. Graphs are the most obvious and usually the best way to encode sets of data consisting of items and relationships between those items (Herman et al., 2000; Spence, 2007). The external evaluators generally agreed that the concept map structure was the best way to display the concept and relationships and that the semantic zooming technique was a valid way to manage cognitive load, but they did have two prominent suggestions to improve the data encoding design.

First, the evaluators had trouble learning what all the encodings meant (node color, node gradient, link thickness, etc.). There was some textual explanation of what these encodings represented, but the prevalence of this confusion indicated that the explanations were not sufficient. In order to address the issue, videos were created to introduce new users to the tool and to better explain what each of the encodings meant. Preliminary results from the classroom assessment corroborate this initial confusion with the data encodings. After a few instances of using the tool though, students did seem to be able to comprehend all the data encodings with ease. This steep learning curve may hinder adoption though, even with video tutorials provided.

The second recurring suggestion the evaluators offered was to improve the overview encoding. There were still concerns about cognitive overload due to the many overlapping links that were present in the overview. Preliminary results from the students in the classroom evaluation corroborate this claim, indicating that the overview was the most difficult view to make sense of. More design work is being conducted to redesign the overview, and this will be an area of continuing work as discussed in Section 7.7.

The Algorithm Level:

The data encoding strategy is carried out via a Java applet supported by graph layout and visualization softwares. Evaluators found the software to be sufficiently fast and efficient in carrying out the design encoding strategy. The evaluators did find software bugs, however, when refreshing the page and when clicking during a transition animation. These bugs could interfere with the encoding design under some conditions. These bugs are currently being addressed to improve the quality of the Adaptive Map tool.

3.5.3 Pilot Testing

In addition to the heuristic evaluations by both content and information visualization experts, feedback was also gathered from engineering statics students. Students are the intended audience for the Adaptive Map tool, and therefore their perceptions of the tool are regarded as important in development process.

Methods:

To gather formative feedback from students, volunteers were solicited from the current statics course at Sweet Briar College, ensuring they were authentic users for the Adaptive Map Tool. Each of the four volunteers was brought in individually for a single thirty minute data collection session. The sessions were conducted late in the semester, so students had nearly completed in the course and were already familiar with most of the content covered in engineering statics.

To gather feedback from each of these students, they were first introduced to the Adaptive Map tool. After that they were then asked to navigate around by themselves and find specific topics. Finally they were interviewed to gather general opinions and points of confusion about the tool. Throughout the session, the researcher took notes on what the student was doing and the responses they gave to questions. The first student was given a very minimal introduction to the tool (less than one minute), and then had major problems understanding how to use the tool. Consequently, the later three subjects were given a more substantial introduction to the tool (about five minutes) where the researcher showed the subject many of the key features of the tool and how to use them. After this introduction, the students were given control of the tool using the researcher's computer and asked to navigate around and find some specific subjects. This hands-on time took about ten minutes. During this time, the researcher did not offer any assistance unless the subject asked the researcher a direct question. This helped the researcher identify any non-intuitive interface controls. Finally, after the student had an opportunity to use and become a little familiar with the tool, an open interview was conducted. This allowed the researcher to pursue any interesting topics, and to use the observed usage to guide the discussion.

Results:

Feedback on the Adaptive Map tool was generally positive, with all students saying they would use such a tool if given one and three out of four students stating that the concept map structure would be helpful in particular. Also when asked how they would use the tool, all four students said they would find the tool most useful for learning information for the first time, two of the four stating that the concept map provides a good and simple overview of the information to come. This was encouraging as it indicates that students are likely to use the Adaptive Map tool as an advance organizer.

Despite the positive impressions of the tool, there were a number of issues encountered and discussed by the students. All four of the students encountered a bug at some point that had to be resolved by restarting the browser. Most of these were caused by using the back and refresh buttons in the browser. This bug has been partially resolved by adding a working back button to the interface, but the refresh error remains a problem. The one observed bug that did not relate to the back or refresh buttons occurred during a period of rapid panning and zooming. Researchers were unable to reproduce this error and have therefore been unable to address it. Another observed usability issue was the continuation of zooming in to topic nodes to open them. Students zoomed into topics expecting them to open, but issues with embedding HTML content pages into the Java Applet make this a continued usability issue.

When asked for feedback on the tool, the most frequently suggested improvement was for the inclusion of more example problems. This is continually being addressed through further content development. Another common suggestion is for instructions on how to use the tool to be included on the website. This suggestion was addressed by adding textual, and then video instructions. Other less common suggestions were to include tabs to common look-up tables (similar to the appendices in a regular textbook), and color coding or boxing of the topic pages to denote particularly important equations. These suggestions have yet to be addressed do to the time constraints on the development process. Also, building upon this more informal pilot testing is the more formal assessment discussed in Chapter 4.

4 Data Collection and Analysis Methodology

The overall research methodology followed a multiple case study approach, with both replication and contrasting cases (Yin, 2009). Because there many unanswered questions about how students would use the prototype tool and what effect it would have in practice, the open-ended and inductive nature of qualitative research offered an advantage (Creswell, 2009). A qualitative approach allows researchers to more fully explore how the prototype tool is used, why it is used, and how it affects student behaviors and understanding within the complex, but authentic usage context of an engineering statics course.

A multiple case study approach was selected as the most appropriate qualitative research methodology for a number of reasons. Case studies focus on one or more "cases," where a case is an individual, organization, or event of interest (Creswell, 2013). The case of interest in this scenario is the event of a student using the Adaptive Map tool in an engineering statics course. A multiple case study approach allows the researchers to explore the differing experiences students had with the tool. The case study here had both replication and contrasting cases (Yin, 2009). Replication cases are multiple similar cases that are of primary interest (in this scenario, the students using the Adaptive Map tool). Contrasting cases are cases that are fundamentally different from the cases that are of primary interest. These cases provide a point of comparison for the researchers that they can use to compare and contrast with the primary cases. The contrasting cases in this scenario are students using a traditional paper textbook (the "status quo" for the engineering course).

In case study research, the researcher pulls together a variety of data sources to write a case profile, or detailed description of what occurred in each case (Yin, 2009). These case profiles, presented in Chapter 5, seek to outline how the student in each case used the tool (either the Adaptive Map tool or the paper textbook), when the student used the tool, for what purpose the student used the tool, and what affect the tool had on student learning.

4.1 The Research Population and Sample

The research was conducted in engineering statics classes at a large mid-Atlantic land-grant university. Two sections of the engineering statics course with the same instructor were selected to serve as the research population. One section was introduced to, and given access to, the Adaptive Map tool; the other section was not introduced or given access to the Adaptive Map tool. From these two sections, volunteers were solicited to serve as the research sample. Section 4.1.1 provides a context for the study in the engineering statics courses at the research site, and Section 4.1.2 provides details on the procedures used to solicit research participants from the identified population.

4.1.1 Engineering Statics at the Research Site

The large mid-Atlantic land-grant university has an undergraduate enrollment of over 28,000 undergraduates pursuing a full range of majors in engineering, the sciences, natural resources, business, humanities, and social sciences. Engineers constitute the largest percentage at 29%. The student body is approximately 58% male and 72% Caucasian, with Asians (7.2%) as the largest minority group. Statics is typically the first engineering science course taken by the students and is usually taken in the fall semester of their sophomore year. A three credit-hour course, statics is offered in a large lecture-based format.

The research population was identified as two roughly one hundred and fifty person sections of the engineering statics course offered in the Fall of 2012. These two sections were chosen because they had a common instructor and they were roughly the same size. One of these two sections was introduced the Adaptive Map tool early in the semester, while the other section was not introduced to the Adaptive Map tool. This setup gave researchers access to two similar bodies of students that differed in their exposure to the Adaptive Map tool.

4.1.2 Volunteer Solicitation Procedure

About one week after the tool was introduced to one section in the population, volunteers from the two sections were solicited via e-mail. This solicitation discussed the purpose of the study, the responsibilities for participating, and the rewards for participating. Those interested in participating were asked to attend the first research session, where they were asked to sign a written consent form before any data was collected. All data collection procedures and forms were approved by the Virginia Tech Institutional Review Board (IRB) before implementation.

Those participants who volunteered to be part of the study were asked to attend four out-of-class experimental sessions over the course of the semester and were asked to fill out a short weekly survey. The first three research sessions consisted of a learning activity where the participant would be asked to use the Adaptive Map tool or traditional textbook to complete a task related to statics. The last session consisted of a short semi-structured interview. Each session required about one hour of the student's time and were conducted one on one with the researcher.

Participation in the study presented minimal risk to the students and had no effect on the students' course grade. The instructor for the course was purposefully not informed of which students volunteered in order to ensure that participation had not effect on the student's course grade. In addition all personal identifiers were removed from notes and transcripts prior to presenting the data to anyone outside of the research group. Students were instead given randomly selected pseudonyms to protect their identity.

Students were rewarded for their participation in two ways. First, students were compensated for their time in the form of an Amazon gift card that was presented to volunteers at the last session. The compensation was pro-rated at a rate of $10 a session, for a maximum of $40 of compensation for participation in all research sessions. In addition, the sessions were scheduled just before course exams and served as a way to help students prepare for upcoming course exams.

4.2 Data Sources Overview

By weaving together variety of data sources, the researchers built a more complete and reliable interpretation of what occurred in each case (Yin, 2009). In addition to building reliability, each source of data was used to measure different aspects of the case. The researchers selected data sources to ensure that all aspects of the research question could be answered. Table 4.1 outlines the data sources collected for each case, the research questions they are mapped to, and the analysis methods that were used to make sense of the raw data.

Table 4.1 Research Questions, Data Sources, and Analysis Methods

Research Question	Data Source	Analysis Method
How are students engaging in learning activities with the proposed tool? How does this differ from the learning behaviors students engage in with traditional textbooks?	Weekly usage surveys (Section 4.3)	Results compiled into usage summary table.
	Semi-structured debriefing interview (Section 4.7).	Interviews recorded, transcribed, thematic analysis conducted.
	CRESST preparation observation notes (Section 4.4.1)	Usage patterns reported.
How do these observed learning behaviors promote or hinder the formation of conceptual understanding?	CRESST explanation sessions (Section 4.4.2)	Sessions recorded and transcribed with notes. Transcripts coded (Section 4.4.3) Transcripts Scored According to CRESST rubric (Section 4.4.4) Concept map of student understanding made from transcript (Section 4.4.5).
	Statics Concept Inventory (Section 4.6)	Scores reported.
Are students experiencing cognitive overload during any of the observed learning behaviors, and if so how is this affecting the learning process?	NASA TLX survey instrument (Section 4.5)	Results compiled into cognitive load summary table. Descriptive statistics calculated.
What factors contribute to students adopting or not adopting the proposed tool for learning activities?	Semi-structured debriefing interview (Section 4.7)	Interviews recorded, transcribed, thematic analysis conducted.

The following sections discuss the data collection and analysis techniques used to collect and make sense of the multiple data sources. These methods are discussed in the order in which they were administered.

4.3 Weekly Usage Surveys

In order to measure student usage patterns of the Adaptive Map tool and the textbook outside of the research sessions, a weekly survey was distributed to the students via e-mail. Each survey consisted of three items, asking the student for their name, how many times they used the Adaptive Map tool (for the Adaptive Map group) or paper textbook (for the paper textbook group) in the past week outside of the research sessions, and for what purposes they were using tool. These surveys were sent to students at the conclusion of each week in order to reduce the time between the actions and the reporting of those actions. A reminder e-mail was also sent out each week to help increase the response rate for the survey.

The first survey was conducted orally at the first research session, right after students signed the consent forms. The questions at this first survey were open ended, and student responses were used to guide the creation of the options for each of the closed form questions on the digital survey used for the rest of the weekly surveys. An example of the survey instrument administered to the Adaptive Map group is shown in Appendix A.

4.4 The CRESST Research Sessions

The Center for Research on Evaluation, Standards, and Student Testing (CRESST) Performance Assessment Model (Baker, Aschbacher, Niemi, & Sato, 1992), was used as a central pillar of the data collection process. This model was originally developed to measure conceptual understanding in the subject of history, but the model has also been adapted to math (Niemi, 1996) and science (Baker, Niemi, Novak, & Herl, 1992) subjects.

The central element to this activity is an explanation of some set of concepts to an imaginary novice. The session begins by giving students subject matter documents and time to look over those documents. After that, the students are asked to write a letter to an imaginary recipient that explains the main issues and summarizes the documents. This letter is then graded according to a rubric by an evaluator familiar with the subject material.

The CRESST method was originally developed to use written explanations in order to reduce the time needed to evaluate a single student (Baker, Aschbacher, et al., 1992), but for this study, written explanations were replaced with an oral explanation session in order to allow researchers to more completely probe the student's understanding of the subject material. For this work, the researcher used methods borrowed from the clinical interviewing technique (Ginsburg, 1997) in order to ensure that the interviewer could probe student knowledge while limiting the bias from the interviewer themselves.

Each of these sessions began with an oral prompt given to the students. The prompt given for the first CRESST is below.

> *"For this session, you are being asked to give me an approximately 20 minute overview of the information in the (structures chapter of your textbook / multi-component assemblies cluster). Treat me like I know everything you have covered in class so far, but that but nothing from this (chapter / cluster). I will ask questions along the way to clarify your explanations.*
>
> *You will have twenty minutes to prepare. Please use (you textbook / the adaptive map tool) to prepare. At the end of the preparation, you will be given the NASA TLX survey to measure the load imposed by the task of preparing to teach me about this information. You can take notes on blank paper to prepare. You will not be allowed to use (your textbook / the adaptive map) while teaching me the information.*
>
> *Any questions before we start?"*

The prompt for the second session was similar, except for the selection of different subject area. Students in both groups were given access to pen and paper to prepare and during the explanation session. Students in the Adaptive Map group were additionally given access to a computer opened to the appropriate cluster, and students in the textbook group were given access to a textbook opened to the appropriate section.

The subject area for the first session was structures, which consisted of Chapter Four of the textbook or the "Multi-Component Assemblies" cluster in the Adaptive Map tool. This subject area was just covered in class, and the session was timed to be just before the course exam on the same subject material. This session was designed to serve as a realistic instance of students using the tools to review for an upcoming exam.

The subject area for the second CRESST session was selected as fluid statics, consisting of Chapter 5.9 in the textbook, or the "Fluid Statics" cluster in the Adaptive Map tool. This is a subject not discussed in the engineering statics course, but the students did learn about distributed loads just before the second session. By choosing a subject just beyond the currently covered content, the session was designed to serve as a realistic analog of students using the textbook or Adaptive Map tool to catch up from a missed class.

Before both sessions, researchers also checked to ensure that the content area covered in each tool was similar in scope. This was done creating a concept map of the information in each tool and ensuring that almost all major topics were consistent across the two tools. The process used to create the concept maps of the content is covered in Section 4.4.5, and the concept maps of each content area for each tool are presented in Section 5.2.

4.4.1 CRESST Preparation Notes

After being given the prompt to prepare for the CRESST explanation, the student was given twenty minutes to prepare an explanation of the material. This time is traditionally unimportant for the CRESST methodology, but researchers for this project found it a valuable opportunity to observe detailed student usage patterns of the Adaptive Map tool and the paper textbook.

The researcher placed himself so that he could see both the student's notes and the computer screen or paper textbook. The researcher took field notes on what was observed including what pages the student visited and in what order, when the student took notes, and how fast the student was moving through the material. The researcher also jotted down anything else that jumped out during the preparation period.

To augment these observation notes, any student notes taken during the preparation period were collected at the end of the session. The observation notes and the student notes were then used to reconstruct an account of the student behaviors observed during the CRESST preparation session.

At the end of the twenty minute preparation period, or when the student declared they were done preparing, they were given the NASA TLX survey to estimate cognitive load imposed by the preparation activities. More on the NASA TLX survey can be found in Section 4.5. This also gave the researcher an opportunity to finish his notes and to set up for the explanation activity.

4.4.2 CRESST Explanation Activity

After completing the NASA TLX survey, students were asked to begin explaining the prescribed subject area to the researcher. The researcher allowed the student to guide the discussion and would not give indications to the correctness of the explanations given. Following the clinical interviewing guidelines (Ginsburg, 1997), the researcher attempted to constrain questions to two categories: (i) asking students to give more details on a subject the student introduced, or (ii) asking the student why something was true or why it is done in the described way. This allowed the researcher to draw out details of the student's understanding while minimizing the feedback given as to the correctness of the information.

Students were told to deliver about a twenty minute explanation in order to more clearly define the expected level of detail, but students were allowed as much time as required to give their explanations through the student-researcher interaction. The researcher had a checklist of core topics and would check them off during discussion as they were addressed. Upon the student reporting that they were done with what they prepared, the researcher would go back and ask the student to explain or expand upon any subjects not covered, or not covered sufficiently in the student's explanation. This would consist of any topic not checked off on the researcher's checklist. These prompts would often consist of "Tell me about X." to minimize guidance form the researcher. This helped to ensure that subjects not discussed were not known by the student, rather than just forgotten in discussion.

All explanation sessions were audio recorded and later transcribed for analysis. Often, students used pictures or referenced their notes during these explanations, and images of drawn pictures and notes were spliced into the transcripts where appropriate. These transcripts were then coded (Section 4.4.3), scored according to a rubric (Section 4.4.4), and then used to develop a concept map of the student's understanding of the subject material (Section 4.4.5).

4.4.3 CRESST Explanation Coding Procedure

After transcribing the CRESST explanation sessions, the transcripts were coded to allow for easier navigation and analysis of the data. Coding of qualitative data is a common first step in qualitative data analysis that helps researchers uncover themes present in the data (Corbin & Strauss, 2007).

The coding procedure began by loading the transcripts into the Weft QDA software (Fenton, 2012). This free software allowed for easier management of the codes and coded documents. The first step to coding was to segment the code. This is a common first step to coding that allows researchers to separate the document into discrete units that represent a single line of thought or interaction (MacQueen, McLellan, Kay, & Milstein, 1998).

After segmenting the transcripts, a set of broad codes were developed to correspond conceptual knowledge and procedural knowledge, contrasting concepts addressed in Section 2.2.1. This set of broad codes was selected because of the tool's focus on helping students develop conceptual understanding. A prior knowledge code was also added, since both conceptual understanding and meaningful learning addressing connecting new information to existing knowledge structures. From here, a set of sub-codes were developed through an iterative process identifying possible themes, defining these themes, and then applying these themes to documents. A codebook (MacQueen et al., 1998) containing the title, definition, inclusion criteria, exclusion criteria, and an examples segments for each code and sub-code was developed and maintained in order to build consistency in the application of the codes. The final CRESST explanation codebook can be seen in Appendix B.

All transcripts were coded by a single researcher, and the documents were carefully examined a minimum of two times in order to build confidence in the applied codes. Codes were applied to entire segments in order to maintain consistent code boundaries.

To assess the validity and reliability of the coding procedure, a measure of inter-coder agreement was used (MacQueen et al., 1998). The procedure for quantifying inter-coder agreement borrowed from Carey, Morgan, and Oxtoby (1996), consisted of the following steps:

1. Have two researchers using the same codebook independently code the same documents.
2. Go through the documents and count the number of instances each coder applies the same code to the same segment. This is labeled an agreement. Also count the number of instances where either one or both coders apply a code to a segment. This is labeled as the total number of codes.
3. The measure of inter-coder agreement is the number of agreements over the total number of codes applied.

The measure of inter-coder agreement should approach or exceed 0.90 (Miles & Huberman, 1994).

The secondary coder selected was an experienced statics instructor, since familiarity with the content material was needed to apply the codes correctly. The secondary coder was given the codebook for this study and segmented, but uncoded transcripts. After an initial practice session where the two researchers coded a single transcript together, the secondary coder applied the codes to a set of four of the eighteen total transcripts. All transcripts were from the first CRESST session to reduce training time. Two transcripts were from the Adaptive Map group and two were from the traditional textbook group, though the secondary coder was unaware of the group each participant belonged to. A measure of inter-coder agreement of 0.62 was achieved, indicating poor inter-rater reliability.

To further examine the reliability of the coding procedure, a measure of code-recode reliability was taken. This process began with the primary coder recoding four of the CRESST transcripts. The same four transcripts used for the inter-rater reliability check were used for the code-recode reliability check. Using the codebook, the original coder applied the codes to the four segmented but uncoded transcripts. The process for calculating the agreement remained the same as for the inter-rater check, comparing the original coded transcripts to the recoded transcripts. A measure of code-recode agreement of 0.90 was achieved, indicating good code-recode reliability.

The poor measure of inter-rater reliability indicates that either the secondary coder required further training to apply the codes consistently and/or that the codebook could use further refinement before being applied with multiple raters. The good measure of code-recode reliability indicates that the primary coder was able to consistently apply the codes to the transcripts though. Further development of the codebook is needed before it can be applied to larger studies, but since the primary coder coded all documents the current codebook was deemed to be sufficient for the research presented in this dissertation.

4.4.4 CRESST Scoring Rubric

According to the CRESST methodology, a rubric was used to quantify and summarize the student's knowledge according to a number of separate measures. The original CRESST methodology calls for a rubric with five separate measures: Prior Knowledge, Number of Principles or Concepts, Argumentation, Text, and Misconceptions.

This original rubric was modified to a four measure scale to better match the task and content information in this research study. First, the argumentation and text measures were eliminated. The argumentation scale was a measure of how students framed the motivations and rationale behind various historical occurrences. This scale did not translate well into the less person-centric context of engineering statics. The text scale was a measure of students' use of specific quotations from the original documents to back up their claims. Because of the more scientific nature of the engineering statics content, students were not asked to back up their claims with evidence in the form of quotations from the text materials, and the scale was not included in the rubric. Second another scale was added, the Procedural Knowledge scale. This addressed the procedures that are central to engineering statics, but that are generally not addressed in the original context of history.

The new revised rubric consisted of four separate measure: Principle Coverage (Number of Principles or Concepts), Prior Knowledge, Conceptual Knowledge (Misconceptions), and Procedural Knowledge. Each of these measures was judged on a five point scale, with students scoring between one and five depending upon the quality of the explanations in the transcript.

The rubric provided a more general tool to evaluate student performance that worked across the two subject areas in this study. In order to build consistency, an addendum was created for each specific topic area. This addendum document would record and manage a list of what was considered an important topic within the subject area, what was considered relevant prior knowledge, and what was considered major and minor errors in either conceptual or procedural knowledge. By maintaining this list, the researchers were better able to consistently apply the rubric to the student transcripts. The complete rubric and the two rubric addendums can be found in Appendix C.

4.4.5 CRESST Student Concept Maps

While the CRESST scoring rubric (Section 4.4.4) gave a good overall impression of student performance, much of the detail of the student transcript was lost when using this rubric. In order to get a better overview of what each participant did and did not understand, as well as to see how each student connected the topics they discussed, concept maps were made by the researcher to represent each student's explanation.

Concept maps have been discussed primarily as a learning aid in this research, but concept mapping began as a way to visualize student's cognitive schemas (Novak & Cañas, 2008). Using transcripts from clinical interviews, which are similar to the CRESST session transcripts, researchers have found reliable ways to transform those student transcripts into concept map representations of the participant's cognitive schemas, and have validated the results by comparing the representations to previously validated measures of student understanding (Matheson & Achterberg, 1999; Novak & Musonda, 1991).

These concept maps were created by carefully reading through the transcripts and building the concept map as students addressed the topics. Any time the student began discussing a specific concept or procedure, that concept or procedure was added as a node. Nodes were linked if the participant discussed any sort of relationship between those topics. Topics and links were color coded to represent the technical correctness of the student's explanation.

For the nodes, green represented a completely correct explanation of the concept or procedure, yellow represented a minor mistake in the explanation, red represented a major mistake in the explanation, and grey represented a topic that was mentioned but not explained fully enough to judge the student's understanding of the topic. For the links, green represented a relationship that was described in a technically correct way, red represented a described relationship that had a technical error in the explanation, and a red dashed link represented a relationship that was incorrect and that should not exist.

In order to validate the concept map generation procedure, the secondary coder (discussed in Section 4.4.3) was also asked to use his coded transcripts to develop concept maps for each of the four transcripts he coded. The secondary coder was trained on how to develop the maps by the primary coder and concept map developer, and then a sample transcript was collaboratively used to create a concept map to illustrate the process. A measure of inter-rater reliability was established as the number of nodes and links in agreement, accounting for small variations in titles used, over the total number of nodes and links in the concept map of the original concept map developer's concept map. Matheson and Achterberg (1999), established inter rater measures of between 0.73 and 0.98. A similar result would indicate good level of agreement between the raters and a reliable method and results. For the four concept maps generated by the secondary coder, a measure of inter-coder agreement of 0.61 was achieved, indicating poor inter-rater reliability.

As with the coded transcripts, a secondary measure of reliability was used to further examine the poor results of the inter-rater check. A measure of map-remap agreement was as a secondary measure of reliability of the concept map generation process. For this, the original concept map creator used his recoded transcripts from the codebook code-recode check to recreate a concept map for each of the four transcripts. These recreated concept maps were then compared to the original concept maps to establish a measure of map-remap agreement. The same procedure used to quantify the inter-rater agreement was used to quantify the map-remap agreement. A measure of map-remap agreement of 0.91 was achieved, indicating a good measure of map-remap reliability.

As with the coding procedure, the poor measure of inter-rater reliability indicates that either the secondary concept map developer requires more training and/or the concept map development procedure needs to be better developed and defined. It is also possible that the poor agreement in coding affected the concept map development process that built upon it, leading to poor agreement in concept maps. The good measure of map-remap reliability indicates that the primary concept map developer is able to consistently develop concept maps though.

To further examine the reliability of the coding procedure, a measure of code-recode reliability was taken. This process began with the primary coder recoding four of the CRESST transcripts. The same four transcripts used for the inter-rater reliability check were used for the code-recode reliability check. Using the codebook, the original coder applied the codes to the four segmented but uncoded transcripts. The process for calculating the agreement remained the same as for the inter-rater check, comparing the original coded transcripts to the recoded transcripts. A measure of code-recode agreement of 0.90 was achieved, indicating good code-recode reliability.

The poor measure of inter-rater reliability indicates that either the secondary coder required further training to apply the codes consistently and/or that the codebook could use further refinement before being applied with multiple raters. The good measure of code-recode reliability indicates that the primary coder was able to consistently apply the codes to the transcripts though. Further development of the codebook is needed before it can be applied to larger studies, but since the primary coder coded all documents the current codebook was deemed to be sufficient for the research presented in this dissertation. Further development of the concept map development process is needed before it can be applied to larger studies, but since the primary coder coded all documents the current codebook was deemed to be sufficient for the research presented in this dissertation.

4.5 The NASA TLX Survey

Though conceptual understanding is the end goal of the proposed research, the author is claiming to promote conceptual learning by managing cognitive load. In order to validate this claim it is important to measure cognitive load as well as conceptual understanding. To do this we need an instrument that is valid, reliable, and sensitive to changes in cognitive load.

Because of the plentiful research on cognitive load theory in the past two decades, there are a variety of methods available to measure cognitive load (Paas, Tuovinen, Tabbers, & Van Gerven, 2003). These methods can first be broken down into the two major categories of measuring either “mental load” or “mental effort” ratings (Paas et al., 2003). Mental load measurement methods are focused on predicting the cognitive load that an interface or visualization will impose on a learner. These analytic tools are useful and informative during the design process, but empirical methods are preferred for more rigorous research. Mental effort measurement methods are empirical in nature and are based on data collected from the user during a task. These measures estimate the actual cognitive load that is imposed on the learner during a task. For the purposes of the quantitative prototype evaluation, only mental effort measurement tools were considered because of their empirical nature.

Towards the goal of measuring “mental effort,” there is once again a divide in the available methods. The two types of measurement for mental effort include physiological measures and self-reported values (Paas et al., 2003). Physiological measurements attempt to approximate cognitive load from the measurement of some physiological response during task completion. These physiological responses include heart rate variations, pupillary dilation variations, and brain activity variations. These measures attempt to eliminate bias by eliminating the subject’s interpretation, which the self-reported values rely on.

Self-reported values are obtained by asking the user to introspectively report their own level of “mental effort” or “mental fatigue”. These values are most often collected through a response to a Likert scale question during or immediately upon completion of a specific task. Though self-reported values arouse questions of bias and reliability, researchers have found self-reported values of cognitive load to be both reliable and sensitive to small fluctuations (Paas, 1992; Paas & Van Merriënboer, 1994; Paas et al., 1994b). Because of the proven reliability of self-reported measures, the ease of implementation of these measures, and the low participant intrusiveness of the measurement instruments, a self-reported value for cognitive load was chosen over a physiological measure. Specifically, the NASA Task Load Index (TLX) instrument (Hart & Staveland, 1988) was used. A copy of the exact survey instrument can be seen in Appendix D.

The NASA TLX survey is a six item survey instrument that is designed to be administered during or directly after a task that measures number of independent workload constructs. Because there was a minimal physical component to the tasks given to students, the "physical effort" item was eliminated reducing the survey to a five item survey. This survey instrument offered a number of advantages. First, the first item which asks for a rating of "mental effort" is a direct measure of cognitive load (Paas, 1992). Second, with only five items, the survey was minimally demanding of the students' time and mental efforts during the CRESST sessions. Third, other constructs such as performance, temporal demand, and frustration were of secondary interest to the researchers. High levels of frustration in particular are an indication of a poor interface design (Hartson & Pyla, 2012). Finally, the tool has been very extensively used and validated across a number of settings (Hart & Staveland, 1988; Hart, 2006), increasing the generalizability of the study's results.

The NASA TLX survey was administered to the students during the CRESST sessions after students had prepared but before they delivered their instruction. By administering the survey directly after the student's interactions with the Adaptive Map or textbook, the researchers hoped to most directly measure the impact the tool had on student's perceived workload.

4.6 The Statics Concept Inventory

A measure of course-wide conceptual understanding of material is the Statics Concept Inventory (Steif & Dantzler, 2005). The Statics Concept Inventory is designed to identify any students' misconceptions by testing the most commonly held misconceptions in statics. The concepts central to statics and commonly held misconceptions in statics were identified through careful observation of statics students (Steif, 2004), and the test was built around these observations. The test has been subjected to extensive psychometric analysis and has been shown to be a valid and reliable measure of the students' conceptual understanding (Steif & Dantzler, 2005).

The Statics Concept Inventory was administered to all research participants digitally through the ciHUB website (Purdue University, 2011). It was administered after the final CRESST session, but before the debriefing interview to gage a post intervention, overall level of conceptual understanding. Pretest scores for the Statics Concept Inventory were not be collected because the Statics Concept Inventory does not reliably measure the relevant prior knowledge of students entering a statics course (Steif & Hansen, 2007).

4.7 Debriefing Interviews

After all other measures, a closing interview was conducted with each research participant. This closing interview took the form of a semi-structured interview designed to explore student usage patterns, student opinions of the tool, and to gather general background information on the research participants. A semi-structured interview format ensured that all major points were addressed, but allowed researchers to pursue interesting themes that emerge during the interview (Patton, 2002). The full interview guide can be seen in Appendix E.

Interviews took approximately twenty minutes to complete and all interviews were audio recorded and transcribed for analysis. Because the directness of student answers, the common interview guide, and the short length of the interviews, identifying themes was possible without the aid of coding. For this reason the researcher did not code the interview responses.

The interview was broken into three major sections.

i. The first section focused on the student's usage of the Adaptive Map tool or their traditional textbook over the course of the semester, expanding upon what was already reported in the weekly surveys.

ii. The second section focused on student's opinions of the Adaptive Map tool or their traditional textbook. This dialog was used to help identify why students chose to adopt or not adopt the Adaptive Map tool.

iii. The final section was more generally focused on the student's perception of the course and the student themselves.

One particular student characteristic that was identified as a possible factor in how students would use the Adaptive Map tool or textbook was the student's learning orientation. Ames (1992) identified two contrasting achievement goal constructs that students could adopt, a mastery orientation or a performance orientation. These two constructs represent two extremes on a continuum, with students generally falling somewhere in the middle. A student with a strong mastery orientation seeks to learn so that they understand the information and so that they can later use that information. They put little importance on formal assessments and are instead introspective in their measure of success. A student with a strong performance orientation, on the other hand, is concerned with performing well on assessments and other external measures of performance. Students with this orientation look to external factors to measure their success in the class.

It was hypothesized that students with a mastery orientation would be more likely to prefer the non-linear format of the Adaptive Map tool where they could explore the information in their own way until they felt comfortable with it. Students with a performance orientation were hypothesized to prefer the linear format of the traditional textbook where they could precisely determine what they had done and what they had left to do. It was expected that this preference for one format or another would affect how they used the Adaptive Map or traditional textbook, which would then affect the nature of the learning the students engaged in with the tool.

A sense of the students learning orientation was measured through the student's response to a number of questions in the final segment of the debriefing interview. These questions were adapted to an open ended format from a previously validated survey tool designed to measure a students learning orientation (Midgley et al., 2000).

5 Within Case Analysis

After collecting the data for each case, the data was pulled together to form a case profile of each student's experiences over the semester. The primary purpose of this chapter is to present the case profile for each participant and to provide relevant background information for the case profiles.

5.1 Overview of the Research Participants

A total of nine student case profiles are presented in this chapter, representing the nine student volunteers who participated in all research activities and who therefore had complete data sets. The primary cases, presented in Section 5.5, are six participants who were given access to the Adaptive Map tool over the course of the semester. These cases represent six replication cases (Yin, 2009), as the aspect of interest (being a student with access to the Adaptive Map tool in an engineering statics class) is kept consistent across all of these cases. There are also three contrasting cases (Yin, 2009), presented in Section 5.6, where students are using a traditional textbook (Meriam & Kraige, 2007). These case studies provide a view into how similar students are using traditional paper textbook over the course of the semester. A partial tenth case, presented in Section 5.4, presents expert usage patterns for a traditional textbook. This gives an indication as to how an expert approaches learning with a textbook and how the same expert then explains the information in the CRESST sessions. The behaviors in the expert profile are therefore behaviors we wish students to emulate in their learning activities.

Table 5.1 provides an overview of the research participants, giving the pseudonym used to identify each student, the tool they used over the course of the semester (Adaptive Map or traditional textbook), states whether or not they adopted the tool for out of the class learning activities, discusses their learning orientation (explained in Section 4.7) and provides the self-reported expected course grade for engineering statics and overall GPA (if provided by the student).

Table 5.1: Overview of Research Participants

Pseudonym	Group	Adopter / Non-Adopter	Learning Orientation	Expected Course Grade	GPA
James	Expert (Traditional Textbook)	NA	NA	NA	NA
Anne	Adaptive Map Group	Adopter	Strong Performance	"A"	
Gabriel		Adopter	Strong Mastery	"B to C range"	2.84
Lillian		Adopter	Strong Performance	"B or B+ Hopefully"	3.40
Lisa		Adopter	Mild Mastery	"B"	3.52
Paul		Adopter	Mild Performance	"B"	3.13
Sonya		Non-Adopter	Mild Performance	"B"	
Aaron	Traditional Textbook Group	Adopter	Strong Mastery	"Hopefully a B"	2.90
Carol		Non-Adopter	Strong Performance	"A or A-"	3.43
Ryan		Non-Adopter	Mild Mastery	"B+"	

5.2 The Case Profile Format Guide

Each case profile should present its own complete and independent story, but because this is a multiple case study there is a need to establish and follow a standard format for telling the story of each participant (Yin, 2009). This makes identifying common themes for cross case analysis easier in later analysis.

In order to set a standard format to follow, a case profile format guide was created. This format guide established what sections of the case profile should be present, what aspects of the story each section should address, and what data sources each section will pull from. The complete case profile format guide is presented in Table 5.2. This guide

Table 5.2: The Case Profile Format Guide

Section Title	What It Addresses	What Data Sources It Draws From
Background	The student's major and general background. The student's overall course performance and performance on the Statics Concept Inventory. The student's learning orientation. The student's overall opinions of the statics course. Reporting of any other unique or student characteristics.	Debriefing Interview Statics Concept Inventory
Adaptive Map and Textbook Usage and Opinions	A detailed account of student usage patterns and reasons for using the tool outside of the research sessions. An account student's opinions of different aspects of the tool.	Debriefing Interview Weekly Usage Surveys
CRESST Session 1 Preparation	What aspects of the tool the student used in preparing for CRESSST session 1. What topics the student addressed and in what order. Self-reported student cognitive load and other TLX survey results.	Session 1 Observation Notes Session 1 Student Notes NASA TLX Survey Session 1
CRESST Session 1 Explanation	A detailed account of the topics the student addressed for CRESST session 1. The researcher's interpretation of the student's understanding of the content material.	Session 1 Transcript CRESST Session 1 Scoring Rubric Session 1 Explanation Concept Map
CRESST Session 2 Preparation	What aspects of the tool the student used in preparing for CRESSST session 2 What topics the student addressed and in what order. Self-reported student cognitive load and other TLX survey results.	Session 2 Observation Notes Session 2 Student Notes NASA TLX Survey Session 2
CRESST Session 2 Explanation	A detailed account of the topics the student addressed for CRESST session 2. The researcher's interpretation of the student's understanding of the content material.	Session 2 Transcript CRESST Session 1 Scoring Rubric Session 1 Explanation Concept Map
Case Summary	A summary of the student's experience. Highlighting of any unique or particularly important findings.	

was created through an iterative process of developing the guide, then using the guide to create a case profile, and then going back to the guide to identify missing aspects the student's story.

5.3 Adaptive Map and Traditional Textbook Profiles

Chapter 5 seeks to present a profile of each participant's experience over the course of the semester with a focus on their interactions with either the Adaptive Map tool or with a traditional textbook. A basic understanding of the Adaptive Map tool and the traditional textbook, particularly the content areas covered in the two CRESST research sessions, will help to understand the student interactions with the tool.

A primary measure of student understanding is the concept map of the CRESST explanation transcripts. These students were learning from the source of the Adaptive Map tool or the traditional textbook though, so it is important to have a concept map of the source material as well. The same procedure used to develop the concept maps for the research participants' CRESST sessions (presented in Section 4.4.5), was used to develop a concept map of the content in the Adaptive Map tool and the traditional textbook (Meriam & Kraige, 2007) for each of the two CRESST research session content areas. Contrasting the concept map of the source learning material with the concept map of student understanding provides an opportunity to see where student understanding differed from the source material.

In the following sections, Section 5.3.1 describes the features of the traditional textbook, Section 5.3.2 presents a comparison of the concept maps of the content in the two tools for the first CRESST session, and Section 5.3.3 presents a comparison of the concept maps of the content in the two tools for the second CRESST session.

5.3.1 Features of the Adaptive Map and Traditional Textbook

The traditional textbook (Meriam & Kraige, 2007) that the Adaptive Map tool was contrasted to is a typical textbook in many regards. It contains explanations of the concepts and processes, worked example problems, and unsolved problems that can be used for homework assignments. In both sections used for the CRESST sessions, the content consisted of approximately twenty five percent explanations, twenty five percent worked example problems, and fifty percent unsolved homework problems. If the homework problems are excluded, ratio between explanations and worked examples is very similar to the Adaptive Map tool.

Similar to the traditional textbook, the topic pages in the Adaptive Map tool contained only text and images. No multimedia or interactive elements were present in order to minimize the differences between the two tools.

Another feature of the textbook that some students used was the end of chapter summary. This was an approximately two page review of the main points in the chapter located at the end of each chapter in the textbook.

5.3.2 Comparison of Content for the First CRESST Session

The content area of the first CRESST session was multi-component assemblies for the Adaptive Map tool and Structures for the traditional textbook (two alternative labels for the same subject). A concept map of the content in each cluster / chapter, with mentioned prior content from other clusters, is presented in Figure 5.1. Figure 5.1 A presents an overview of the content in the Adaptive Map tool, while Figure 5.1 B presents an overview of the content in the traditional textbook. These maps match the way the concepts are presented in the topic pages, and the concept map in the cluster view itself in the case of the Adaptive Map tool. This map should represent the cognitive schema of someone who understands the information in the Adaptive Map tool (Figure 5.1 A) or the traditional textbook (Figure 5.1 B) exactly as it is presented.

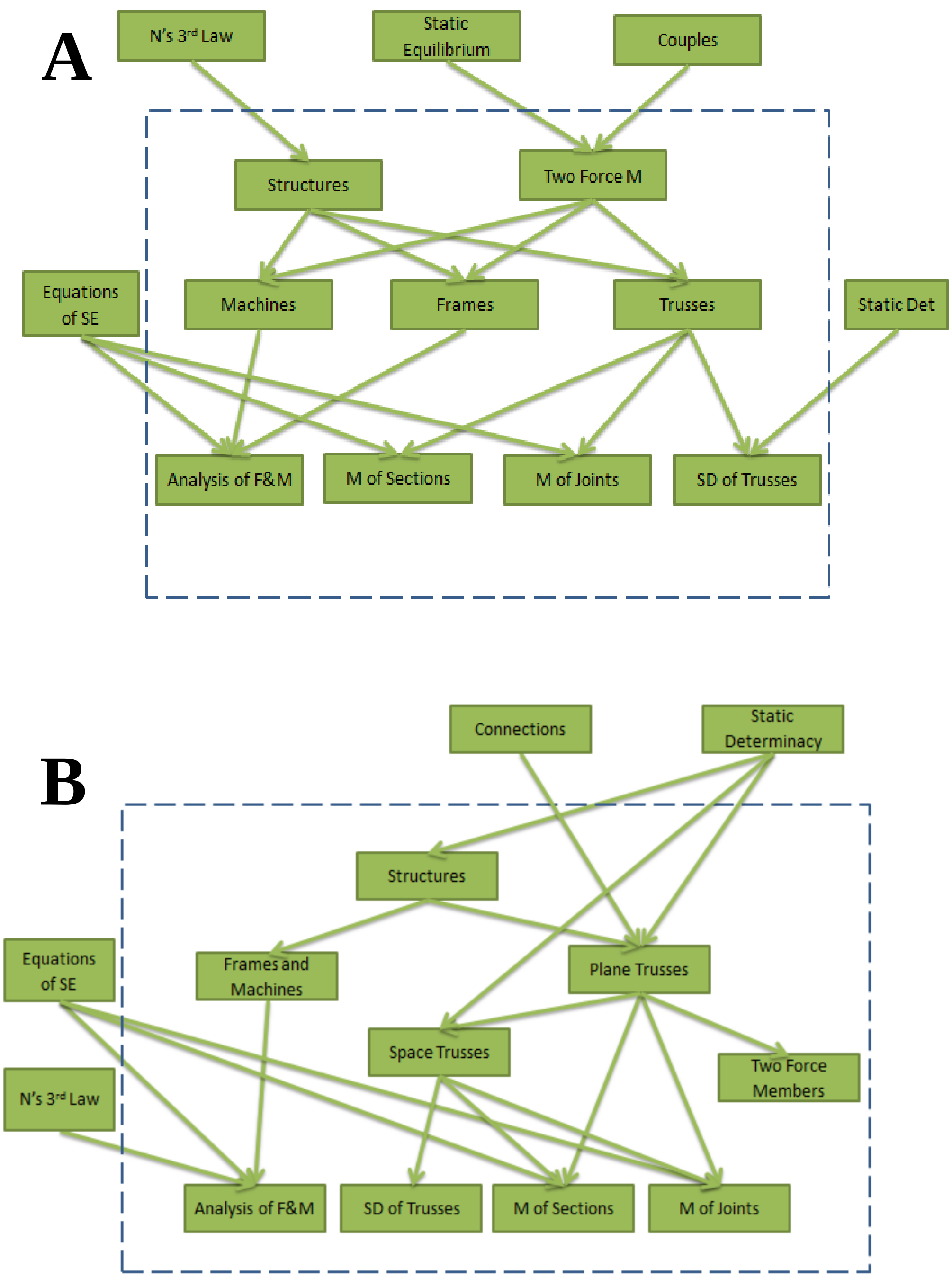


Figure 5.1: The Adaptive Map (A) and Traditional Textbook (B) Concept Map Representations of the Content Area for the First CRESST Session

5.3.3 Comparison of Content for the Second CRESST Session

The content area of the second CRESST session was fluid statics. A concept map of the content in each cluster / chapter, with mentioned prior content from other clusters / chapters, is presented in Figure 5.2.

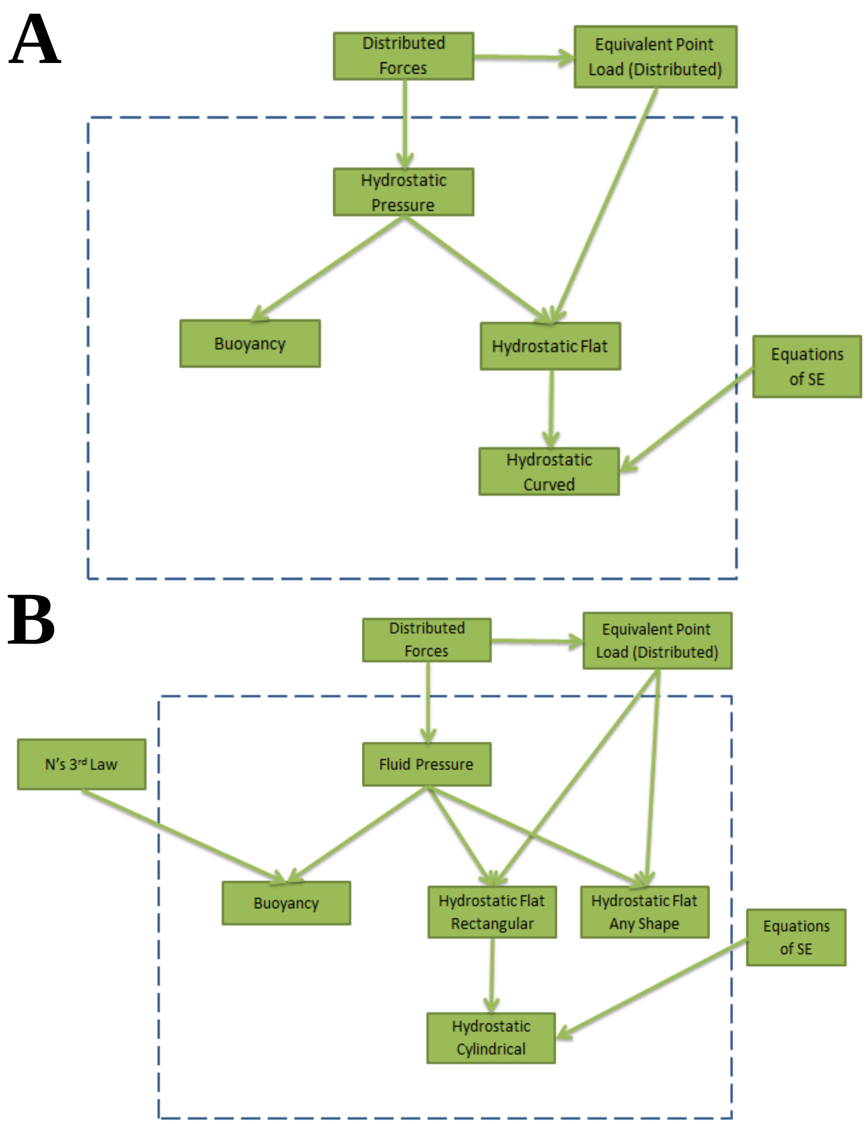


Figure 5.2: The Adaptive Map (A) and Traditional Textbook (B) Concept Map Representations of the Content Area for the Second CRESST Session

Figure 5.2 A presents an overview of the content in the Adaptive Map tool, while Figure 5.2 B presents an overview of the content in the traditional textbook. These maps match the way the concepts are presented in the topic pages, and the concept map in the cluster view itself in the case of the Adaptive Map tool. This map should represent the cognitive schema of someone who understands the information in the Adaptive Map tool (Figure 5.2 A) or the traditional textbook (Figure 5.2 B) exactly as it is presented.

The content area of the second CRESST session was fluid statics, and a concept map of the content in that section, with mentioned prior knowledge is presented in Figure 5.4. This concept map was built by carefully reading through the content and treating the text like a student explanation transcript. This map should represent the cognitive schema of someone who understands the information in the traditional tool exactly as it is presented.

5.4 Expert Profile

To provide an example how an expert explains or learns material in the subject area (a practice we would like students to emulate), an experienced statics instructor was asked to complete each of the two CRESST sessions in the same manner as the student participants. This expert, given the pseudonym James, was not the same expert who helped develop the concept maps, so his cognitive schemas did not necessarily match the concept maps in the Adaptive Map tool. Though James did not help develop the tool, he was familiar with the research goals of the project.

James used the traditional textbook to prepare the twenty minute explanations, and was given the same prompts and material as the students in the traditional textbook group with a few key differences, described later. The expert was very familiar with the content in the first CRESST session (multi-component assemblies / structures), having taught the material to students several times. The expert was not familiar with the content in the second CRESST session (fluid statics) though, as this was not part of the statics curriculum for the course he had taught. This meant that the first session for him was review, just as it was for the research participants, and that the second session was new content that built upon what was covered in the class (distributed loads), just as it was for the students. The expert's situation therefore mirrored the circumstances of the student research participants.

Because prior knowledge has been shown to have a large effect on cognitive load (Paas et al., 2004), cognitive load measurements were likely to be vastly different for the expert. Because of this, the NASA TLX survey was not administered to the expert. Also, because the sessions were administered remotely for the expert, direct observations of the preparation were not possible. Instead, interviewer asked the expert to recall and state how he used the textbook to prepare before each of the explanation sessions.

CRESST Session 1 Preparation:

When asked how he used the book to prepare. James first stated,

> *"Well I guess mostly all I used the book for was a way to structure it so that my notes were structured the same way that the book was outlined."*

He stated that he went through the content, looking at the headings and subheadings and then reading a little bit of the explanations right under the headings to make sure the understood what each section was talking about. Since James was already pretty familiar with the content, James said "for the most part I didn't use [the textbook] that much." He used the textbook primarily to serve as an overview of the information and to fact check the notes he was writing down.

James went through the book linearly without flipping back at all. He spent most time reading the overview on what structures were and reported going "quickly" through the rest of the sections in the chapter. He focused on the explanations and spent no time looking at homework problems or worked examples.

CRESST Session 1 Explanation:

James begins by stating that this chapter is about structures and by contrasting this chapter with previous chapters by stating,

> *"So I would relate [structures] or distinguish that from what we have done previously, in previous chapters we have been considering equilibrium usually of like a single body at one time. And we have been isolating and drawing free body diagrams single bodies and applying equations of equilibrium to those to solve for some force that's acting on that body. In this chapter in structures we will… it's going to require analysis of multiple bodies that make up some larger body, so in addition to isolating perhaps a single body applying equilibrium equations to it, we may separate out some piece or component of that body and use equilibrium to determine the forces that are internal to that structure or that body."*

Here he correctly distinguishes a structure from a single body. James also goes on to state that we will still assume each component is rigid, unbreakable, and that it is in equilibrium. He also says there will be two types of structures and that the types of members are what separates them.

Next James states that the first type of structure we will look at is a truss, which is made entirely of two force members. James begins an extended discussion on two force members, correctly describing the conditions in which they exist, and why the forces at the two connection points must be equal, opposite, and collinear.

After describing two force members, James states that there are two ways to analyze trusses and that he will talk about plane trusses first for each method and then space trusses. He describes the process for the method of joints completely and correctly, addressing Newton's 3rd Law and Two Force members in his explanation of why the method works.

Next James moves on to the Method of Sections. He first explains when the Method of Sections is preferable to the Method of Joints, and then moves on to give a complete and correct explanation of the method. Next James briefly discusses space trusses and how there are more equations in the Method of Joints and Method of Sections.

After this James moves on to discuss Frames and Machines. He starts by stating that Frames and Machines have at least one multi-force member, which distinguishes it from the truss which is made entirely of two force members. James correctly describes how to analyze frames and machines, referencing the need to remember Newton's third law for connected bodies.

Here, the interviewer asks James if frames and machines are the same thing. James is able to distinguish, but he refers to them collectively because they are analyzed the same way.

Then the interviewer asks James if the Method of Joints and Method of Sections could be used on frames and machines. James says they could be used, but then goes through a list of complications and states that is why they are usually not used.

After this, James states he is done and the interviewer then asks if James could say anything about static determinacy. James says yes, and then goes on to correctly describe what static determinacy is and how it applies to structures.

Table 5.3: James's CRESST Session 1 Rubric Scores

Category	Score
Principle Coverage	5/5 Moore
Prior Content	5/5 Moore
Conceptual Knowledge	5/5 Moore
Procedural Knowledge	5/5 Moore

As can be seen in Table 5.3 and Figure 5.3, James did very well in explaining the subject material, as would be expected from a content expert. James covered all the topics in the area. He also grounded the topics well in the content from outside of the section, having made more connections to outside topics than even the book. James's understanding of the material was complete and deep, and his explanation of the processes was all technically correct and thorough. As can be seen in Figure 5.3, the concept map of James's explanation was entirely correct and highly interconnected. This again matches what we would expect from someone with a deep understanding of the information (an expert). The layout is similar to the concept map representation of the textbook, but does have some key differences. First, James placed more importance on two force members and put that topic at a more basic level of the schema than the book, and James also connected more of the ideas explicitly than the book did.

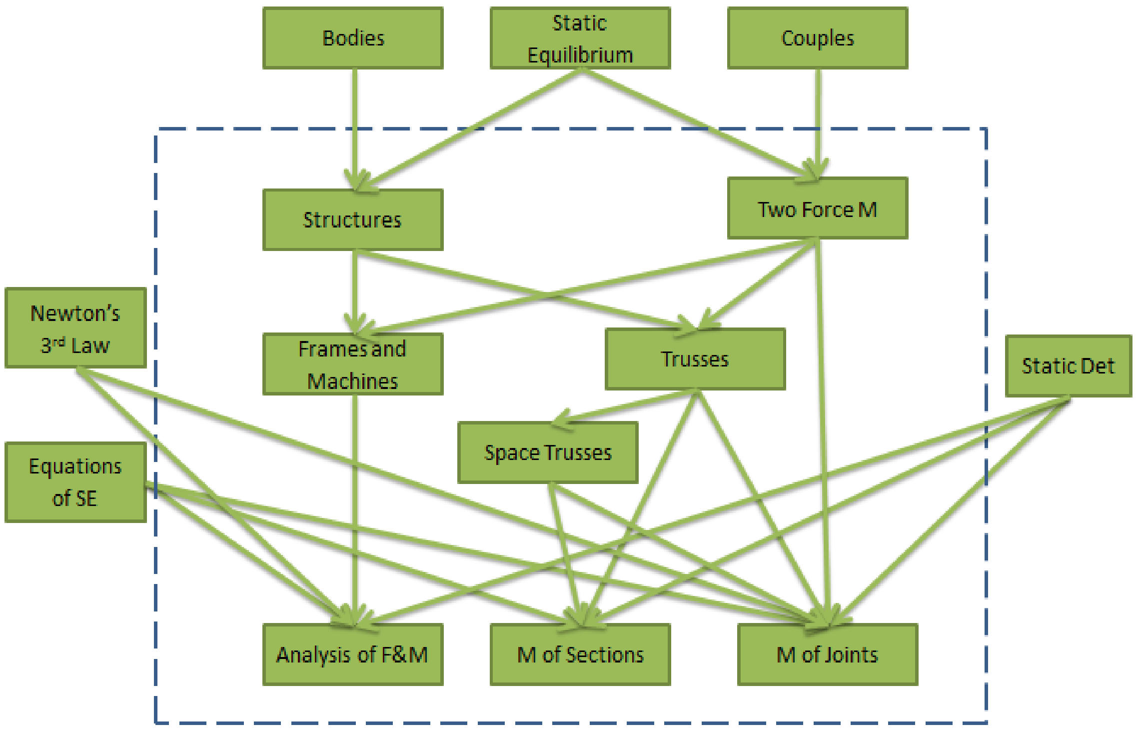


Figure 5.3: James's CRESST Session 1 Explanation Concept Map

CRESST Session 2 Preparation:

James reported that the information in this section was not familiar to him but he went through the material in much the same way as the first CRESST session. He stated that,

"I used the section headings as a guide on how to go through it."

Here James is using the section headings as a form of an advance organizer. He is getting an overview of the information from the headings. James reported spending more time reading through the more detailed content and copying down equations to his notes. These are two things he did not do for the first CRESST session because of his familiarity with the content.

James again only took one major pass through the information, trying to pull a key point from each paragraph as he went to make sure he understood the content. He did report flipping back a few times to previous content within the chapter when he found a term he did not understand. This differs from the first CRESST session where he said he did not have to flip back at all.

CRESST Session 2 Explanation:

James starts by saying that fluid statics is really an application of the distributed load information they covered previously in the chapter. He then goes into an explanation of what a fluid is and discusses fluid properties that are relevant to fluid statics. Next he explains that a fluid will exert a pressure, which is a force distributed over an area, on any object in contact with the fluid.

James goes on to say that pressure increases with depth, and correctly states that the relationship between pressure and depth is pressure is equal to pressure at the surface of the liquid plus the density of the liquid times gravity times the depth in the liquid. Then James discusses what gage pressure is and how it differs from absolute pressure.

Next James moves on to analyzing pressures on flat surfaces. He relates the topic back to hydrostatic pressure and brings in the topic of equivalent point load to find the resultant of the distributed load. He discusses integration of the pressure distribution and finding the area and centroid of the pressure distribution, which are the two methods available to find the resultant. James also states that converting the distributed load to a point load is necessary before applying the equations of equilibrium.

Next James moves on to Buoyancy, which he says he did not have as much time to cover. He states,

> *"Buoyancy again is just the result of equilibrium equations applied to body that's submerged in a fluid. In that, if the fluid is the only other thing besides the weight of the, or besides the mass of the body that is creating*

some force on that body then in order for the body to be in equilibrium it has to counteract the weight force.

The interviewer pushes to see if the buoyancy force is always equal and opposite to the weight as his statement above suggests. James states that it is if the body is in equilibrium, which is technically correct, but misses the main relationship that buoyancy force is equal to the density of the fluid times gravity times the volume submerged. James also incorrectly states that the buoyancy force always acts on the centroid of the object. When questioned by the interviewer about why buoyancy forces exist, James is able to correctly identify the pressure increasing with depth as the reason, relating the topic back to hydrostatic pressure.

Next James starts discussing stability in hydrostatic loads, discussing the meta-center and saying stable systems have righting moments when tipped. This contradicts his earlier statement saying buoyancy forces and weight forces always act on the centroid, and therefore would exert no moment.

Next James says that he is done, and the interviewer asks if he can say anything about hydrostatic pressures on curved surfaces. He says he didn't get to read anything but they could probably do some sort of vector integration to find the resultant.

Table 5.4: James's CRESST Session 2 Rubric Scores

Category	Score
Principle Coverage	4/5 Moore
Prior Content	5/5 Moore
Conceptual Knowledge	3/5 Moore
Procedural Knowledge	3/5 Moore

As seen in Table 5.4 and Figure 5.4, James covered all topics except for the hydrostatic pressure on curved surfaces. He anchored his explanation well in the prior content material and had a good understanding of the basic information in the section.

James did have some major misconceptions with buoyancy though. In terms of procedural knowledge, James's misconceptions of buoyancy also lead to his inability to correctly calculate the buoyancy forces. As we can see in Figure 5.4, the layout of James's explanation closely matches the textbook layout, except that James lumped together discussion of hydrostatic forces on flat rectangular surfaces and on any flat surface.

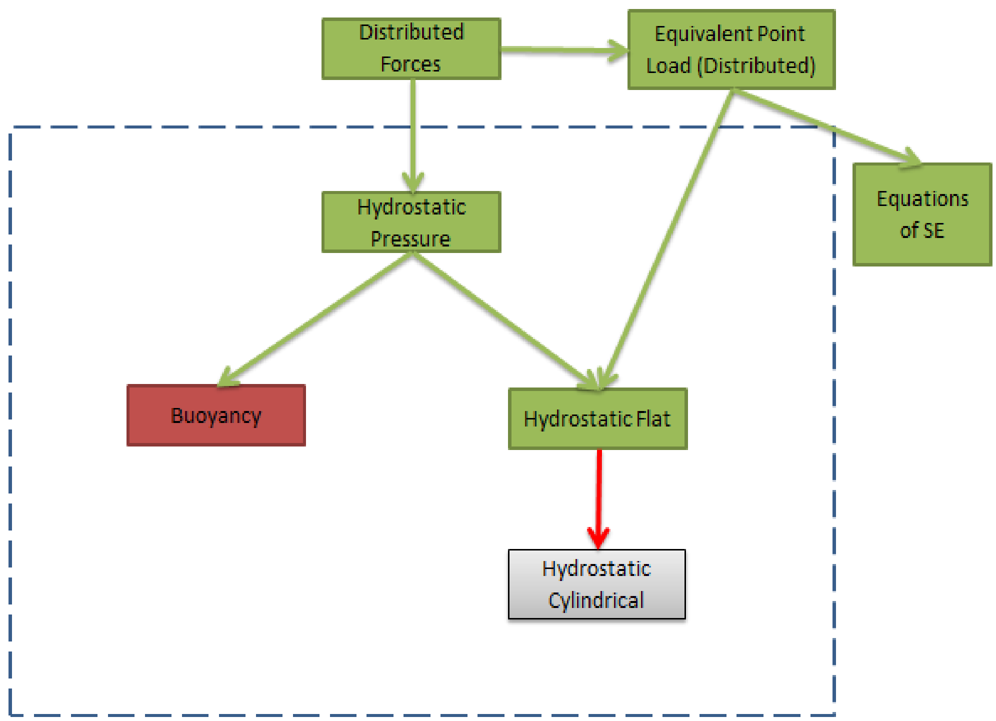


Figure 5.4: James's CRESST Session 2 Explanation Concept Map

5.5 The Adaptive Map Student Profiles

This section presents the case profiles of the six research participants who were introduced to the Adaptive Map tool and who used the Adaptive Map tool during the data collection sessions.

5.5.1 Anne

Background:

Anne is an Asian female student in the Industrial and Systems Engineering Department. She admits that English is not her first language, and she had difficulty pronouncing and understanding some words. Her responses also tended to be shorter and more direct than other participants, because she seemed to think through what she was going to say before she said it.

Despite having some difficulty with the English language, Anne is a high performing student. She reports an expected grade of A, putting her expected grade higher than any other self-reported grade for the research group. Her grade of 74.1% on the Statics Concept Inventory also places her at the top of research group in terms of performance. She appears to have a strong performance orientation to learning, putting a high degree of importance on grades, comparing her performance to others regularly, and preferring to solve problems that are familiar rather than novel.

Anne reported positive feelings overall for the course but found the course time consuming, saying “I think it’s interesting, but it really needs effort.” She expressed a positive opinion of the professor of the course.

Adaptive Map and Textbook Usage and Opinions:

Anne most often reported using the Adaptive Map tool once a week through the weekly surveys. She also reported not using it at all before the first session and during Thanksgiving break, and reported using it “two to three times” once as well. During the final interview Anne reported using the tool on “one or two times” a week on average.

Anne described the role of the textbook as a source of more detailed information, and for filling in holes in her notes. While her notes served as the primary source of information she went to outside of class, the textbook served a way to expand upon her notes.

> *"For me I think notes are more important. But when I need to know like exact, exact concepts or just information, I will use textbook. So I will have more precise information about the concept."*

During the semester, the Adaptive Map filled the role of the primary textbook for Anne. She said she used the textbook only to look up problems, but if she needed to learn something she went to the Adaptive Map.

> *"I used my textbook because all the homework problems are on the textbook, so I used my textbook when I need to do homework, but when I need to look up for information, I used the Adaptive Map."*

Anne reported using the Adaptive Map tool to review information covered in class, study for tests, and to look up information to solve homework problems. The primary reason for using the Adaptive Map tool was reported to be review, rather than solving homework problems. She reported using the tool for review more than any other research participant.

Anne's opinions of the tool were positive overall, reporting that she liked both the layout and the content in the tool. Anne reported liking the simpler language of the Adaptive Map tool during one of the CRESST sessions and reported liking the concept map layout of the tool as a way to show how everything was related during the debriefing interview.

> *"I think it's better than the traditional textbooks because it relates the concepts to one another, rather than just listing all the concepts or the contents. So you have a better understanding of what you learn and what you need."*

Anne felt that the tool made it easy to look up information to solve homework problems. She also reported that she felt she got a better big picture of what she was learning. When asked for an example of a good or bad experience she had with the tool, Anne said she had a good experience with the Adaptive Map when covering "trusses" (her discussion indicated she was actually discussing structures). She felt she got a better understanding of the different types of structures and the methods that could be used for each one by using the Adaptive Map tool.

CRESST Session 1 Preparation:

Anne began preparing for the first CRESST session by carefully looking over the Multi-Component Assemblies cluster map, and clicking on a few nodes. She quickly looked at the "Connections" topic page (outside of the cluster) when it popped up, but after skimming the page she went back to the multi-component assemblies cluster. Next she hovered over all the nodes and some of the links to read the descriptions before opening up individual topic pages. She took notes on some of the descriptions that popped up.

The first page Anne opened was the "Method of Joints" topic page, where she completely read the explanation and took notes in the description part of the page (not the worked problems). Next, Anne opened the "Static Determinacy in Trusses" topic page. She skimmed through this page and closed it. Next she opened the pages on frames and then machines, and then analysis of frames and machines, and finally trusses, skimming each of these pages. After that she zoomed out to the cluster view again spent more time writing down notes.

Then she returned to the "Static Determinacy in Trusses" topic page and read the page more slowly and completely this time. She then went on to the "Method of Sections" topic page and slowly and carefully read the content. Finally, she zoomed back out to the cluster view and took some more notes. She read the description for the "Newton's Third Law" node and she stated that she was prepared for the explanation part of the session.

Overall Anne seemed to spend more time looking at and reading the information in the cluster view than any other user. She read and even took notes on information contained within the concept map. Anne did not start with more basic concepts and move to advanced topics; for the most part she seemed to follow the links when moving from topic to topic. The skimming of the topics also most likely indicated that Anne was familiar with many of the concepts and procedures before the session.

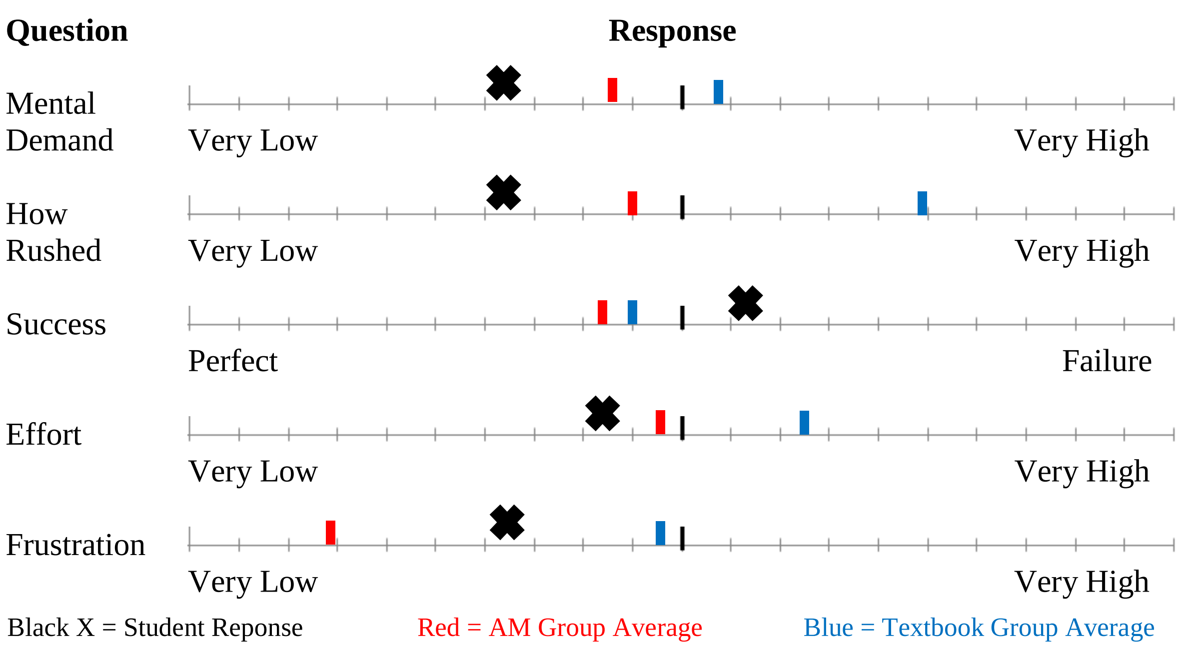


Figure 5.5: Anne's CRESST Session 1 TLX Results

Figure 5.5 shows that the preparation activity imposed a lower than average cognitive load on Anne. It is also interesting to note that while Anne did very well explaining the topics (as discussed in the next section), she self-reported a lower level of success than most other participants. This would seem to indicate low confidence in her performance. Anne also reported a higher level of frustration than any other Adaptive Map participant, though it is still as low or lower than all textbook participants.

CRESST Session 1 Explanation:

Anne begins by discussing what multi-component assemblies are and how they are broken down into trusses frames and machines. She also throws in a statement about Newton's Third Law, indicating that it is "is the base of all the three types of assemblies," but no further explanation of this connection is given. She then went on to correctly describe the differences between trusses frames and machines. Upon questioning from the interviewer about what an "assembly" was she was able to explain the concept more broadly and relate the concept to "connection types" discussed in other chapters.

She said she would start by looking at trusses and said there are two ways to analyze trusses; the method of joints and the method of sections. She goes through each of these methods giving a brief, but mostly correct process for each of these methods. Anne omits the step of solving for external reaction forces before engaging in the rest of the process for both methods, a minor procedural error. During her discussion on the methods she makes it clear that she understands and can apply the equations of static equilibrium in the context of the methods of joints and sections. She also describes static determinacy in trusses and other assumptions needed to use the methods of joints and sections interspersed with her description of the methods.

Next Anne moves on to frames and machines, glossing over the definition of frames and machines and quickly moving onto the method used to analyze frames and machines.

Anne has a brief, but correct, description of the process to analyze frames and machines. Again she relates this procedure to the equations of equilibrium. After this she claims she has covered everything and opens it up for questions.

The researcher first asks her about static determinacy to see if she has an understanding of the implications of having a determinate or indeterminate structure. Anne is able to identify and discuss the implications correctly. Next the researcher goes on to question Anne about two force members. She shows understanding that the forces on each end of the member are equal and opposite, but when drawing a free body diagram Anne adds both X and Y components to each side, which is a conceptual mistake. Finally the researcher asks if the methods of sections and joints could be used on frames and machines. Anne responds no, citing the fact that two force members are assumed for these methods. Anne's full understanding of the connection is unclear, but this matches the layout of the Adaptive Map she was viewing.

Table 5.5: Anne's CRESST Session 1 Rubric Scores

Category	Score
Principle Coverage	5/5 Moore 5/5 Pierce
Prior Content	4/5 Moore 5/5 Pierce
Conceptual Knowledge	3/5 Moore 3/5 Pierce
Procedural Knowledge	4/5 Moore 4/5 Pierce

As can be seen in Table 5.5 and Figure 5.6, Anne addressed all topics in the subject area and she anchored the information well in prior content. The exception was Newton's Third Law which she was not able to meaningfully relate to the subject material. Anne had some major misconceptions about two force members, but otherwise, her conceptual understanding of the material was complete and correct. Finally, Anne omitted the step of solving for external reactions for both methods of analyzing trusses, deemed to be a minor procedural mistake.

As seen in Figure 5.6, Anne's explanation concept map matches the Adaptive Map cluster view very closely. In particular, we can see that Anne tried to connect Newton's Third Law to the discussion on multi-component assemblies as is seen the Adaptive Map tool. Her explanation however does not match this connection as discussed on the topic pages of the Adaptive Map tool. The only difference between Anne's explanation concept map and the concept map in the Adaptive Map tool is that Anne connected her discussion on static determinacy in trusses to the Method of Joints and Method of Sections.

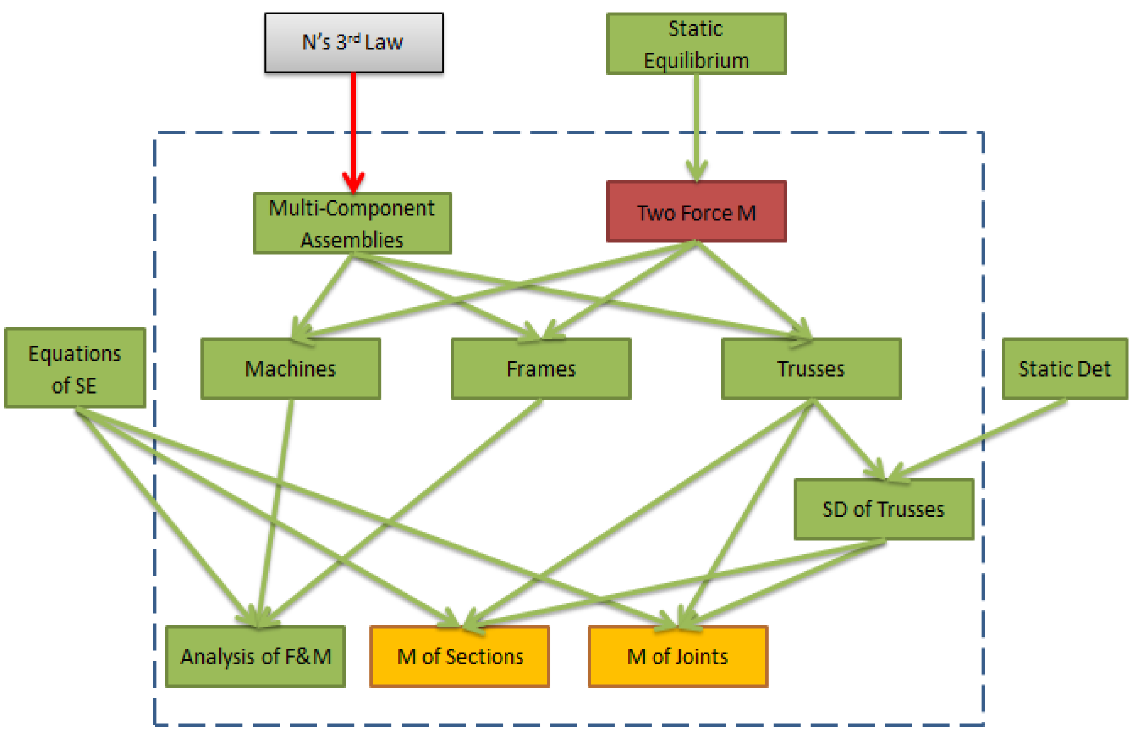


Figure 5.6: Anne's CRESST Session 1 Explanation Concept Map

CRESST Session 2 Preparation:

Anne began the preparation for her second CRESST session by carefully examining the cluster map and reading all descriptions and links. She then opened the "Hydrostatic

Pressure" topic page, carefully reading and taking notes on the page. Next Anne opened the "Hydrostatic Pressure on a Flat Surface" topic page, looking at the link to the "Equivalent Point Load of a Distributed Force" node that popped up before opening the Hydrostatic Pressure on a Flat Surface" topic page. She read the page carefully and took notes. Next she moved onto the "Hydrostatic Pressure of Curved Surfaces" topic page, again reading carefully and taking notes. Finally Anne looked at the "Buoyancy" topic page, reading the description and taking notes before opening the page.

After looking through all of the topic pages, Anne looked back at the "Hydrostatic Pressure on a Flat Surface" and "Hydrostatic Pressure" topic pages, skimming the pages this second time and taking a few more notes.

During all the time looking at the pages, it was noticed that Anne spent almost no time looking at the worked examples, instead focusing on the explanations at the top of the page and the map itself. Also, Anne spent more time looking at, and reading information in, the cluster view than any other research participant for the second CRESST session.

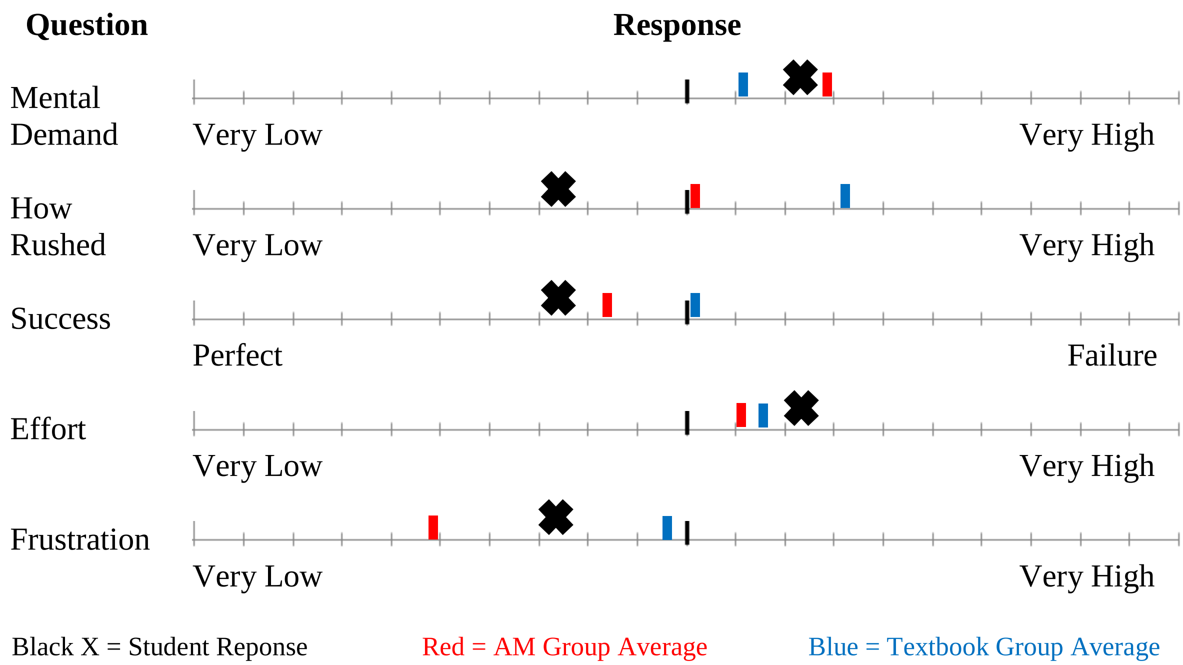


Figure 5.7: Anne's CRESST Session 2 TLX Results

Figure 5.7 shows that Anne reported an average level of cognitive load, though she reported a slightly lower level of being rushed, possibly linked to the fact that she finished going through the content where many others did not. When compared to the previous CRESST session, Anne reported higher levels of mental demand and effort than in last session. This is expected as the material was unfamiliar to the students. Anne also reported higher levels of success, indicating that she felt better about her performance in the second CRESST session.

CRESST Session 2 Explanation:

Anne starts her instruction by stating what hydrostatic pressures are and offers and equation to calculate hydrostatic pressure in a liquid. The interviewer asks what each of the variables in the equations mean and Anne is able to correctly explain what all variables represent. Next Anne describes the difference between absolute and gage pressure, relating the difference back to the "pressure at the surface" variable in the hydrostatic pressure equation.

After that, Anne says there are two types of surfaces that these pressures will act on: there are flat surfaces and curved surfaces. This matches the distinction in the Adaptive Map. Anne starts with flat surfaces and explains that they use the equivalent point load, just like they did for distributed forces on beams.

> *"Anne: For the flat surface, we basically just convert the distributed force into the equivalent point like for what we did for the equivalent point load before and…*
>
> *Interviewer: So where have you done that before?*
>
> *Anne: The distributed load, that beams."*

Anne is also able to relate the process of coming up with the equivalent point load back to hydrostatic pressure that she talked about right before this topic.

> *"Anne: And we are trying to find the magnitude and point of application, there are two ways to find them. One is by integration and one is by, create a volume which the base of the volume is flat surface which pressure is acting on. Yeah… and the height is the magnitude of the pressure. So…*
>
> *Interviewer: How do you find that, the magnitude of the pressure?*
>
> *Anne: Isn't it given in the problem… Sorry, what do you mean?*
>
> *Interviewer: So, how do you know what the magnitude of the pressure is? Say I have something that, say I have some flat surface and I put it in water, how would I…*
>
> *Anne: Oh, by this [points to "P = Po + rho*g*h" formula]"*

When discussing the method to solve for the equivalent point load, Anne mentioned both integration and composite parts; however, she only explained the method of composite parts, which she explained correctly.

Next Anne went on to discuss how to calculate the equivalent point load on a curved surface. She correctly goes through the process of separating out a body of water and analyzing the forces on that body to find the reaction to the pressure on the surface. She relates this process back to hydrostatic pressure on a flat surface by explaining that one of those forces is just a hydrostatic pressure on a flat surface.

> *"Anne: And this is [points to arrow acting on the vertical surface of the quarter circle], and we can use this to find the pressure [points to notes on hydrostatic pressure on a flat surface]. It's the same as how we find the pressure on the flat surface.*
>
> *Interviewer: Okay, and this is just a flat surface, and this is the…*
>
> *Anne: Like what we find on this part [again points to notes on hydrostatic pressure on a flat surface].*
>
> *Interviewer: So we are finding the equivalent point load?*
>
> *Anne: Yeah, yeah."*

Anne seems to be using pressure and equivalent point force interchangeably here, which is incorrect; however she seems to understand that one needs to change the distributed pressure into a point load. She relates this process back to the equations of equilibrium, explaining that you use the known forces in the equations of equilibrium to find the unknown reaction force, which is equal and opposite of the equivalent point load the pressure exerts on the curved surface.

Finally, Anne moves onto buoyancy and begins by explaining how buoyancy force is related to hydrostatic pressure.

> *"Anne: Buoyancy is the net upward hydrostatic pressure force that act on submerged or floating object. The reason why there is only upward force is because that the side of the forces, the side will be canceled out. [draws a circle with two equal and opposite inward forces acting on it]. And because of this, this equation [points to P = rho g h], the more the, the more the depth, the pressure will be so the net force will be upward.*

Interviewer: Okay, so the pressure on the bottom is greater than…

Anne: …yeah on the top.

Interviewer: Okay.

Anne: So that is why it is upward force."

Anne goes on to give a formula to explain how to calculate the buoyancy force and is able to correctly explain what all the variables in the equation stand for upon questioning. When the interviewer asks Anne if the buoyancy force changes depending on the object, she at first has some confusion, but eventually is able to state that buoyancy forces do not change with the density of the object, only the weight does.

"Interviewer: Okay, so is the buoyancy force changing at all depending on the density?... The density of the object?

Anne: Yeah.

Interviewer: So the buoyancy force is changing?

Anne: Uh… the buoyancy force only… it only depends on the volume of the object. Like how much.

Interviewer: Okay, so like if you had two balls of the same size, one that's made of wood and one that's made of steel.

Anne: The force would be the same. The only thing that is different would be the weight of the object."

When further questioned about why some objects float on the surface of the water, Anne is able to correctly state that the object will reach equilibrium where the buoyancy force from the submerged volume and the weight of the object are equal and opposite.

Table 5.6: Anne's CRESST Session 2 Rubric Scores

Category	Score
Principle Coverage	5/5 Moore 5/5 Pierce
Prior Content	5/5 Moore 5/5 Pierce
Conceptual Knowledge	5/5 Moore 5/5 Pierce
Procedural Knowledge	5/5 Moore 5/5 Pierce

As can be seen in Table 5.6 and Figure 5.8, Anne's explanation covered all topics, she anchored the topics in relevant information outside of the cluster, there were no misconceptions identified, and the procedures she discussed were all correctly explained. The concept map of Anne's explanation also perfectly matches the concept map in the Adaptive Map tool.

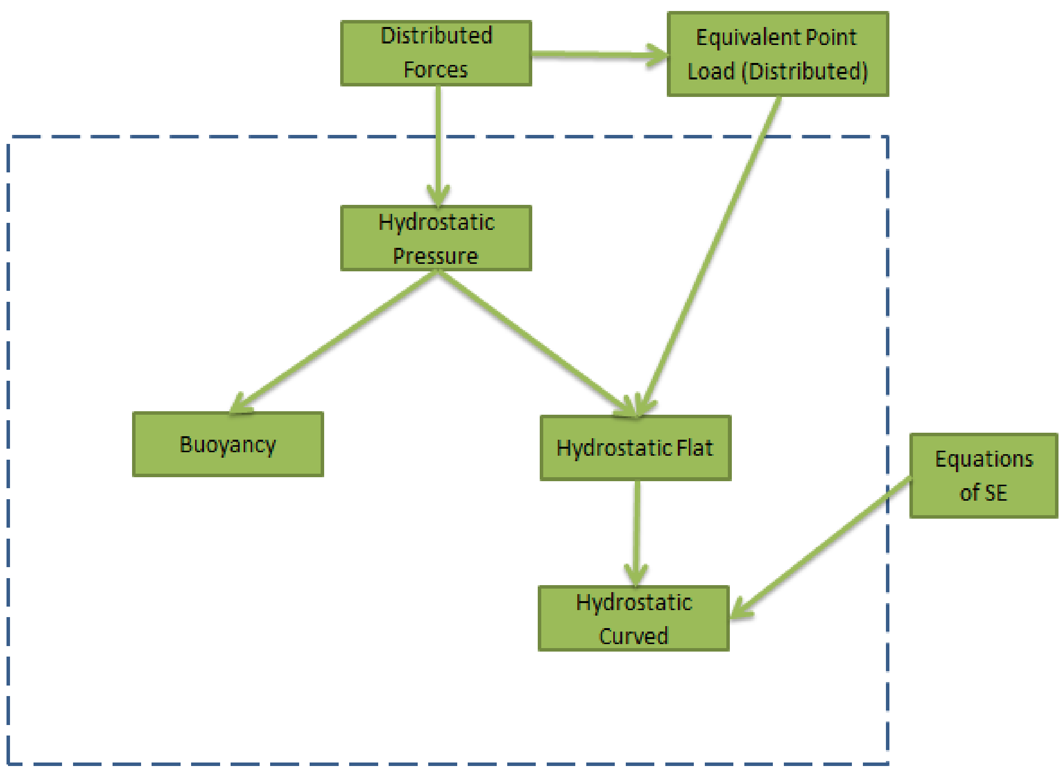


Figure 5.8: Anne's CRESST Session 2 Explanation Concept Map

Case Summary:

Anne was a regular user of the Adaptive Map tool, using the tool once or twice a week outside of the research sessions. She used the tool primarily to review information from lecture and study for tests, but also to look up information for homework problems. Anne stated that she felt the concept map layout helped her understand what she was learning and needed to learn. Further endorsement of the concept map structure can be seen in the fact that Anne spent time in both sessions examining, taking notes on, and presumably processing the information in the cluster view before she opened up any topic pages. This is an indication that the tool was used as an advance organizer, as it was intended to be used. Anne exhibited a deeper understanding of the information in both sessions than all other research participants, with the highest measures of conceptual learning of any participant. This is particularly evident in the second CRESST session, where the concept map of Anne's explanation perfectly matched the concept map of the information present in the Adaptive Map tool.

5.5.2 Gabriel

Background:

Gabriel is a Latin American male student in the Industrial and Systems Engineering Department. He self-reported that English is not his first language, and sometimes had difficulty understanding speech or text and often had difficulty putting his thoughts into words.

Gabriel is a low performing student. He reports an expected course grade of "somewhere in the B-C range" putting him as the lowest self-reported grade of any research participant. His reported GPA of 2.84 also is the lowest of any participant. His grade of 18.5% on the Statics Concept Inventory is the second lowest overall and lowest in the Adaptive Map group. Gabriel appears to have a strong mastery approach to learning. He reports a course goal of learning the material to be prepared for other courses. He also reported that he placed little importance on grades and that he prefers to solve problems that were not familiar to him.

Gabriel reported positive feeling overall for the course, attributing most of this to his positive opinions of the professor. He also reported that he felt they covered a lot of material in the course, most likely indicating that he felt the course took a lot of work.

Adaptive Map and Textbook Usage and Opinions:

Gabriel was the heaviest user of the Adaptive Map tool, having reported using the tool two or three times a week for five weeks this semester in the weekly surveys. Towards the end of the semester; however, Gabriel had three weeks where he reported no usage for the Adaptive Map tool (one of these weeks was Thanksgiving Break). The later time period also corresponded with topics that did not have developed-in-house topic pages. During the final interview, Gabriel reported using the tool "twice on average, two maybe three times" per week.

Gabriel described the role of the textbook a reference for when one does not understand something or for when one is trying to solve problems. Gabriel seemed to separate the roles of the textbook and the Adaptive Map in this course. He saw the Adaptive Map as a source for clear explanations of the topics, and the textbook as a source for homework problems and for more worked examples.

Gabriel reported using the Adaptive Map tool more often than the textbook. Initially he would look at both, but because of the "simpler vocabulary" in the Adaptive Map tool topic pages, Gabriel went straight to the Adaptive Map tool for instances later in the semester. Gabriel reported using the tool primarily to look up information to solve homework problems, but he also reported using the tool to study for tests on some occasions.

Gabriel's opinions of the tool were very positive. He reported liking the search feature, he reported liking how simple and easy to understand the vocabulary is, and he reported liking the option to change font size. Also during his discussion of a good experience he had with the Adaptive Map tool, Gabriel described a scenario where he liked having the links to guide him to the information he needed.

> *"Yeah, method of sections. That is where I used it mostly. Cause at first I didn't use it much. But my best experience is when… it was easier. I would just happen to search and it would come and I will click something, like it will have the little arrows, so if I needed this information like I would look over here and… I don't know if I'm explaining this very well."*

Some things Gabriel did not like were the small number of example problems available through the Adaptive Map tool, the fact that he could not use some of the touch screen gestures he had available in other programs on his computer, and the fact that his computer would often crash while using the Adaptive Map tool (a problem frequently encountered with Apple computers). He also reported that he didn't like the fact that topic pages opened in separate tabs. In the CRESST sessions, he was observed not closing the tabs and instead just clicking back to the Cluster Map tab. This led to a large number of tabs being open as he visited more and more pages.

CRESST Session 1 Preparation:

Gabriel began preparing for the first CRESST session by opening the Multi-Component Assembly topic page and carefully reading through this page. Gabriel created headings in his notes based on what he read on the "Multi-Component Assemblies" topic page.

Next Gabriel moved on to open the "Trusses" topic page, and then the "Frames" topic page. On each of these pages he read the information carefully and took notes on the pages. Next Gabriel moved on to the "Analysis of Frames and Machines" topic page. He again read the page carefully and took notes. It was noticed that he did not read through the worked example on this page, quickly scrolling past them.

Next Gabriel opened the "Static Determinacy in Trusses" topic page. He read through this topic page, but there was a visible look of confusion on his face while reading. He also did not take any notes while reading this page.

Next Gabriel went to the "Method of Sections" and the "Method of Joints" topic pages. For each of these pages he read the information carefully and took notes. It was noticed that Gabriel did look through the worked example problems on the "Method of Joints" topic page.

Overall Gabriel seemed to focus on the topic pages, rather than on the cluster view. He generated an outline from the "Multi-Component Assemblies" topic page and spent almost no time examining the cluster view. He did seem to follow a logical top down path through the topic pages. Gabriel also was observed to go back to the cluster view by clicking on the Cluster Map tab, rather than closing the topic page. This left each topic page open even after he finished reading it. At a few points he took time to go back to close all of the open tabs.

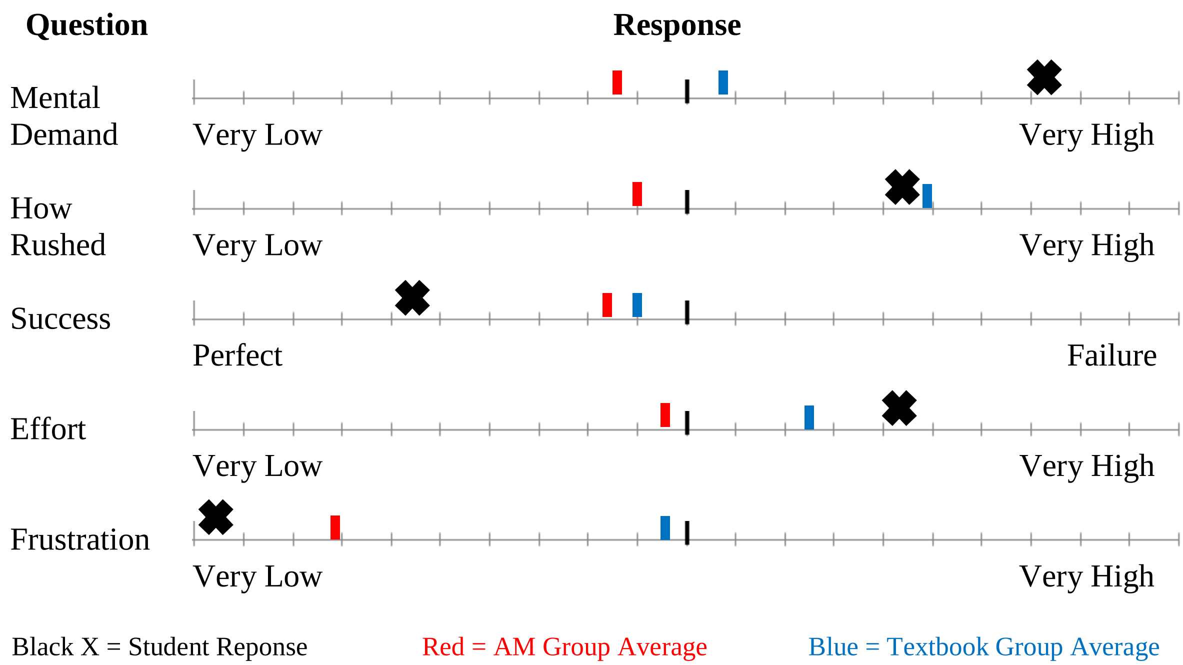


Figure 5.9: Gabriel's CRESST Session 1 TLX Results

Figure 5.9 shows that Gabriel reported a very high cognitive load, higher than any other research participant. It is suspected that Gabriel's difficulty with the English language may explain part of the high cognitive load. He also reported a higher than average level of success, indicating that he felt he was successful in learning the information. Finally, Gabriel reported the lowest possible score for frustration, which is an indication of high usability for the interface.

CRESST Session 1 Explanation:

Gabriel begins by stating…

> *"I guess today we will talk about multi-components. Multi-components is comprised of trusses, frames, and machines."*

He then says that he will start with trusses, and that trusses are comprised entirely of two force members which allow for special methods of analysis. He then goes on to explain what a two force member is and give an example of a two force member. Then Gabriel states that there are two methods used to analyze two force members, the method of sections and the method of joints.

Gabriel correctly explains the method of joints, stating that you need to solve for external reaction forces first. He illustrated the process through an example, and correctly related the equations of equilibrium and moments to the process.

Next he moves on to explain the method of sections, correctly explaining this procedure and addressing the equations of equilibrium where appropriate.

After the method of sections, Gabriel defines a frame as something that contains a three or more force member, and two force members as well. This statement is not entirely correct as frames do not have to have two force members, though frames often do contain two force members. Gabriel draws an example of the frame, a basketball backboard with the pole supporting it. A basketball hoop is an example of a frame, but Gabriel draws in pin joints at each end of the pole, making the whole structure non-rigid. He then identifies the pole as a two force member, which is correct with the pin joints, but would not be true if the connections were realistically depicted as fixed connections. Gabriel's explanation of how to analyze frames and machines is correct if we ignore the problems with his chosen example. He also briefly addresses the need to have the same number of equations as unknowns (being statically determinate) though he does not use this term directly.

Next Gabriel goes on to explain that a machine is a non-rigid version of a frame, which is a correct statement. He says that you analyze them in the same way as frames.

Gabriel brings up Newton's Third Law at this point and explains how it pertains to the analysis of frames and machines. He correctly explains the topic using his example of the basketball hoop and pole. After that, Gabriel states that he is done with his instruction.

The interviewer at this point asks for clarification on the difference between frames and machines. Gabriel states that frames support loads while machines transfer loads, and then he gives a correct example of each type of structure.

Next the interviewer asks Gabriel what a multi-component assembly is. Gabriel responds by stating that they are trusses, frames and machines. He does not identify that they are any collection of connected bodies - the defining characteristic of any assembly.

Next the interviewer asks Gabriel to talk more about two force members. The interviewer draws a two force member in tension with two arrows pointing outward. Gabriel states incorrectly that one force is in tension (the upward arrow) and the other compression (the downward arrow). This shows a clear misconception of what tension and compression mean.

The interviewer then asks why the forces have to be equal and opposite, and Gabriel correctly attributes this to the members being in equilibrium. He also incorrectly attributes the need to be equal and opposite to Newton's Third Law though.

> *"Interviewer: Okay. And then... so it's always got two forces acting on it, tell me about those two forces.*
>
> *Gabriel: Okay, the reason that there is always two forces is that, so if it is in equilibrium meaning that all the forces had be add up to zero. If there are not two forces then they would not be in equilibrium. If the one force not add up to zero then it would not be equilibrium.*
>
> *Interviewer: Okay.*
>
> *Gabriel: And the reason that one force is always opposite the other is that it has to satisfy Newton's Third Law."*

The interviewer then asks why the forces are always drawn as collinear forces, he asks why they cannot be parallel but not collinear. Gabriel correctly attributes this to the couple that is exerted by the two parallel forces, but he seems unsure of that answer himself.

Finally, the interviewer states that he saw Gabriel looking at the page on static determinacy and asks if Gabriel could talk about that. He states that he did not have enough time to look at it and doesn't really know what it is.

Table 5.7: Gabriel's CRESST Session 1 Rubric Scores

Category	Score
Principle Coverage	5/5 Moore
Prior Content	3/5 Moore
Conceptual Knowledge	3/5 Moore
Procedural Knowledge	4/5 Moore

As can be seen in Table 5.7 and Figure 5.10, Gabriel addressed all major topics in the subject area. He also connected outside topics to the cluster, but had major misconceptions about tension and compression and incorrectly linked Newton's Third Law to two force members. Conceptually, Gabriel had a few errors. He had major misconceptions about two force members and did not really seem to be able to define a multi-component assembly, he was just able to give examples of what a multi-component assembly was. Additionally he had trouble defining a frame in one of his example problems. Procedurally, Gabriel gave correct explanations, but again his example problem with a "basketball frame" had inconsistencies and technical errors.

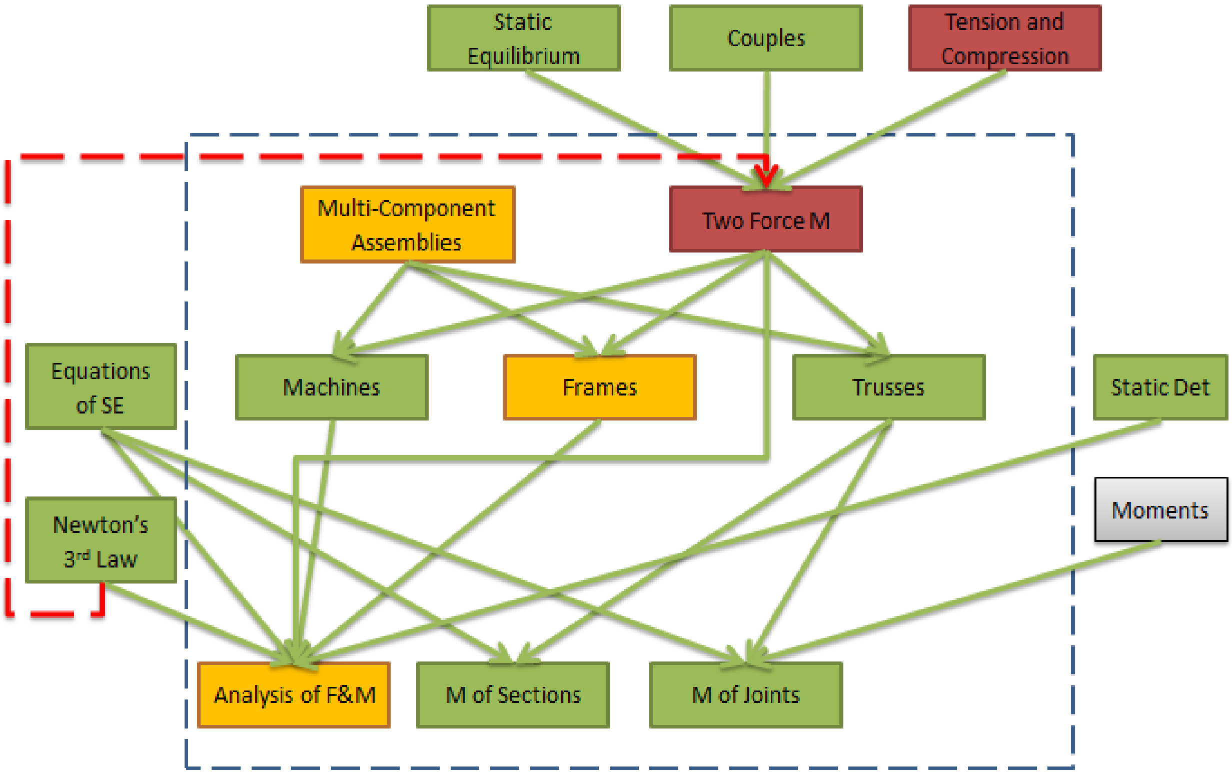


Figure 5.10: Gabriel's CRESST Session 1 Explanation Concept Map

CRESST Session 2 Preparation:

Gabriel began preparation for the second CRESST session by quickly looking over the cluster map and then opening the "Distributed Forces" topic page. He read through the information on this page and took some notes.

Next Gabriel went back to the map, and navigated to the "Buoyancy" node. He read the description of this page and then opened the topic page. He read the page carefully and took some notes, but skipped the worked example problems. He then opened the "Hydrostatic Pressure" topic page, carefully read this page and took some notes. Next Gabriel went on to "Hydrostatic Pressure on a Curved Surface" topic page and carefully read the content and took notes.

After the “Hydrostatic Pressure on a Curved Surface” topic page Gabriel went back to the “Buoyancy” topic page, clicking on the already open tab directly. He quickly read through the description again and read through the worked example. Then Gabriel went back to the “Hydrostatic Pressure on a Curved Surface” topic page, again clicking on the tab directly. He read through this page again.

Next Gabriel opened the “Equations of Static Equilibrium” topic page and quickly skimmed this page. Gabriel then opened the “Hydrostatic Pressure on a Flat Surface” topic page and read and took notes on this page. Finally, Gabriel went back to the “Hydrostatic Pressure on a Curved Surface” topic page, opening it through the tab, and read through the page for a third time. This last time he had a look of confusion on his face.

Overall, Gabriel took a rather haphazard path through the topic pages, not following a logical order to the pages. It was also observed that Gabriel kept all of the topic pages open after reading them and on multiple occasions used the open tabs to navigate from one topic page to the next. He was the only participant observed to do this.

This navigation behavior is not the navigation behavior that the designers intended, and it interferes with the ability of the concept maps to serve as advance organizers. Gabriel states that he wishes he could zoom right into the topic page from the cluster view, which would alter his navigation pattern, most likely to pattern where he was more likely to use the concept maps as advance organizers. The software made such a design difficult though. Topic pages opening in a separate browser tab serves as an example of a design compromise that had to be made because of the limitations of technology used.

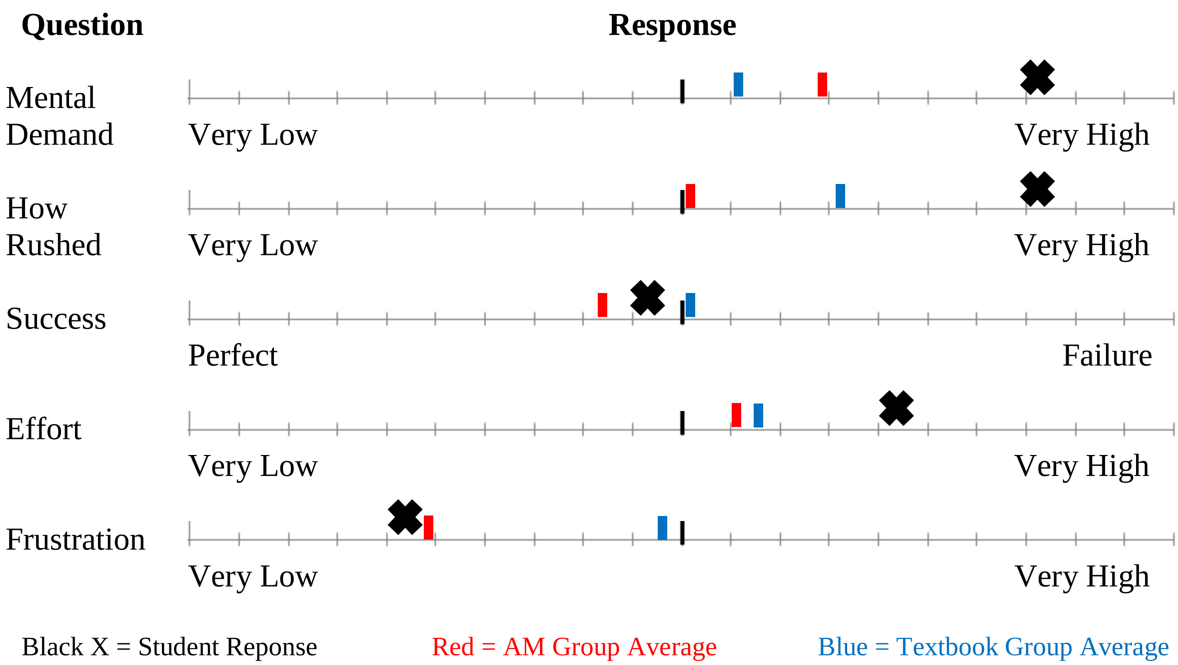


Figure 5.11: Gabriel's CRESST Session 2 TLX Results

As seen in Figure 5.11, Gabriel again reported higher cognitive load levels than any other research participant in this session, and he reported being more rushed than any other research participant in this session. This may be a result of a poor user experience or it may be a result of language difficulties. Despite high cognitive load levels, Gabriel reported average levels of success and frustration.

CRESST Session 2 Explanation:

Gabriel starts with the following statement.

"Gabriel: Thermal fluid right?

Interviewer: Fluid statics."

He stated he had previously covered distributed forces, and where they converted a distributed force to a single point force. He indicates that hydrostatic pressure builds upon this. However, Gabriel incorrectly adds another layer of complexity by saying that density needs to be taken into account in addition to the "uniform distributed load". He mentions an example of a neutrally buoyant water balloon from the buoyancy page here as well. Overall, Gabriel seems to understand that hydrostatic pressure builds on what they covered with distributed forces, but he has some major misconceptions about hydrostatic pressure.

Next Gabriel asks the interviewer if he wants him to start over. The interviewer says no, but says he would like to go back and discuss distributed loads. The interviewer asks "What is a distributed load?" Gabriel correctly expands upon his earlier explanation of what a distributed load is and also says that they need to be converted to a single point load to be analyzed. He goes on to correctly explain how to use integration to solve for the equivalent point load, using some examples. He correctly ties in the equations of static equilibrium to this discussion by saying that you must solve for the equivalent point loads before using the equations of static equilibrium.

Next Gabriel begins discussing buoyancy, tying this to the discussion on distributed loads.

> *"Gabriel: So we use the same concept of distributed force, it like buoy...*
>
> *Interviewer: Buoyancy?*
>
> *Gabriel: Buoyancy. My notes say that you want to... any object that is submerged will experience a hydraulic... hydrostatic pressure. So you want to replace that pressure with the one force.*
>
> *Interviewer: Okay, so is the hydrostatic pressure... You are doing the same thing you were doing over here with the Peq.*
>
> *Gabriel: Correct.*
>
> *Interviewer: So is the hydrostatic pressure like this [points to diagram of distributed force].*
>
> *Gabriel: Yes, but it's going to be more than that because you have to consider density. Because it is going to be in the water. So the water also has density."*

The exchange above highlights several misconceptions that Gabriel has. He seems to be blend together the concepts of hydrostatic pressure, hydrostatic pressure on a flat surface, and buoyancy in his discussion. He also incorrectly brings up density again as an extra complication to the distributed force.

After this Gabriel states that he is done. The interviewer asks for more about the relationship between hydrostatic forces and distributed forces. Gabriel incorrectly states that hydrostatic forces are equally distributed over a submerged object, and seems unsure if a hydrostatic pressure is a distributed force.

Next the interviewer asks if we can find the equivalent point load for a hydrostatic force like we did for a distributed force. Gabriel says yes, which is correct, but when giving an example uses the function of the surface below the water instead of the function of the force distribution to calculate the equivalent point load.

Table 5.8: Gabriel's CRESST Session 2 Rubric Scores

Category	Score
Principle Coverage	3/5 Moore
Prior Content	3/5 Moore
Conceptual Knowledge	2/5 Moore
Procedural Knowledge	2/5 Moore

As seen in Table 5.8 and Figure 5.12, Gabriel only addressed hydrostatic pressure, buoyancy and briefly mentioned hydrostatic pressure on a flat surface. Gabriel displayed an understanding of distributed forces and the equivalent point load, but he incorrectly added complexity to the relationship between distributed loads and fluid statics. Conceptually, Gabriel seemed to blur the topics together and had major misconceptions in all subjects. The blurring together of topics also severely interfered with his procedural knowledge.

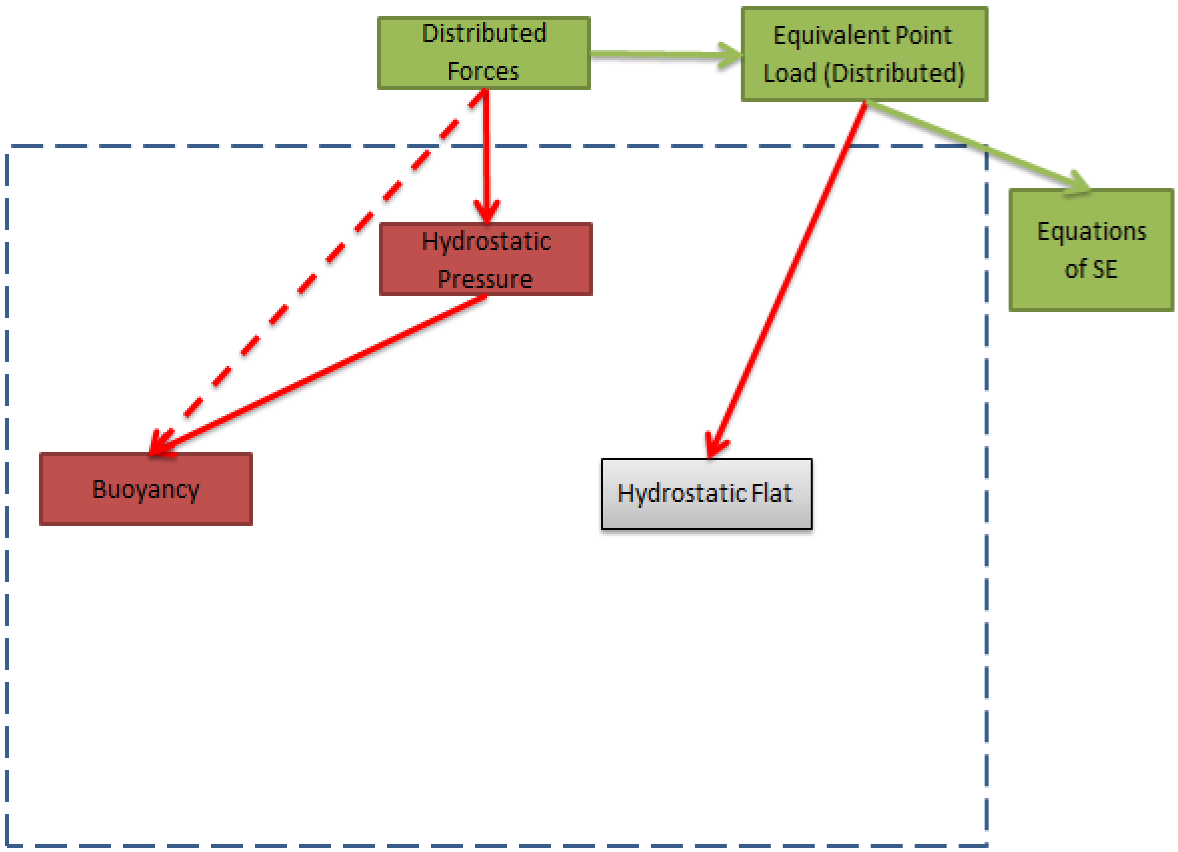


Figure 5.12: Gabriel's CRESST Session 2 Explanation Concept Map

Case Summary:

Gabriel was the heaviest user of the Adaptive Map tool, using the tool primarily to look up information to solve homework problems. Gabriel reported liking the content, the concept map layout, the search function, and the options of the Adaptive Map tool. In both CRESST sessions, Gabriel took a haphazard path through the topics, though this was more evident in the preparation for the second session. This indicates that he was not using the links in the cluster view to guide him from topic to topic. Gabriel was also the only participant observed to use open tabs to navigate between topic pages. Gabriel had an average understanding of the topics he reviewed in the first CRESST session, but had major difficulties understanding the new information in the second session.

5.5.3 Lillian

Background:

Lillian is a female student in the Mining Engineering Department. She is fluent in English and discusses little about her career aspirations beyond the course.

Lillian is mid-range in terms of her performance. The reported expected grade for the course is "B or B+ hopefully" and her GPA of 3.40 puts her around the average for course grades, though her Statics Concept Inventory score of 25.9% puts her below the average on the test. She appears to have a strong performance orientation to learning, using grades as a measure of success and preferring to "take baby steps" in homework by solving something that is just a bit beyond what she can already do.

When asked about her opinions of the course, Lillian reported that "it was not that bad". She said others had "hyped up" the course, and that she had some trouble initially but that everything went smoothly after the beginning. Her language indicates a view of the course as an obstacle to overcome.

Adaptive Map and Textbook Usage and Opinions:

Lillian reported using the Adaptive Map tool sporadically. In the weekly survey, she was split evenly between reporting no usage, using the tool once in the week, and using it two or three times. There was no apparent pattern in how often she used the tool over the semester. During the closing interview, Lillian said she used the tool about once a week on average. Lillian reported using the Adaptive Map tool as her primary source of information and reported using her paper textbook only to look up homework problems, not for any information.

Lillian described the role of the textbook as unnecessary. Her response below to the question "What is the role of a textbook?" shows her general dislike of textbooks.

> *"I mean, I don't think they are very useful, like I barely used my textbooks at all in my classes. Like I usually go to my teacher or use the internet or something. And I mean I guess for like homework problems that's okay, but like textbooks in general seem very confusing. Like the way they explain things are always like different from like the way you learn things in class, so I mean… I don't know, I don't like them very much."*

Despite this general dislike of textbooks, Lillian used the Adaptive Map tool and seems to have generally positive opinions of the Adaptive Map tool. This indicates that she did not view the Adaptive Map tool as filling the role of a textbook as she sees it.

Lillian reported using the Adaptive Map tool to study for exams, to review information from classes she missed, and to look up information to solve homework problems. In the interview, she indicates that reviewing information, for exams or just to review, was the primary use of the Adaptive Map tool.

Lillian's opinions of the tool were positive overall, reporting that she liked both the content and the layout of the tool. She indicated that the content was clearly written and easy to understand, comparing the tool to the course instructor who she also thought was good at giving clear explanations. For the layout, she reported,

> *"I mean I liked it a lot. It was just easy to click from one thing to the next, instead of just having to look through a list and like… I don't know it seems a little confusing. Cause it's all like connected, and so like if I was looking at something but was confused about something that was in another section, I wouldn't have to go back and go through, I could just click it cause its connected to it."*

This indicates that she mainly liked the fact that all of the relevant information was pulled together so that she could more easily find the information. When asked for something she didn't like about the Adaptive Map tool, she reported that she was frustrated by the search bar that did not give her any feedback if she did not get any valid results.

When asked for a good or bad experience, Lillian reported the following scenario.

> *"Well, um probably good was like the moments in 2D. I think maybe, this was like maybe even after we had our first test, but we were learning like the 3D stuff, but I didn't like feel very prepared to start learning the 3D stuff yet because I was still confused about 2D. So I looked back on it and it like really helped, helped me understand like how to use them, like how to actually use them to help me learn 3D."*

Lillian reported that the tool helped her get a better big picture of the course because the "web" helped her see all the connections between the topics. She also reiterated that she would like to see the search bar fixed because that is how she found a starting position in the map.

CRESST Session 1 Preparation:

Lillian began her preparation for the first CRESST session by opening and reading the "Two Force Members" topic page. She read this page and took notes. Next Lillian skipped ahead to the "Method of Joints" topic page and then to the "Method of Sections" topic page. She spent time carefully reading and taking notes on these two pages.

As the end of the session was approaching, Lillian follows the link back from the "Static Determinacy in Trusses" node back to the "Static Determinacy" node. She opens the "Static Determinacy" topic page and carefully read and took notes on this page. The preparation time runs out while Lillian was on this page.

Overall Lillian skipped around in the information she looked at, though her examination of the link back to the "Static Determinacy" node shows that the map was guiding her through the content. The observer also noticed that Lillian did not spend any time looking at the worked example problems; instead she focused on the explanations towards the top of each topic page.

Figure 5.13 shows that Lillian reported very low cognitive load levels. These levels were lower than any other research participant. The low measure of overall effort also supports the low cognitive load measurement. She also reported not being rushed, despite running out of time before finishing and a higher than average level of success.

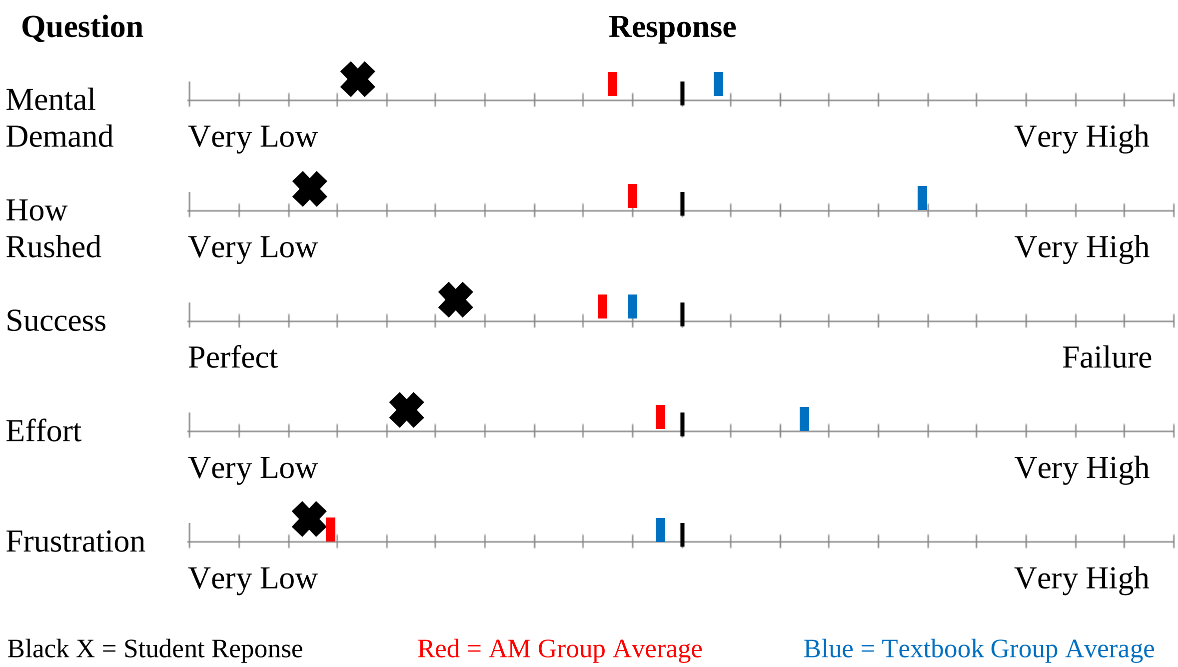


Figure 5.13: Lillian's CRESST Session 1 TLX Results

CRESST Session 1 Explanation:

Lillian starts her explanation by stating what two force members are, and saying that they are members in structures. Lillian says that two force members have two equal and opposite forces and explains that they have to be equal and opposite for the member to be in equilibrium.

She then moves on to explain that this is applied in the method of joints, which can be used to analyze structures made entirely of two force members. She correctly explains the process for applying the method of joints, though she omits the step of solving for external reaction forces first. She also discusses the equations of equilibrium in this method where appropriate.

Here the interviewer asks Lillian what kind of structure this is called, to which Lillian correctly responds "a truss." The interviewer also asks Lillian what the defining features of a truss are, to which she correctly responds the two force members, though she does not state it has to be all two force members and she does not seem confident in her answer. Finally the interviewer asks if it is possible for the equal and opposite forces in a two force member to be not collinear. Lillian goes back and forth, but incorrectly decides that is a possibility so long as they are equal and opposite. Lillian then continues with a more detailed description of the method of joints.

After the Method of Joints, Lillian moves on to the Method of Sections. Lillian explains that this method is used to find the forces in a specific member in the middle of a truss. Her explanation of the method is complete and correct, again addressing the equations of equilibrium where appropriate. This time Lillian does address using the entire truss to solve for the external reactions first.

After the Method of Sections, Lillian moves on to explain static determinacy, first stating that she didn't get to cover all of it. In her explanation, Lillian gives a correct interpretation of what static determinacy is, but does not connect it to anything she discussed previously. After that Lillian states that she is done.

Here the interviewer goes back and asks some questions about the content she didn't cover. When asked what a multi-component assembly or structure is, she correctly responds that it is anything with more than one part.

Next the interviewer asks about frames and machines. She states they [the class] haven't covered machines in class but they did discuss frames. She does not offer a description of what a frame is, but she gives a very short description of how fames and machines are analyzed. Her description is too short however to judge her understanding though.

Table 5.9: Lillian's CRESST Session 1 Rubric Scores

Category	Score
Principle Coverage	3/5 Moore
Prior Content	4/5 Moore
Conceptual Knowledge	4/5 Moore
Procedural Knowledge	4/5 Moore

As can be seen in Table 5.9 and Figure 5.14, Lillian did not discuss a large portion of the topic area; the frames and machines branch of the cluster map to be specific. With the topics she did cover however, she anchored the explanation in relevant information outside of the topic area, and she had only minor misconceptions and made only minor procedural mistakes. Conceptually, Lillian made the mistake of saying forces on two force members did not need to be collinear, and procedurally she omitted solving for external reactions before analyzing each joint in the method of joints. In relating the topic area to prior knowledge, Lillian mentions static determinacy but does not relate it to the topic area in any way.

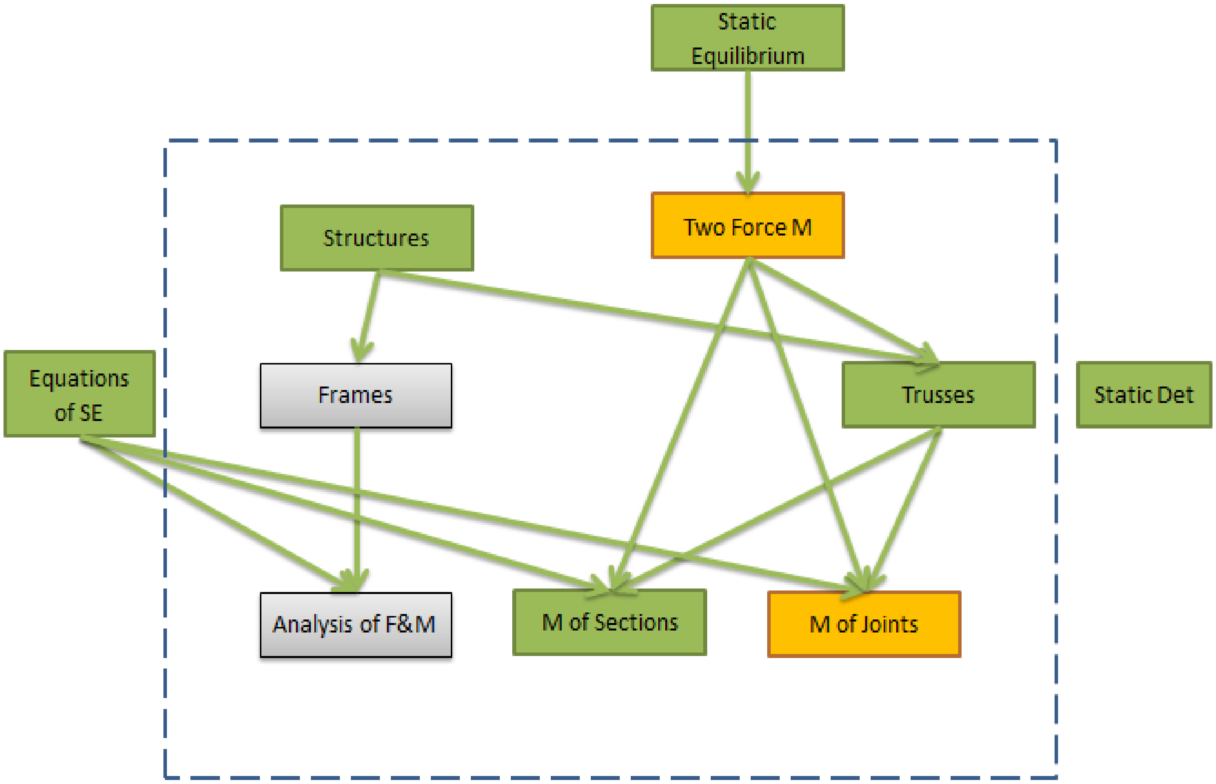


Figure 5.14: Lillian's CRESST Session 1 Explanation Concept Map

CRESST Session 2 Preparation:

Lillian began preparation for her second CRESST session by looking over the cluster map, hovering over nodes and reading the descriptions. She took down some notes based on these descriptions.

Next Lillian opened up the "Hydrostatic Pressure" topic page and read through the page carefully and took notes. After reading the "Hydrostatic Pressure" topic page Lillian went back to the cluster view and clicked on the "Hydrostatic Pressure on a Flat Surface" node. This caused the "Equivalent Point Load" node to appear, which she hovered over for a second to read the description.

Next Lillian opened up the up the "Hydrostatic Pressure on a Flat Surface" topic page. She read this page carefully and took notes on it. After reading the "Hydrostatic

Pressure on a Flat Surface" topic page, she opened the "Equivalent Point Load (Distributed)" topic page. Lillian read this page carefully and took notes on the page. After this Lillian went back to the "Hydrostatic Pressure on a Flat Surface" topic page and skimmed the content there. Then she went back to the "Equivalent Point Load (Distributed)" topic page and skimmed the content there. After this the time for preparation was over.

Overall, Lillian showed indications of using the cluster view as an advance organizer. This can be seen in the initial action of hovering over the nodes and reading them. Lillian also seemed to take time to read nodes, and sometimes the associated topic pages, that appeared as she navigated around the map. This a clear indication that she used the concept map to guide her path through the information.

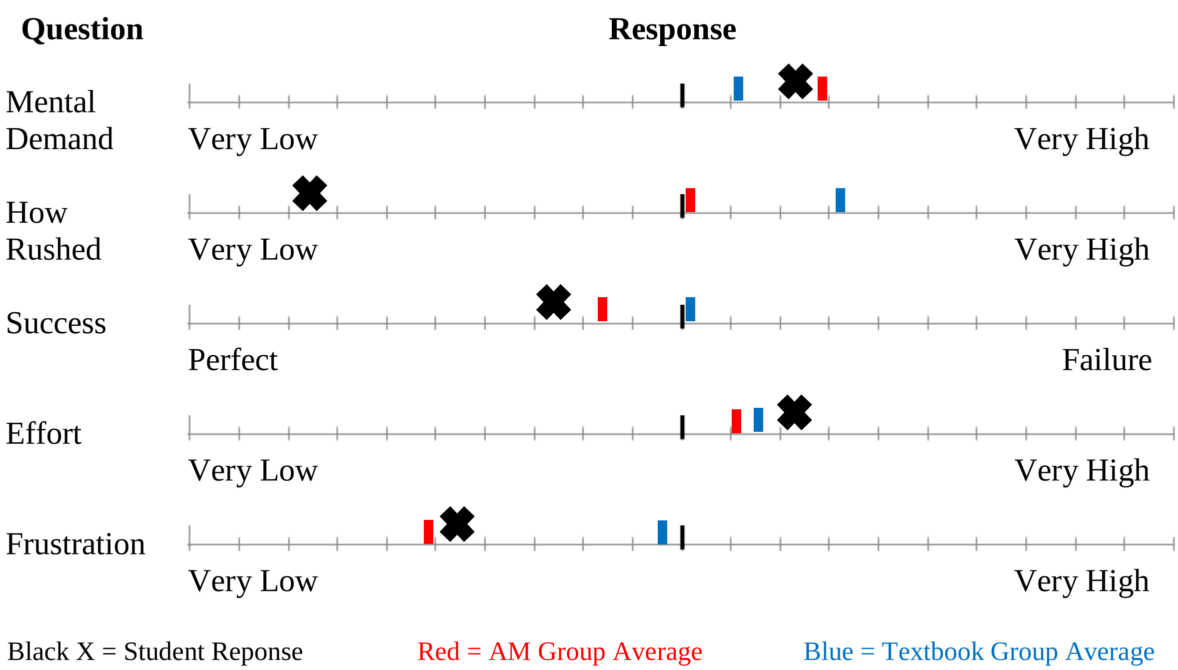


Figure 5.15: Lillian's CRESST Session 2 TLX Results

Figure 5.15 shows that Lillian reported average cognitive load levels and average levels of all other metrics except for how rushed the activity was. Like last time, Lillian reported not feeling rushed despite not being able to get to all of the topic pages.

CRESST Session 2 Explanation:

Lillian begins her explanation by stating,

> *"So it has the same concept that there is loading distributed from the liquid putting pressure on whatever object it is in contact with."*

Here Lillian correctly identifies hydrostatic pressure as a type of distributed force that a liquid exerts on a body in contact with the liquid. She then goes on to show an example of hydrostatic pressure from water in a bowl. She also briefly makes a distinction between absolute pressure and gage pressure.

Next Lillian ties in the equivalent point load.

> *"And then uh... And this pressure that the water is doing is called hydrostatic pressure. This distributed load can be changed to an equivalent point load, same as if forces were acting on a beam."*

She briefly mentions that she does not understand what the equivalent point load for parallel point loads (another topic node in the forces cluster). She then says you find the equivalent point load by "integrating along the length of it."

In explaining how to integrate to find the pressure function to find the equivalent point load and the point of application of the equivalent point load, Lillian uses the surface of the object as the *F(x)* function rather than using the pressure distribution. This is a major procedural error that would give invalid results.

After that Lillian says she is done. The interviewer asks her if she can say anything on buoyancy or hydrostatic pressure on curved surfaces and she says no.

After the recording, she went back and said that she forgot to mention the relationship *P = P naught plus rho g h*. She understood what all of the variables stood for except for *h*, which she had some confusion on.

Table 5.10: Lillian's CRESST Session 2 Rubric Scores

Category	Score
Principle Coverage	2/5 Moore
Prior Content	3/5 Moore
Conceptual Knowledge	3/5 Moore
Procedural Knowledge	2/5 Moore

As can be seen in Table 5.10 and Figure 5.16, Lillian covered only half of the topics in the prescribed topic area. She built up her explanation from information on distributed loads and the equivalent point load, but a major misconception about the equivalent point load carried over into her discussion on hydrostatic pressure on a flat surface. Additionally Lillian did not understand what the *h* stood for in the relationship *P = P naught + rho g h*. This was a second major procedural error. Conceptually, Lillian failed to relate pressure to the pressure distribution on a flat surface, instead using the function of the surface itself. This was a major misconception. As can be seen in Figure 5.16, Lillian's explanation matches the base of the cluster view in the Adaptive Map view, though the more advanced topics were missing in the explanation.

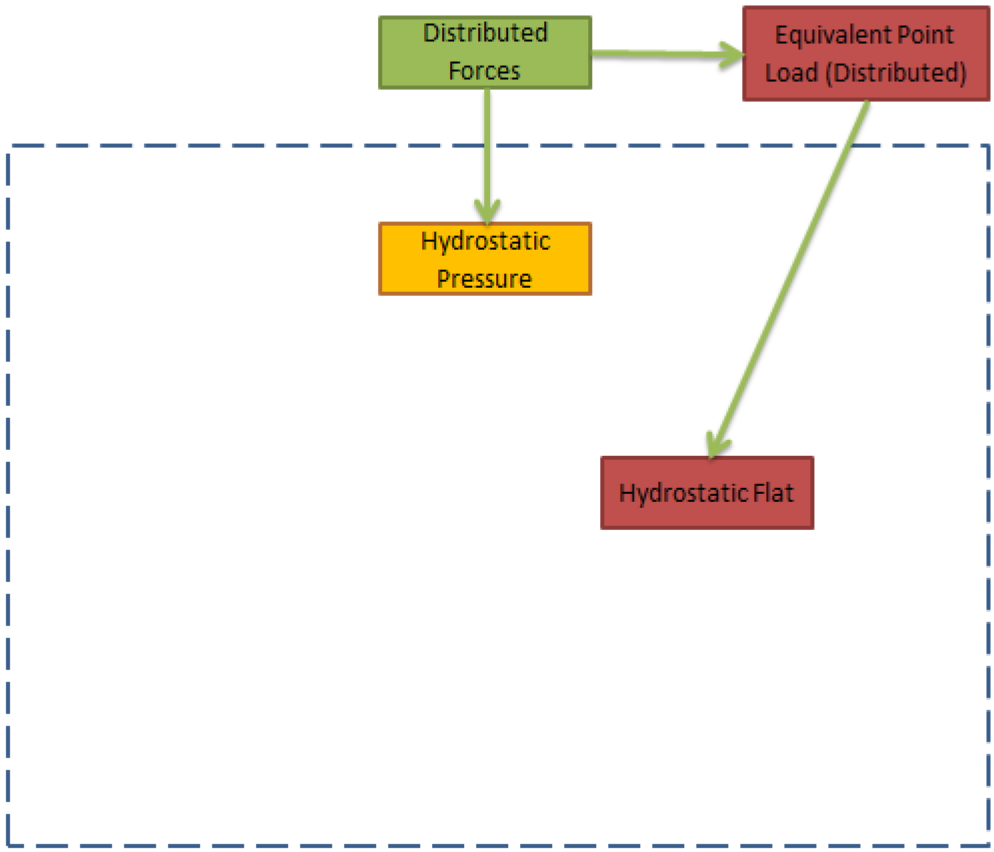


Figure 5.16: Lillian's CRESST Session 2 Explanation Concept Map

Case Summary:

Lillian was a sporadic user of the Adaptive Map tool. She used the tool primarily to review information and to study for tests, but also to look up information to solve homework problems. Lillian reported liking the concept map layout of the Adaptive Map tool, saying it helped her see how everything fit together. In both CRESST sessions Lillian spent time examining the concept map layout in the cluster view, indicating that she was using the tool as an advance organizer. Lillian also used the link to guide her path through the information, even when this led her outside of the prescribed cluster. It was also observed that in both of the CRESST sessions, Lillian seemed to take her time going through the information, learning at her pace and not covering everything for the preparation and in the explanation activities. She reported not feeling rushed despite not getting to some of the topics in both sessions, indicating little stress about not finishing her review for the research sessions. In the second CRESST session, Lillian tried to build her explanations, and presumably understanding, off of what she already knew from the class. She did have some major issues with distributed loads.

5.5.4 Lisa

Background:

Lisa is a female student in the Industrial and Systems Engineering Department. Lisa is fluent in the English language and does not discuss her career aspirations beyond college.

Lisa reports an expected grade of “B,” reports a GPA of 3.52, and her Statics Concept Inventory score is 37%, which positions her as an average performing student. Lisa has a mild mastery orientation. She reports that grades are important, but only because she believes that they essential to getting a good job after college. Lisa also reports that understanding the information is important, particularly if she can relate it to industrial systems engineering. She also reports preferring to solve problems she doesn’t know how to do because she likes learning the new information.

Lisa reported mixed feelings for the course reporting, “I kind of enjoy it, I think it’s kind of interesting, but I’m not sure how it’s relevant to me.” She also stated that most of the examples are for mechanical and civil engineers, and she wished that she could see how the course related to her major in industrial systems engineering.

Adaptive Map and Textbook Usage and Opinions:

Lisa reported using the tool once a week for all but two weeks on the weekly survey (one of which was thanksgiving break). She also reported not using it before the first research session. During the final interview session Lisa reported using the tool "once or twice" a week on average. She also reported using the Adaptive Map tool "about the same amount" as the paper textbook. She described the two tools as filling the same role for her.

Lisa described the role of the textbook as "more of a supplemental tool," where notes from lecture should serve as the primary out-of-class information source and then the textbook should be a backup if your notes do not have the information you need. She also described a scenario where the instructor is not very good and then the textbook has to serve as the primary source of out-of-class information, but says that this should hopefully not be the case.

In her own experiences, Lisa primarily used the Adaptive Map tool to review information covered in class and to study for exams. She only once reported using the Adaptive Map tool to help look up information to solve homework problems. For that task Lisa usually used her notes from lecture.

> *"I basically used [the Adaptive Map tool] most when there were gaps in my notes. And I didn't know how things connected, so that's where, like I didn't really understand the textbook layout of it, so I would use the Adaptive Map to kind of go and find the area where I was lacking in my notes and that's where I would use it."*

Lisa's opinions of the tool were mixed. She reported liking that she could see the flow of the information. This let her see how ideas were related.

> *"So like if you were looking at one subject and you wanted to know how it related to something else you could just look at the map and see how it*

> *related to other things, whereas in the textbook it's a little harder, you have to look harder to see how things relate."*

Lisa reported not liking the concept map layout when searching for information that she was not already familiar with. If she was already familiar with a number of the concepts in the cluster, she liked seeing the connections and being able to fill in the gaps, but if she was not familiar with any topics in the cluster, she found it difficult to find the bit of information she needed. Finally, Lisa also reported liking the search function that was available in the tool, but did report having some technical problems with it at times.

When asked for an example of a good or bad experience with tool, Lisa reported an incident where she repeatedly typed in something in the search bar and was given no feedback.

CRESST Session 1 Preparation:

Lisa began preparing for the first CRESST session by opening the "Multi-Component Assemblies" topic page. Here she began taking notes on multi-component assemblies and on trusses, frames and machines. After reading and taking notes on this page, Lisa went back to the cluster view and looked at the "Newton's Third Law" and "Equations of Static Equilibrium" nodes. She took some notes but did not open these topic pages.

Lisa skipped the "Trusses" topic pages and instead flowed the link down further to the "Method of Joints" topic page. She read this page and took a few notes. Next she moved on to the "Method of Sections" topic page and read this page and took a few notes.

After reading about the methods of joints and sections, Lisa opened the page on machines. She quickly read through this page and took a few notes. After examining the page on machines, she moved on and opened the "Analysis of Frames and Machines" topic page. She read through this page, moving more slowly through the content than for previous pages. She also took some notes while on this page.

As the end of the preparation time was announced to her, Lisa went back to the cluster view and looked around. She opened up the "Connections (Planar)" topic page that was linked to trusses and quickly skimmed through the topic page. She also opened the "Static Determinacy in Trusses" topic page, skimming through the topic page and taking a few notes.

Overall, Lisa seemed to take a haphazard path through the content, jumping from one topic to the next. The concept map did seem to guide her in a way through the information, but she did not strictly follow the links. Instead she seemed to use the concept map to identify the next area she needed to review. It was also observed that Lisa spent very little time looking at example problems on the topic pages, instead focusing on the content explanations.

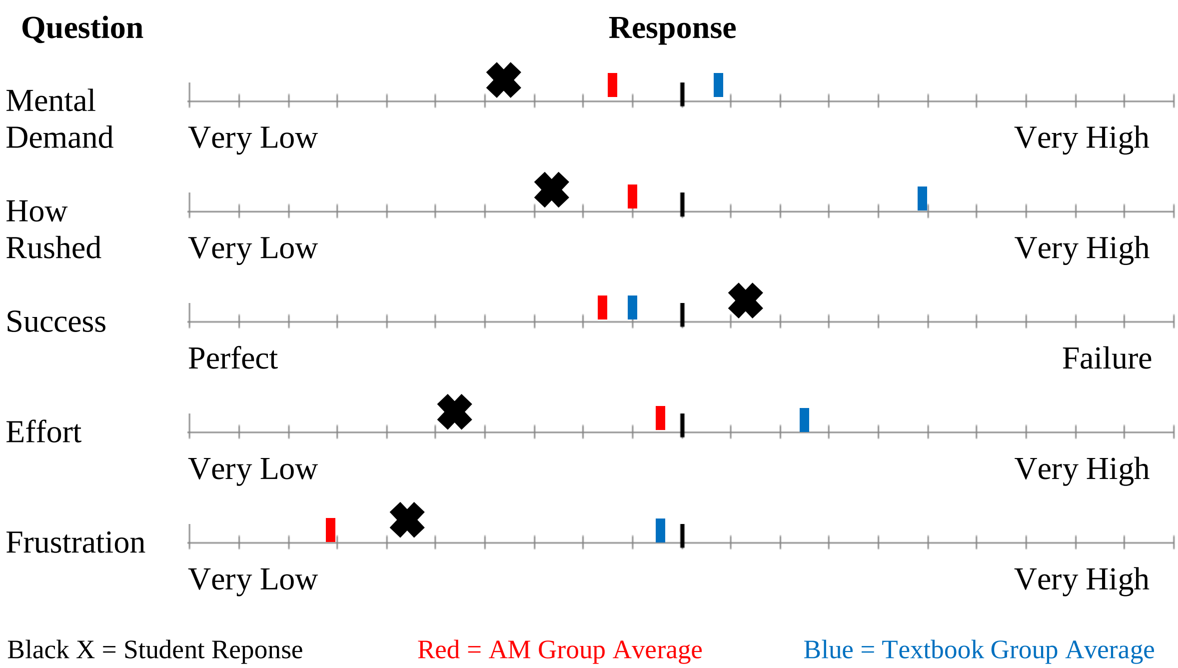


Figure 5.17: Lisa's CRESST Session 1 TLX Results

In Figure 5.17, we can see that Lisa reported a slightly lower than average cognitive load. This is supported by a lower than average measurement for overall effort. Other results are close to the Adaptive Map group averages.

CRESST Session 1 Explanation:

Lisa began by stating that the chapter is about multi-component assemblies, which are collections of connected bodies. She also says they are broken down into trusses, frames and machines.

She then goes on to say that she will start by discussing trusses, which are made entirely of two force members. She gives a short but accurate description of what two force members are. Next Lisa begins explaining how to analyze trusses,

> *"Lisa: And so when you do go in to solve them. You want to first go in and make a free body diagram, and first figure out... You want to first split it into its components. And then you can start with the method of joints.*
>
> *Interviewer: Sorry, what do you mean by split it into its components?*
>
> *Lisa: Each of the two force members. So I guess you are going to put each of those... no... yes... no.*
>
> *Well you want to split it into components where the members have loads on them. Because that's when you have too many unknowns. Yeah..."*

This analysis procedure more closely fits the analysis of frames and machines, and is not a correct way to analyze trusses.

Lisa next starts to discuss the Method of Joints, seeming to start over with her analysis procedure. Though she omits the step of finding the external reaction forces first, the rest of her explanation of the procedure is correct. She connects the method back to solving the equations of equilibrium.

She also interjects that it is important to make sure one has enough equations to solve for all the unknowns, and that the problem solver may want to pick a different joint if there are too many unknowns (relating static determinacy to the method without using the term static determinacy). Lisa also notes that when the problem solver does solve for a value, he or she wants to make sure to note if the force in the member is tensile or compressive and to be careful with signs, because messing up the signs can mess up the whole process.

Next Lisa moves on to the Method of Sections. Lisa again omits the step of solving for external reaction forces, but other than that she correctly explains the Method of Sections. Lisa then goes on to explain that sometimes you can combine the Method of Sections and the Method of Joints.

Lisa then discusses what a frames and machines are, saying that a frame contains one or more three or more force members and that a machine is non-rigid as a whole. These descriptions are short, but technically correct. She correctly explains that you analyze frames and machines in the same way, breaking the assembly into parts and analyzing the components separately. She also explains that you can analyze frames as a whole to solve for external reactions, but not machines. This distinction is not quite correct because frames need to be independently rigid to be analyzed as a whole. In her explanation of the process, she indicates that you can use matrices to solve the equations of equilibrium if you have lots of equations (a topic discussed in the Adaptive Map tool two links away from the assigned cluster, this was also a topic not discussed in the traditional textbook or in class).

Lisa then indicates that she is done and the interviewer goes on to ask some questions. The interviewer notices Newton's Third Law written down in Lisa's notes and asks how

Newton's Third Law relates to the discussion. Lisa says it mostly applies to two force members, incorrectly associating these two concepts.

Next the interviewer asks Lisa to expand upon the discussion of the two force members. The discussion mostly just reiterates what has already been said. During the discussion Lisa attributes the equal and opposite forces to both equilibrium (correct) and to Newton's Third Law (incorrect).

Finally, the interviewer asks Lisa if she can say anything about static determinacy. Lisa says she did not get much time to look at it, but she says it is just making sure there are enough equations to solve for all the unknowns, which is correct.

Table 5.11: Lisa's CRESST Session 1 Rubric Scores

Category	Score
Principle Coverage	4/5 Moore
Prior Content	4/5 Moore
Conceptual Knowledge	5/5 Moore
Procedural Knowledge	4/5 Moore

As seen in Table 5.11 and Figure 5.18, Lisa covered all topics but did not discuss frames and machines long enough for the researcher to judge if she understood the difference between the concepts. Lisa anchored the explanation well in outside topics, though she incorrectly associated Newton's Third Law with two force members. Lisa did not have any misconceptions in the topics she covered. Procedurally she omitted solving for external reactions first in the method of joints and method of sections. She also had a small error solving for external reaction forces with the analysis of frames and machines. These were each small procedural errors. As seen in Figure 5.18, the core of the concept map of Lisa's explanation matched the Adaptive Map tool, though some more peripheral topics such as Newton's Third Law and static determinacy differed. Also, Lisa connected matrix equations (two steps from the topic area) to the discussion in a way that matched the Adaptive Map tool.

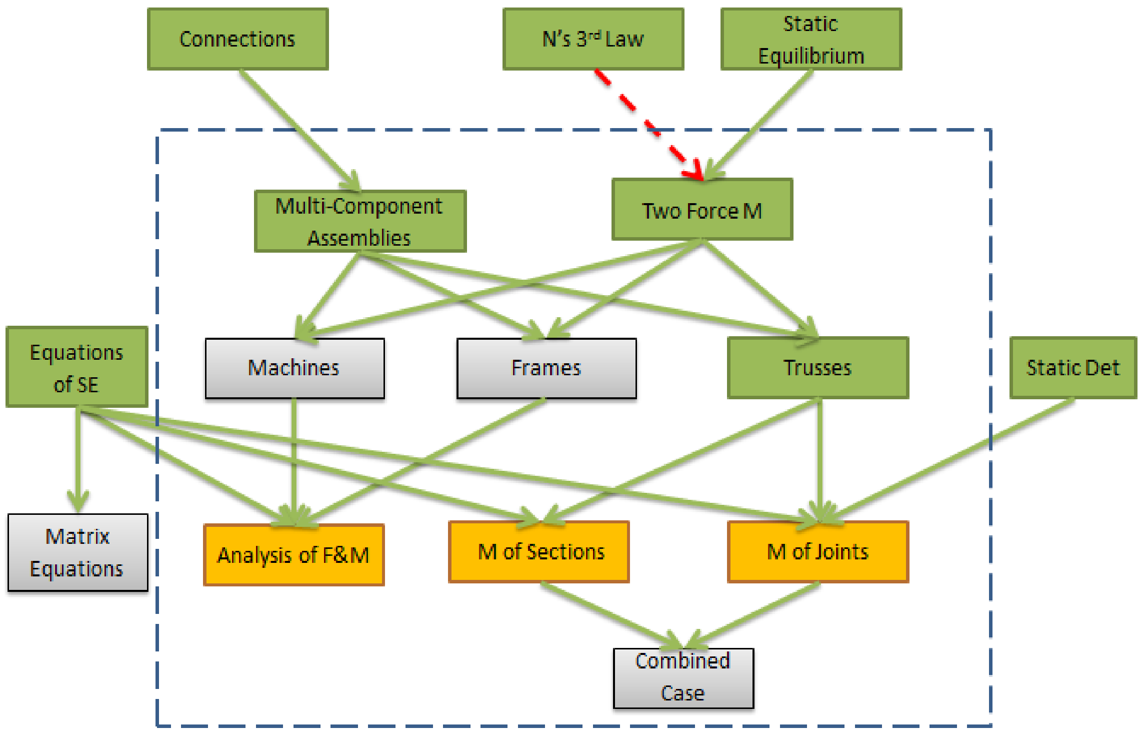


Figure 5.18: Lisa's CRESST Session 1 Explanation Concept Map

CRESST Session 2 Preparation:

Lisa began preparing for her second CRESST session by looking over the cluster view for a short time. After looking at the concept map, Lisa opened up the "Hydrostatic Pressure" topic page and began reading the page. She took numerous notes while on this page.

Next Lisa moved onto the "Buoyancy" topic page and took some notes on this page. Here she focused on the explanation and only skimmed through the worked example. After that, she visited the "Hydrostatic Pressure on a Flat Surface" and "Hydrostatic Pressure on a Curved Surface" topic pages, and took some notes and only skimmed through the worked examples again.

Next Lisa looked at the cluster view, hovering over nodes and links to get the descriptions. She then visited the "Equations of Static Equilibrium" topic page and the "Hydrostatic Pressure" topic page, skimming each of these pages. After this she declared she was done preparing.

Overall, Lisa showed some indication of using the concept map as an advance organizer. She looked at the map before opening the topic pages, and later used the concept map as a summary of the cluster by looking at the map after reading a number of the topic pages.

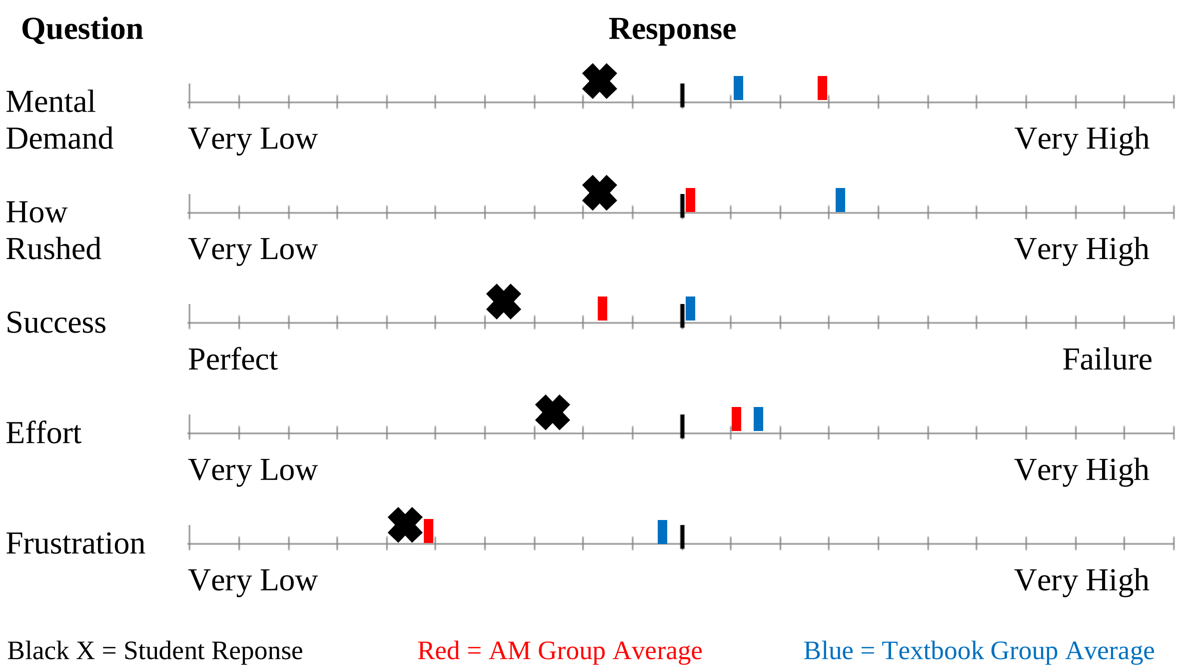


Figure 5.19: Lisa's CRESST Session 2 TLX Results

In Figure 5.19, we can see that Lisa again reported slightly below average cognitive load levels. This is also supported by the below average mental effort levels. It is interesting to note as well that Lisa's reported level of success is noticeably higher than in the first session.

CRESST Session 2 Explanation:

Lisa started her second CRESST session by correctly identifying that a hydrostatic pressure is a type of distributed force that a liquid in equilibrium exerts on any object in contact with the liquid. She states that distributed forces are forces that are applied over an area or a volume, and that a pressure is a surface force.

Next she discusses the relationship *P = P naught + rho g h*. She seems to have a firm grasp of what all of the variables mean except for *h*. When asked how this relates to an object that covers a range of depths, she incorrectly relates *h* to the depth of the equivalent point load. Then she discusses absolute and gage pressure, correctly relating the concepts back to the equations she discussed earlier.

Next Lisa begins to discuss buoyancy, correctly discussing the relationship *F = rho g V*. She also states that for an object to be in equilibrium, the buoyancy force must be equal and opposite to the weight force. This statement is correct, but from here she makes the incorrect assertion that only objects that are neutrally buoyant are in equilibrium (floating objects are not).

> *"Interviewer: Okay, you said that the objects were in equilibrium.*
>
> *Lisa: For them to be in equilibrium the buoyancy force must be equal to the weight, but they are not in equilibrium which is... with them not in equilibrium the object, if it's like floating and part of the object is submerged and part of it is above the surface of the liquid, that's when it's in buoyancy because the net forces on the object aren't in equilibrium which causes the buoyancy force. Which is the upward hydrostatic force.*
>
> *Interviewer: So like if a log is sitting floating in a lake, is that in equilibrium.*
>
> *Lisa: No.*
>
> *Interviewer: Okay.*

Lisa: Because it has like the buoyancy force acting on it which is why it is floating, why it is not submerged in the water. If it were like submerged in the water, and not on the bottom and not on the top, like floating on the top, then it would be in equilibrium because like it's weight would be equal to the buoyancy force so it would be just submerged, it would just be in the water."

This would seem to indicate that she may not fully understand that buoyancy forces change depending on the level of the water line (the volume submerged).

After that Lisa moves on to discuss hydrostatic pressures on a flat surface. Here she experiences further difficulties stemming from her earlier misunderstandings of hydrostatic pressure. The equations she gives are correct, and she is able to correctly identify most of the variables, but does not correctly connect the hydrostatic pressure to the function of the distributed force that she is trying to find the equivalent point load earlier. She instead brings up the depth of the equivalent point load, though these equations can be used to solve for the depth of the equivalent point load.

Next Lisa moves on to discuss hydrostatic pressures on curved surfaces. She correctly discusses the procedure to do this, correctly relating it back to hydrostatic pressure on a flat surface and the equations of static equilibrium. She still has issues understanding hydrostatic pressure on a flat surface which is part of the procedure, but they do not interfere with the procedural elements unique to analysis of curved surfaces.

After this Lisa states that she is done. The interviewer asks one question about how buoyancy relates to hydrostatic pressure and Lisa is not able to correctly identify how hydrostatic pressure relates to buoyancy.

Table 5.12: Lisa's CRESST Session 2 Rubric Scores

Category	Score
Principle Coverage	5/5 Moore
Prior Content	3/5 Moore
Conceptual Knowledge	2/5 Moore
Procedural Knowledge	2/5 Moore

As can be seen in Table 5.12 and Figure 5.20, Lisa discussed all topics in the prescribed topic area. She connected explanations to outside topics in meaningful ways, but added in some erroneous connections to outside topics. Conceptually, Lisa had major issues connecting the idea of hydrostatic pressure to either the force distribution in hydrostatic pressure on a flat surface or to buoyancy. Procedurally Lisa had major errors calculating the hydrostatic force on a flat surface and the buoyancy force. As you can see in Figure 5.20, Lisa's explanation concept map perfectly matches the Adaptive Map layout except for the addition of some erroneous links.

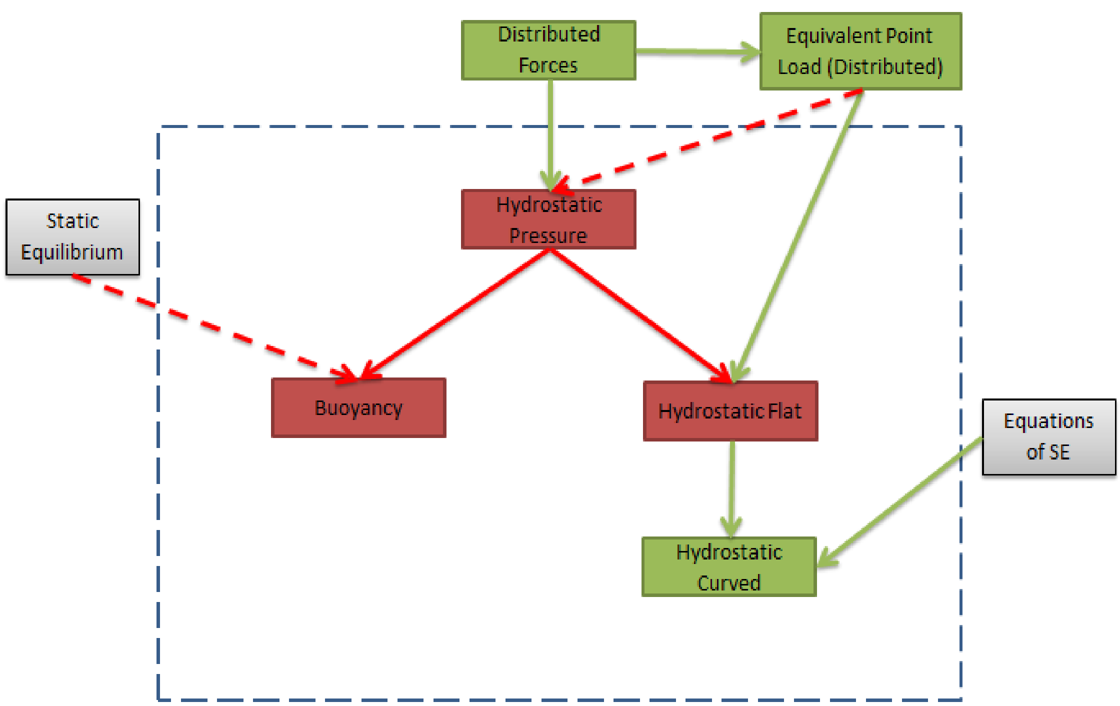


Figure 5.20: Lisa's CRESST Session 2 Explanation Concept Map

Case Summary:

Lisa was a regular user of the Adaptive Map tool. She used the tool primarily to review and fill in gaps in her notes. Lisa reported liking the concept map layout for the tool, but preferred to use the tool to review information that had already been covered rather than to learn new information. In the CRESST sessions, Lisa spent time looking at the map both before and after reading the topic pages. She seemed to use the concept map to plan her path through the information. In the first session, the review, Lisa seems to have a good grasp of all of the core topics in the prescribed area. In the second CRESST session however, Lisa seems to have a few big misconceptions of the material, though she does try to relate and build up the topics from what she already knows.

5.5.5 Paul

Background:

Paul is a male student in the Mechanical Engineering Department. He is fluent in English, and discusses little about his goals beyond the course.

Paul overall is a mid-performing student. He reports an expected course grade of "B", which puts him at an average or just below average expected course grade. His reported GPA of 3.13 also places him as an average student. His Statics Concept Inventory score is a 59.3%, though which is the second highest of any participant. Paul has a mild performance orientation to learning. On one hand, he reports a goal of being prepared for future classes and likes being challenged in homework problems, but on the other hand he reports grades as being very important and reports that he compares his performance on homeworks and tests to others.

Paul reported positive feelings for the course, putting most of this on the quality of the professor.

> *"I really enjoyed the course. I think I have a better understanding of everything that was covered in it. That probably has a lot to do with my teacher. Dr. Liao is awesome and I… I really liked the course actually."*

Adaptive Map and Textbook Usage and Opinions:

Paul reported using the Adaptive Map tool usually about once a week in the weekly surveys. He also reported using it two to three times one week and not at all another week. During the final interview Paul reported using the tool "either once or twice a week" on average during the debriefing interview.

When asked for the role of the textbook, Paul gave the following answer,

> *"It should be used to further the lecture a little bit. And to help clarify any discrepancies or questions there are from the lecture. Help do homework. Basically just be a layout for the class."*

He was then asked if courses should follow the layout of a textbook. He seemed to back out of this original statement, but did say that everything covered in the course should be covered in the book, and that they should at least match a little bit. He then gave the following example of when he thought the textbook and the course did not match up well.

> *"I know for example in our physics class it is very hard to connect what they say in lecture to what's in the textbook. It's almost like reading a children's book compared to Shakespeare. It's like two different worlds, so they should coincide pretty closely."*

During the semester, Paul said he split his time between the Adaptive Map tool and the paper textbook, using each about equal amounts of time. For information outside of class though, Paul reported first going to his notes from lecture, and then going to the textbook or Adaptive Map tool to fill in the holes in his notes.

Paul primarily used the tool to look up information to solve homework problems. This contrasted with the paper textbook, which he used exclusively to look up the problems themselves. Paul was also the only participant to report using the tool to look up information before class. When asked about this instance, Paul reported that it was after one of the CRESST sessions (the first CRESST session based on the date reported). Through the data collection session he touched on something that had not yet been covered in class and reported the he was curious so he looked at this information more closely after of the research session but before it was covered in class.

Paul's opinions of the tool were mixed, reporting that it was a "really unique idea" to organize information with concept maps. Paul reported liking the convenience of the search bar where he could simply type in and jump right to a relevant topic. Paul also seemed to like the interaction design, finding the navigation system to be easy use. On the other hand, Paul reported that lines connecting the topics could be busy or confusing.

> *"They were helpful in some cases but… most of the time not. They weren't very useful for me. For what I used it for."*

When asked for an example of a good or bad experience with the tool, Paul reported using the search bar to jump straight to the topic he needed.

When asked for a recommendation to improve the Adaptive Map tool, Paul suggested integrating homework problems into the Adaptive Map tool. He discussed having a very large number of homework problems in the paper textbook and felt the addition of homework problems to the Adaptive Map tool was important. He also said he didn't know where he would put the problems, under the broad headings or under the individual topic pages.

CRESST Session 1 Preparation:

Paul began preparing for the first CRESST by opening up the “Multi-Component Assemblies” topic page. He wrote a few notes and then went back to the cluster view. He navigated around a little bit then clicked on and opened the “Equations of Static Equilibrium” topic page. Paul then searched for the term “frames” and ended up opening the “Analysis of Frames and Machines” topic page. He read this page and took some notes and copying an example from this page into his notes.

Next Paul searched something else (typed in too fast to decipher) and was directed to the “Trusses” topic page. He took a few notes while on this page and then went back to the cluster view. He navigated to the topic pages on two force members, machines, back to trusses and then finally to static determinacy. When visiting each of these pages he seemed to read quickly through the pages while skimming the information and he took no notes while on these pages. Next Paul went back to the cluster view and read some links while hovering over them. He then navigated to the Method of Sections topic page and time ends while he is examining the example problems shown on that page.

Overall, Paul seemed to jump around from topic to topic. He did not follow a logical order through the topics, and he is the only participant observed to have used the search bar while preparing for the CRESST sessions.

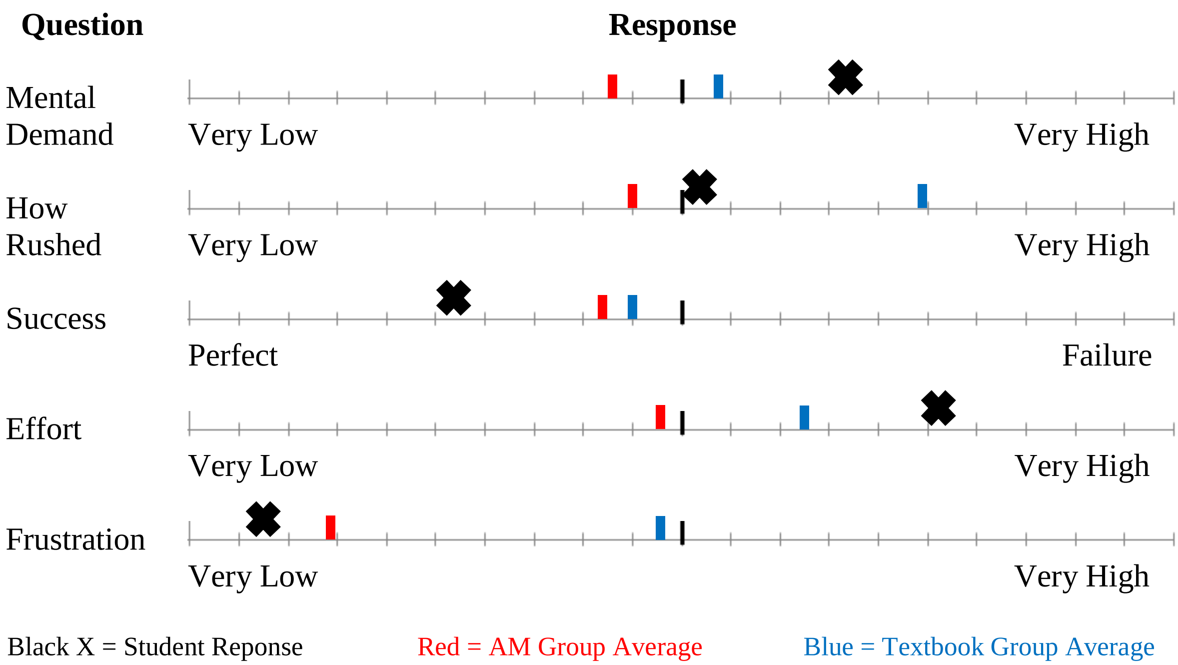


Figure 5.21: Paul's CRESST Session 1 TLX Results

Figure 5.21 shows that Paul reported an above average level of cognitive load, which is corroborated by the above average level for overall effort. It is also interesting to note that Paul reported an above average level of performance and a low level of frustration

CRESST Session 1 Explanation:

Paul began with the statement,

> *"In chapter four, it discusses multi-component assemblies, mainly frames trusses and machines."*

This shows an interesting meshing of the Adaptive Map tool and the paper textbook. The Adaptive Map tool does not have chapter numbers, though chapter four is the equivalent chapter in the paper textbook. The term "multi-component assemblies" however is not used in the paper textbook, the term "structures" is used instead. This shows he is pulling from both his memory of the textbook and lecture and from the Adaptive Map tool as well.

Next Paul correctly defines frames as one type of multi-component assembly that contains at least one three or more force member. Paul says that it is usually best to determine external reactions first, which is correct, and he then starts to discuss different types of connections and the reaction forces they would have. Through this he draws out an example and uses this to illustrate the analysis. In his example he connects a two force member and a multi-force member. The forces on these connected bodies are not drawn as equal and opposite as Newton's Third Law would dictate.

He then starts to discuss two force members, saying that they have only two forces acting on them and that these forces have to be equal and opposite. He also says that the problem solver has to arbitrarily assume either tension or compression, and then if the wrong assumption is made the results will be negative after solving the equations.

Next Paul introduces trusses with the statement,

> *"Then for a truss, which is a... it just sort of seems like a more complex frame. And so the Eiffel tower is an example of a truss it's made entirely of two force members."*

In this statement he does identify the key element of the truss, consisting entirely of two force members, but he instead seems to focus on complexity as the key distinguishing factor. When pushed further for the difference between trusses and frames, Paul becomes unsure of the differences and may not see the relationship between two force members and three or more force members.

> *"Interviewer: Okay. So what makes a frame and a truss different?*
>
> *Paul: A frame... I'm not exactly sure.*
>
> *Interviewer: Okay.*
>
> *Paul: Based on what I found [referencing notes], frames the definition is a multi-component assembly of at least one three or more force members.*

> *And a truss is made entirely of two force members. That was two definitions that I found."*

Paul says that there are two methods used to analyze trusses, the Method of Joints and the Method of Sections. He starts with the Method of Joints. Paul's explanation of the Method of Joints is all correct, however in an example he leaves off a force in the free body diagram he draws of the one joint he chooses.

Next Paul moves on to the Method of Sections. Paul explains that the problem solver first solves for external reactions and then cuts the truss, but does not continue his explanation beyond this point.

Next Paul moves on to define machines as something that transfers a load, but that "generally they follow the same principles." This definition does not address the key element of having a three or more force member.

Paul quickly describes a method of analysis similar to frames, but adds that if joints lie along a line of symmetry, only the forces at those joints that are perpendicular to the line of symmetry will be present. This was a claim that was not discussed in either the Adaptive Map tool or the paper textbook, and was most likely discussed in lecture.

Next the interviewer pushes Paul to see which methods apply to which types of multi-component assemblies. The following interaction occurs,

> *"Interviewer: Okay. So you talked about the Method of Joints and Method of Sections. Can you use those on frames and machines too?*
>
> *Paul: Um... Not to my knowledge, no.*
>
> *Interviewer: Okay. Why?*
>
> *Paul: Um, I do not know?"*

This is correct, but Paul is not able to describe why these methods are not applicable.

Next Paul says that he is done and the interviewer begins asking questions. First the interviewer asks Paul what a multi-component assembly is in general. Paul correctly describes them as being any collection of connected bodies.

Next the interviewer asks about Newton's third law. Paul is able to correctly explain what Newton's third law is and how it is used in the analysis of frames and machines.

Then the interviewer asks Paul to elaborate on two force members. The interaction below shows confusion between two force members and special circumstances in trusses.

> *"Interviewer: Okay. The other thing I wanted to ask more about is two force members. So you said in your definition that trusses are made entirely of two force members. What is a... Can you draw some two force members and talk a little more about that?*
>
> *Paul: Two force members... Let's see... A member is a two force member if there are three bars coming to a point and two of them are collinear, then the third one is going to be a two force member if there are no additional forces acting on that. So if there are no external forces acting on that joint then this bar, component is going to be a two force member.*
>
> *Interviewer: Okay.*
>
> *Paul: And we just draw those in the direction of the bar because now it's just a single force instead of having an X and a Y component. We know the direction."*

Paul does go on to say that the forces on each end of two force members need to be equal and opposite. When asked why, Paul is initially unsure, and then correctly ties this to static equilibrium. When asked if the forces need to be collinear, Paul incorrectly says that they do not need to be collinear.

Finally the interviewer asks Paul about static determinacy. Paul is able to correctly describe this as having more unknowns than equations, but he also blames this on the object not being in equilibrium, which is not correct.

Table 5.13: Paul's CRESST Session 1 Rubric Scores

Category	Score
Principle Coverage	4/5 Moore
Prior Content	4/5 Moore
Conceptual Knowledge	2/5 Moore
Procedural Knowledge	4/5 Moore

As seen in Table 5.13 and Figure 5.22, Paul covered all topics in the prescribed topic area, but did not cover the method of sections in enough depth to judge understanding. Paul also took a very haphazard and illogical path through the topics in his explanation. Paul anchored his discussion in outside topics, though many of these connections did not match the connections in the Adaptive Map tool. He also erroneously related static determinacy to static equilibrium. Conceptually, Paul had major misconceptions about two force members and could not correctly distinguish trusses from frames and machines. These were two major misconceptions. His low conceptual understanding score here contrasts with his high overall score on the Statics Concept Inventory. Procedurally, Paul's explanations are correct, though he makes two minor mistakes in the example problems he uses for the method of joints and the analysis of frames and machines. As seen in Figure 5.22, the concept map of Paul's explanation differs from the Adaptive Map tool more than any other participant in the Adaptive Map group.

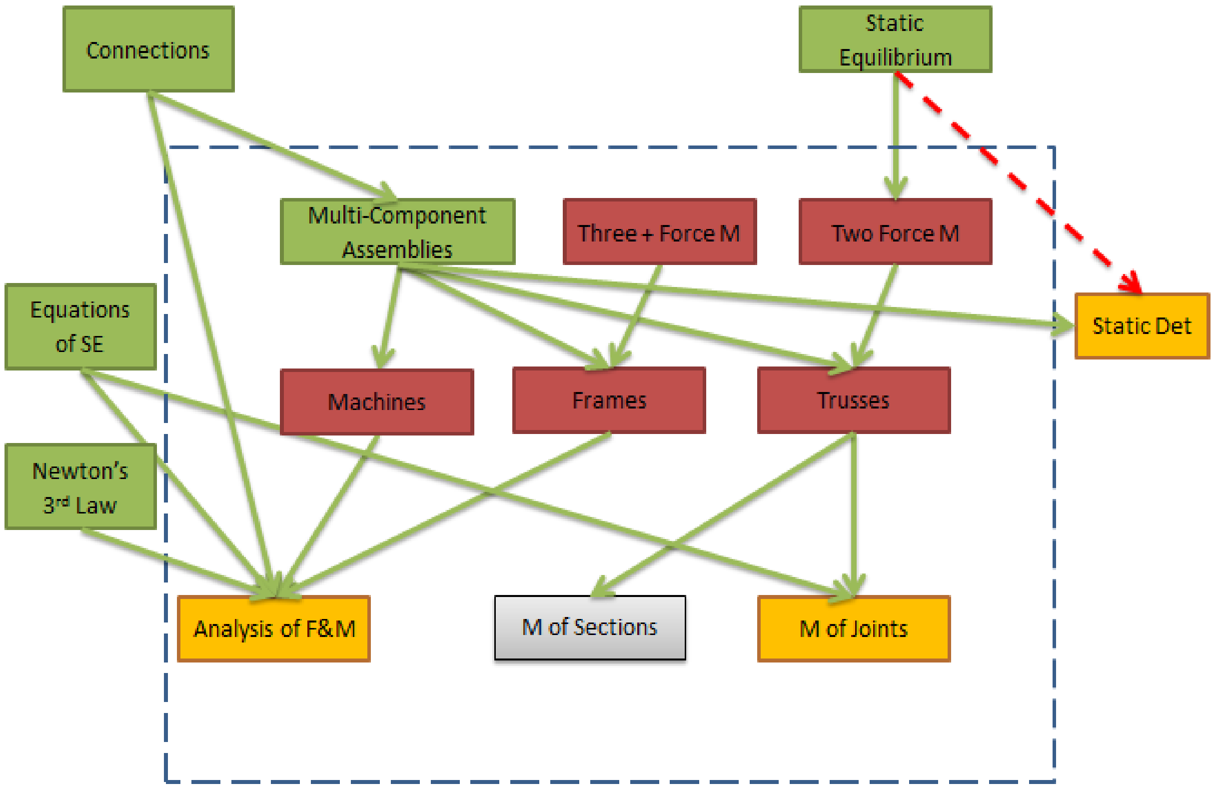


Figure 5.22: Paul's CRESST Session 1 Explanation Concept Map

CRESST Session 2 Preparation:

Paul began preparing for his second CRESST session by looking at and copying down the description for the "Hydrostatic Pressure" node. He then opened the "Hydrostatic Pressure" topic page and read and took notes on this page, copying down a diagram.

Next Paul went back to the cluster map. He clicked on the "Distributed Forces" node and then clicked back on the "Hydrostatic Pressure" node. Next Paul opened and read the "Buoyancy" topic page; he read the description and skipped over the worked problem. Next Paul went to and read carefully the "Hydrostatic Pressure on a Flat Surface" topic page and then the "Hydrostatic Pressure on a Curved Surface" topic page. On each of these pages he looked at both the explanations and the worked problems, taking notes on both. Finally, Paul navigated back to the "Buoyancy" topic page and read through and took notes on the worked example problem.

Overall, Paul seemed to follow a more logical path through the topics than he did for the first CRESST preparation session. His note taking was also far more extensive for this second session and he seemed to spend more time carefully reading the topic pages.

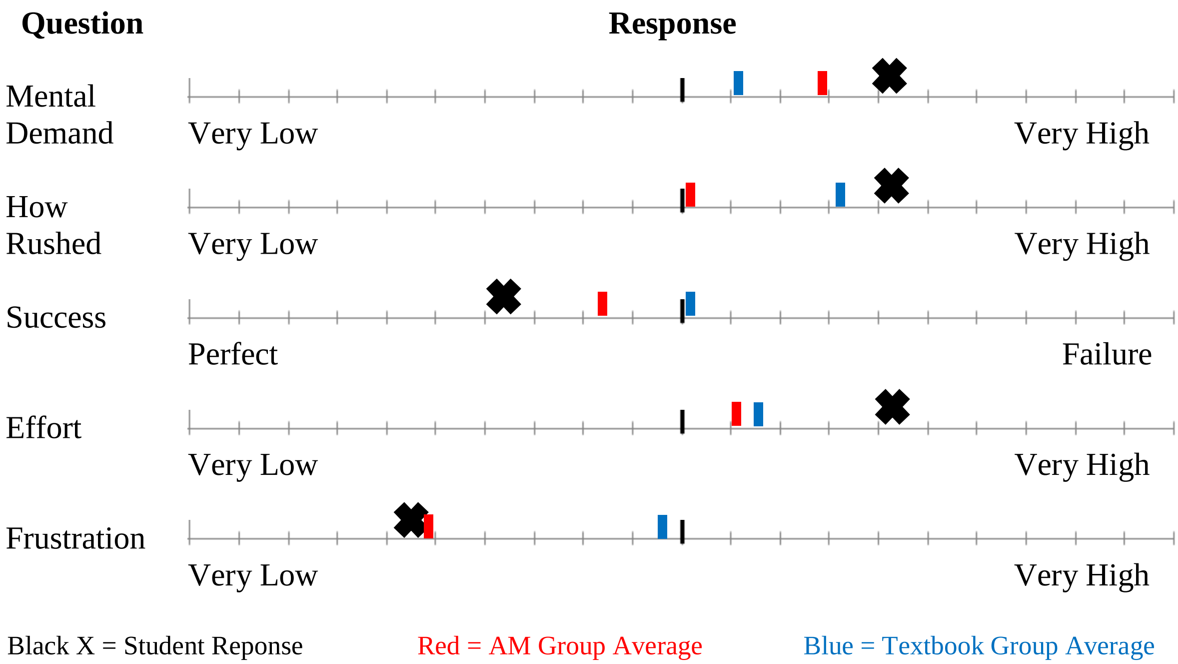


Figure 5.23: Paul's CRESST Session 2 TLX Results

In Figure 5.23, we can see that Paul again reported higher than average cognitive load levels, though in this session scores are not very high above the average. Other metrics are reported as close to the average.

CRESST Session 2 Explanation:

Paul started his instruction on hydrostatic pressure by explaining that hydrostatic pressure is the pressure a liquid exerts on any surface it is in contact with. He used a diagram he copied from the Adaptive Map tool to correctly illustrate some hydrostatic pressures. Next Paul went on to explain how to calculate the magnitude of the hydrostatic pressure as *P = P naught + rho g h*. The interviewer questions Paul about some of these variables and Paul is able to correctly identify what the variables represent. Next Paul correctly identifies the difference between absolute pressure and gage pressure.

After discussing hydrostatic pressure, Paul begins to discuss buoyancy. He begins by correctly relating buoyancy back to hydrostatic pressure.

> *"And the buoyancy pressure is the pressure that the liquid exerts on an object... for example if we have water and there is a rectangle submerged the liquid is putting pressure all the way around the surface but since pressure increases with depth the pressure at the bottom is going to be slightly more than the pressure at the top which is going to push the object upward."*

Paul then correctly describes the relationship to calculate the buoyancy force as *F = rho g V*, and seems to understand what the variables represent. Next Paul describes an example of a neutrally buoyant object from the Adaptive Map tool, but this is not really connected to the rest of the discussion on buoyancy.

After that Paul goes on to discuss hydrostatic pressures on a flat surface. He correctly identifies the equation to calculate the magnitude and position of the equivalent point load of the pressure on the surface, but he mistakes the *x* in the equation for the depth. This is a slight error that will cause the equation to be invalid. After mentioning *Feq* and *xeq*, the interviewer asks Paul what these are equivalent too. Paul responds by correctly relating this procedure back to the equivalent point load done in class with beams.

Next Paul moves on to discuss hydrostatic pressures on curved surfaces. Here Paul outlines a procedure that is mostly correct. He correctly redefines the body of analysis, he correctly explains that one side has a hydrostatic force from on a flat surface, but then he mixes up the depth of the center of mass of the redefined body of analysis and the depth of the equivalent point load on the flat surface. This is a slight error with this procedure. Finally, Paul correctly ties this back to the equations of equilibrium to solve for the last force.

After this Paul declares that he is done. The interviewer asks to go back and discuss buoyancy, specifically the example of the neutrally buoyant water balloon that Paul brought up earlier. In his discussion, Paul correctly defends the fact that buoyancy forces do not change with the weight of the object, only with the volume.

> *"Interviewer: Okay, so... I want to go back and ask quickly about buoyancy again. You talked about this water balloon here in the pool. So the weight going down and the buoyancy going up are the same?*
>
> *Paul: Right so the balloon would be in equilibrium, and that case.*
>
> *Interviewer: Okay.*
>
> *Paul: But if we replaced the balloon with a similar object... say a piece of foam with the exact same volume the buoyancy force would be much more than the... more than the weight of the foam, so the foam object would float to the top. And similarly if we had a metal ball the mass of the metal ball would be greater than the buoyancy and the ball would sink.*
>
> *Interviewer: Okay. So you said these two are the same size, I am assuming this is the same size.*
>
> *Paul: Right.*
>
> *Interviewer: So all three are the same size. So the weight obviously changes. Does the buoyancy force change at all?*
>
> *Paul: No. I think the buoyancy force stays the same."*

When asked why that was true, Paul responds in the following manner.

> *"The force that the water is putting on the object... Well Newton's laws don't quite agree with me there... I was going to say the buoyancy stays the same because the water doesn't change so it exerts the same pressure on the object, but the weight of the object changes so the buoyancy force is essentially less effective at pushing to the top of the surface."*

Here Paul initially ties in Newton's Third law, which is not related to the scenario descried, but then he correctly identifies the water as the source of the force and since the water is not changing, the force is not changing.

Table 5.14: Paul's CRESST Session 2 Rubric Scores

Category	Score
Principle Coverage	5/5 Moore
Prior Content	3/5 Moore
Conceptual Knowledge	3/5 Moore
Procedural Knowledge	4/5 Moore

As can be seen in Table 5.14 and Figure 5.24, Paul discussed all topics in the subject area. Paul related the discussion to relevant outside topics, though he did not discuss hydrostatic pressure as a distributed force and he erroneously related Newton's Third Law to buoyancy. Conceptually, Paul did seem to have a complete and correct understanding of hydrostatic pressure and buoyancy, but he did not connect this to the force distribution for hydrostatic pressure on a flat surface. This disconnect was deemed to be a major conceptual error. Procedurally Paul made some minor mistakes explaining how to analyze hydrostatic pressure on a flat surface and hydrostatic pressure on a curved surface.

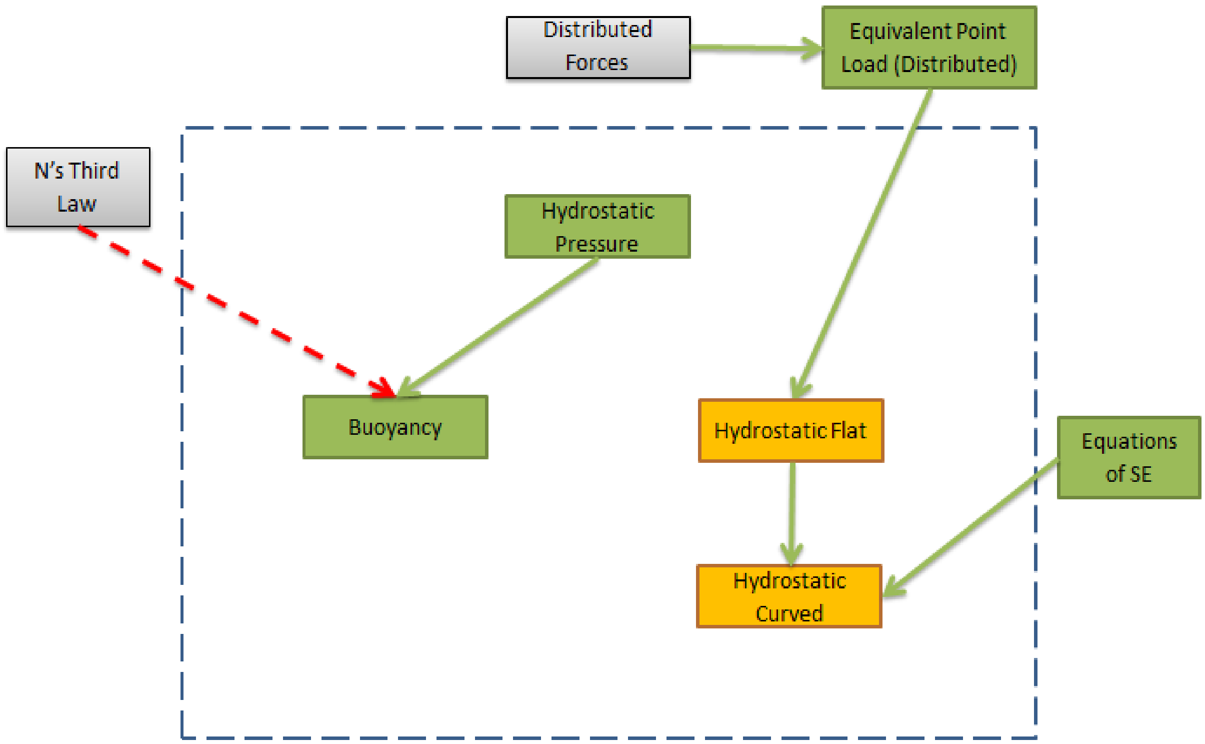


Figure 5.24: Paul's CRESST Session 2 Explanation Concept Map

Case Summary:

Paul was a regular user of the Adaptive Map tool. He used the tool primarily to look up information to solve homework problems. Paul reported that the concept map layout got in the way for him more than it helped. He did however seem to like the search function that could bring the relevant topic page right to him. Paul is an interesting case because he seemed to pay little attention to the concept map layout, particularly for the first CRESST session. This gives some insight into the effects of the content without the concept map layout. In the first CRESST session, Paul seems to have major misconceptions about a number of the foundational concepts in the cluster. For the second CRESST session, he did not use the search feature and spent more time looking at the cluster view. Though he spent more time looking at the cluster view than in the first session, Paul still spent less time examining that cluster view than most other participants. Paul had better understanding of the material in the second session than in the first, but he still lacked some foundational connections.

5.5.6 Sonya

Background:

Sonya is a Muslim female student in the Civil and Environmental Engineering Department. She is fluent in the English language. Sonya originally had interests in Theater and Fine Arts in high school, but her interests in environmental issues, along with a perceived usefulness of an engineering degree, is what drew her to engineering.

> *"I realized that one of the main things I am interested in is environmental issues and sustainability issues and stuff, so my dad really encouraged me to do environmental and, since they don't have environmental engineering department here, I decided to do environmental and civil. That's why I decided to… and it's more realistic to be honest. Like getting jobs in the fine arts it's a little bit more difficult."*

Sonya is a mid-range performance student with an expected grade of "B" and a Statics Concept Inventory score of 33.3% (which is just below the average). Despite being about average for performance in both measures, Sonya appears to have a low sense of self efficacy in engineering that causes her to worry about her performance often. This leads to a mild performance orientation to learning, striving to prove to herself that she does belong in engineering. When asked if she ever compared her performance on homework and exams, she responded,

> *"I do. I have a very bad habit of feeling incompetent compared to people in my major or something, so that's why. I don't have that competitive edge, but… I'm definitely not a competitive person at all. I know that sounds bad, but the thing is I always strive to do my best but it's just going for the best job and all those things are not as important to me I guess as with other people. But at the same time I feel incompetent sometimes. If I see people doing better on exams I sometimes question, you know why am I doing this? Like why am I doing engineering?"*

This low self-efficacy shows up in her content explanations where she is often not very confident in her explanations of the information. Countering this focus on performance is a stated goal to understand the information and a desire to work on problems she doesn't know how to do so that she can learn the information

Sonya reported positive feelings overall for the course, attributing most of that to the professor in the course. She also thought of the course as being useful, as indicated by the statements that this was the first course in her major and that this course was the foundation for more advanced learning.

Adaptive Map and Textbook Usage and Opinions:

Sonya did not use the Adaptive Map tool at all outside of the research sessions. This was reported on both the weekly surveys and in the interview. Sonya is a unique case because she was the only participant to report not using the Adaptive Map tool outside of the research sessions.

Sonya described the role of the textbook as a supplement to class, describing information that the professor did not get to discuss in class.

> *"I guess, my definition of it would probably be, the teacher is teaching you some information, but often the teacher doesn't have ample time to convey all the information that we need to know, and often times that's like background information, to like understand a specific topic. So I generally like textbooks that, it fills in the holes that teacher didn't really discuss if that makes sense."*

The primary out of class learning tool that Sonya reported using was her notes from lecture. With the exception of looking up homework problems, Sonya did not report using the paper textbook either. Sonya reported taking detailed notes during lecture and using those to review and solve homework problems. Her habit of taking very detailed notes can also be seen with the detailed notes she took during the CRESST preparation sessions.

Sonya's opinions of the tool were mixed. She did not like the concept map based navigation system, describing it as "confusing." She said she would have preferred a more traditional looking table of contents style navigation page that listed all the topic and sub topics and had links to all those pages. Her positive feedback on the tool was on the content. Sonya said the content information (both the text and the diagrams) was much easier to understand, particularly for people who had never seen the information before. Sonya also wanted more information on "how to actually solve problems," expressing a desire to see more worked examples and explicit procedural instructions.

When asked for an example of a good or bad experience she had with the tool, Sonya said she had a bad experience during the training before the first problem session. After being shown how to use the tool, she was asked to find a specific topic by the researcher. She was unable to find the topic and was eventually shown where to find this topic by the researcher. Since she reported not using the tool before this first session, this would have been her first unguided experience with the Adaptive Map tool.

CRESST Session 1 Preparation:

Sonya began her preparation for the first CRESST session by taking notes on Newton's Third law before opening any topic pages (she did not open the "Newton's Third Law Topic" page). Sonya then opened the "Multi-Component Assemblies" topic page and began taking notes on that page. From there she drew headings for trusses frames and machines in her notes.

Sonya appeared to go through the nodes one level at a time, left to right. This matches the way someone would read text, and indicated that she was not following the links from one topic to another. After the "Multi-Component Assemblies" topic page she went on to the "Two Force Members" topic page, then "Machines", then "Frames", and then to the "Trusses" topic page. Finally she went through the "Analysis of Frames and Machines," the "Method of Joints" and then the "Method of Sections" topic pages. She did not open the "Static Determinacy of Trusses" topic page.

During the preparation time, Sonya spent little time looking at the cluster map view, switching quickly from one topic to the next. When switching between topics, Sonya was also observed to zoom into topics to try and open the topic pages. With regards to the rest of the layout, this would be an intuitive way to open the topic pages but because of software limitations this action did not open the topic pages. She clicked on the nodes to open the topic pages after trying to zoom in several times. When Sonya did open pages, she generally spent time reading the topics carefully and did not revisit any topic pages.

Despite not spending much time examining the map and not following the links, Sonya's notes were organized in a similar way to how information was presented in the cluster map. She used the higher level pages to make a broad overview and then filled in the appropriate information from lower levels in the space she left on the page. The end result took the form of a hierarchy that matched the structure of the Adaptive Map tool. Since both the visual of the cluster view and the content itself could be used to create this structure though it is difficult to say exactly where she picked up the overall organization of her notes.

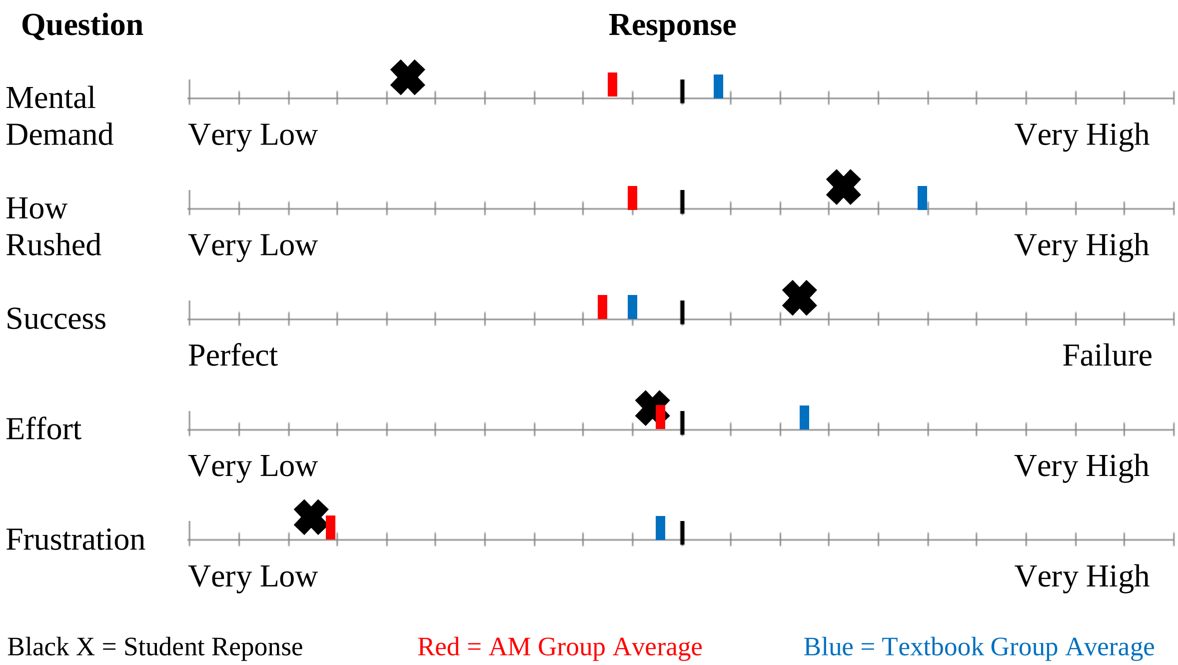


Figure 5.25: Sonya's CRESST Session 1 TLX Results

As seen in Figure 5.25, Sonya reported a below average cognitive load level, though she reported a higher than average level of being rushed. Overall effort, a backup measure of cognitive load, was reported to be average. She also reported a higher than average expected level of failure. This matches with the generally low self-efficacy described in the debriefing interview, though her explanation for the session scored higher than average on most scales (as discussed in the next session).

CRESST Session 1 Explanation:

Sonya began by addressing Newton's Third Law stating…

> *"Sonya: Okay so one of the basic things that we need to know before we kind of assess problems of multi-component assemblies, is Newton's Third Law, which states that for every force there is an equal and opposite for that kind of counteracts it I guess, that there is an opposite reaction, sorry."*

This does not meaningfully relate the Newton's Third Law to multi-component assemblies. After that Sonya changes subjects to multi-component assemblies, correctly explaining what they are, generally how they are analyzed, and explaining they are broken down into trusses frames and machines.

Sonya moves on from there to trusses, correctly explaining that they are rigid structures that consist entirely of two force members. She explains that if there are members that are not two force members that it is a frame or machine. Then she gives a short, but correct explanation that two force members have two equal and opposite forces in them.

Sonya then says that there are two ways to analyze trusses, "sections" and "joints". She explains the method of joints and then the method of sections through an example problem. Her explanations and calculations are correct, but at two points in the examples she adds external loads because the zero force members she finds "don't sound right." Sonya's examples do not cover finding external reactions first, usually an important first step in both methods. This step was not necessary in the examples though, because of the way that she set up her example problems and because of the fact she did not follow through with all of the joints or equations.

Next Sonya moves onto frames, quickly but correctly explaining what they are before moving on to how to analyze them. She then discusses the basic process of breaking down the frame into parts and analyzing each as a rigid body. While drawing a free body diagram of the first member, which is a two force member, she incorrectly adds two component forces to each end of the member. She does recognize that these forces need to be equal and opposite however, attributing this to static equilibrium.

Then Sonya correctly identifies the other member as a multi-force member and draws a correct free body diagram of this member. She correctly applies Newton's Third Law to the connection between the two members. When solving the equations of equilibrium she encounters problems solving for the unknowns because of the extra unknown she introduced through the incorrect free body diagram of the two force member.

Finally, Sonya explains that a machine is similar to the frame except that it is not rigid and that it is analyzed in the same way as frames. After that she says she has nothing more to cover.

The interviewer asks her to explain more about multi-force members and Sonya explains the difference through an example. She appears to know enough to correctly identify two force or multi-force members. She does not address why the two forces are equal and opposite though.

Then the interviewer asks her how Newton's Third Law, which she addressed at the beginning, relates to the information she talked about. At this point Sonya incorrectly associates Newton's Third Law with two force members, stating that is why the forces in a two force member have to be equal and opposite.

Finally the interviewer asks why forces on two force members have to be collinear through an example. In discussion, Sonya correctly identifies that the forces must be equal and opposite to be in equilibrium. Through discussion Sonya also cautiously explains that she things the member will rotate if the forces are not collinear, correctly relating the information to couples without officially mentioning couples.

Table 5.15: Sonya's CRESST Session 1 Rubric Scores

Category	Score
Principle Coverage	5/5 Moore
Prior Content	4/5 Moore
Conceptual Knowledge	4/5 Moore
Procedural Knowledge	4/5 Moore

As seen in Table 5.15 and Figure 5.26, Sonya addressed all topics in the prescribed topic area. Sonya grounded her discussion of Multi-Component assemblies in relevant prior content, but incorrectly connected Newton's Third Law to two force members and multi-component assemblies. Conceptually, Sonya had some difficulty with two force members. She was able to discuss them and draw correct free body diagrams of them while discussing trusses, but during discussion of frames she added two components two each end of a two force member. This was regarded as a minor misconception because it was drawn correctly at one point and incorrectly at another. Procedurally, Sonya omitted the step of solving for external reaction forces first in the Method of Joints and Method of Sections. She found some zero force members in her examples and was uncomfortable with the result so she added forces to eliminate the zero force members. This shows low confidence in her knowledge, but was not technically a procedural error. Sonya's misrepresentation of the two force member in her example for analyzing a frame, led to a minor procedural error in the analysis of frames and machines. Overall, Sonya was deemed to have two minor procedural errors in her explanation.

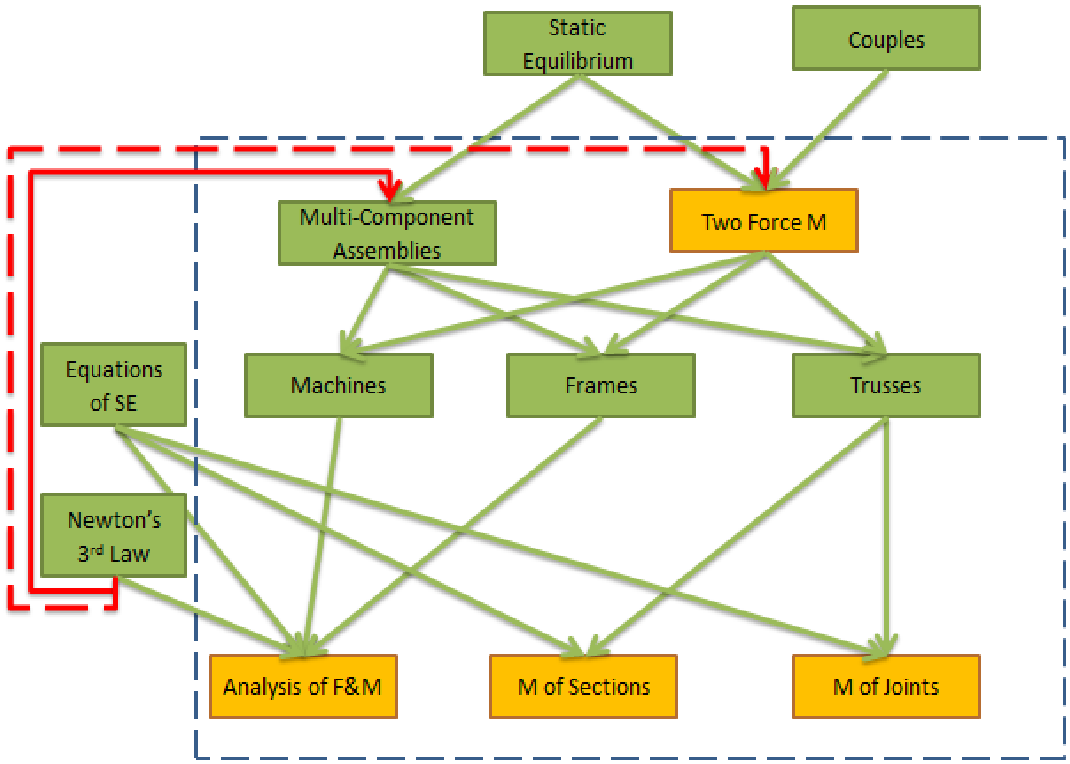


Figure 5.26: Sonya's CRESST Session 1 Explanation Concept Map

CRESST Session 2 Preparation:

Sonya started preparing for the second CRESST session by looking at the cluster view, and then clicked on and opened the "Distributed Load" topic page, which is outside of the prescribed cluster but connected to the central "Hydrostatic Pressure" node in the prescribed cluster. Sonya read the topic page carefully, taking just over ten minutes of the allotted twenty minutes and taking two thirds of a page of notes.

After reading the "Distributed Forces" topic page, Sonya navigated back to the "Hydrostatic Pressure" topic page. She opened the topic page and carefully read the information and took notes. As part of Sonya's notes, she copied down a diagram exactly from the topic page. Sonya stayed on this topic page until the end of the twenty minutes, finishing after reading about absolute pressure.

After the explanation session, Sonya was asked by the interviewer if she understood what the bounds of the prescribed topic area were. This was asked because she spent more than half of the allotted time outside of the prescribed topic area. She explained that she knew that this was outside of the topic area, but she also understood that it was essential to understand distributed forces to understand hydrostatic pressure and that she did not understand distributed forces well going into the session.

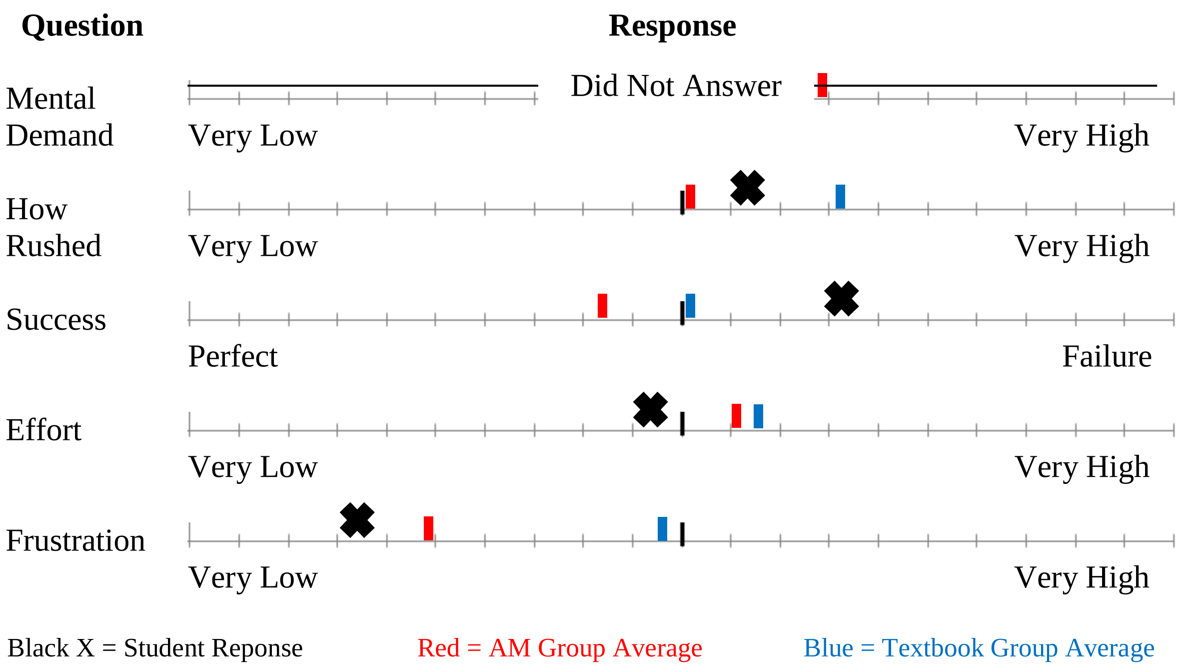


Figure 5.27: Sonya's CRESST Session 2 TLX Results

As seen in Figure 5.27, Sonya did fill in a value for the first item on the survey, leaving the researcher with only the secondary measure of cognitive load, the overall effort metric. This value was reported as being slightly below average. Again, Sonya reports a higher than average expected level of failure, matching her overall low self-efficacy. Other values were reported as being close to average.

CRESST Session 2 Explanation:

Sonya begins the session with the statement "Okay, so this section is about distributed forces…" and begins her discussion of fluid statics by introducing distributed forces without mention of how this relates to fluid statics. Sonya correctly explains how distributed forces differ from point forces and what the difference between body and surface forces are. Next there is an exchange with the interviewer in which Sonya has some confusion about the statement "same force and moment as the distributed force" she saw on the Distributed Forces topic page.

> *"Sonya: The surface force would be one where you see all the forces being applied on it and each one of these forces has the same acceleration and will produce the same moment…*
>
> *Interviewer: So sorry can I pause for a second. So you were talking about, these forces were exerting the same force and the same moment?*
>
> *Sonya: They were exerting the same acceleration.*
>
> *Interviewer: What do you mean by that?*
>
> *Sonya: Since...*
>
> *Interviewer: Like the same acceleration as what, is my question.*
>
> *Sonya: I mean all of them have the same exact acceleration. Which would probably be equal to... this... I am assuming that it means that, the sum of all the forces divided by the mass, maybe, I'm not quite sure."*

Sonya seems to be confusing all the little arrows in the diagrams of distributed forces exerting the same force and moment (which is an incorrect explanation), and the equivalent point load, which exerts the same force and moment as the distributed force.

Next Sonya moves on to explain that you cannot use directly in the equations of equilibrium, so you need to convert them to point loads first. After explaining this, Sonya revisits the questions posed earlier clears up the confusion she had about the "same force and moment" statement.

> *"And that's the equivalent point load and it has, yeah, this is the one, it has the same acceleration and it exerts the same moment as the distributed loads. Sorry I thought... cause.... Sorry."*

After that Sonya correctly explains that the equivalent point load can be used for external forces, but that it was not applicable to the analysis of internal forces.

After explaining distributed forces, Sonya moves on to hydrostatic pressure, the first part of the prescribed topic area that is discussed. In the introduction, Sonya correctly links her discussion of distributed forces to the new topic of hydrostatic pressure.

> *"So we move onto hydrostatic pressure, and that's where you have... It's a distributed force a liquid in equilibrium exerts on surface that are directly in contact with the fluid."*

Sonya goes on to give a correct description of what hydrostatic pressure is and to correctly describe the relationship to calculate the hydrostatic pressure in a liquid. Despite correctly explaining what each variable in the equation stands for, Sonya next goes on to do a sample calculation and plugs in an incorrect value for *h*, which should be the depth of the liquid, but instead Sonya plugged in the height of the liquid above the bottom of the container.

Next Sonya moves on to explain that there are two ways to measure pressure, gage and absolute pressure. She correctly explains what absolute pressure is and then states she did not have time to get to gage pressure. After that she states she didn't get to cover anything else.

The interviewer asked Sonya to expand on the relationship between distributed forces and hydrostatic pressure, and Sonya correctly answered that hydrostatic pressure is a type of distributed load. Next the interviewer asked how the discussion of equivalent point load related to hydrostatic pressure. This began an exchange on pressure and distributed loads, showing that Sonya thought they referred to the same thing, but was not confident in that.

> *"Interviewer: Okay. How might... You talked about the equivalent point load here, like how might that play into this, the hydrostatic pressure part?*
>
> *Sonya: Um... I think when we are solving.... Because essentially... All of these... I don't know if I can ask you a question but...*
>
> *Interviewer: Go ahead.*
>
> *Sonya: This is a bad question, but is a pressure like considered a force?*
>
> *Interviewer: I can't answer that right now.*
>
> *Sonya: Okay, let's just say yes for now. So all of these forces…"*

After assuming that pressure is a distributed force (pressure is a surface force specifically), Sonya goes on to explain that you would probably need to use the equivalent point load to replace the pressures with point forces. With this statement Sonya begins to address the information on the "Hydrostatic Pressure on a Flat Surface" topic page, though she does not specifically address this by name.

Table 5.16: Sonya's CRESST Session 2 Rubric Scores

Category	Score
Principle Coverage	2/5 Moore
Prior Content	5/5 Moore
Conceptual Knowledge	4/5 Moore
Procedural Knowledge	4/5 Moore

As seen in Table 5.16 and Figure 5.28, Sonya covered less than half of the material in the prescribed topic area. This reflects her preparation where she spent the majority of time outside of the prescribed topic area. The topics that Sonya does address are correctly and completely connected to the relevant prior content. Conceptually, Sonya is unsure if a pressure is a type of distributed force. She did end up correctly guessing that a pressure is a distributed force, but this uncertainty was regarded as a minor misconception. Though she only addressed the most basic topic within the assigned section, she had only one minor misconception, leading to a score of four out of five. Procedurally, Sonya correctly explains the relationship between pressure and depth, but during an example problem she measures depth from the bottom of the liquid to the point of interest. This conflicted with her earlier explanation and was regarded as a minor procedural mistake. Again, Sonya only addressed a single topic in the assigned section, but had only a minor procedural error so she received a score of four out of five. The low score for principle coverage here may be artificially inflating the conceptual knowledge and procedural knowledge scores.

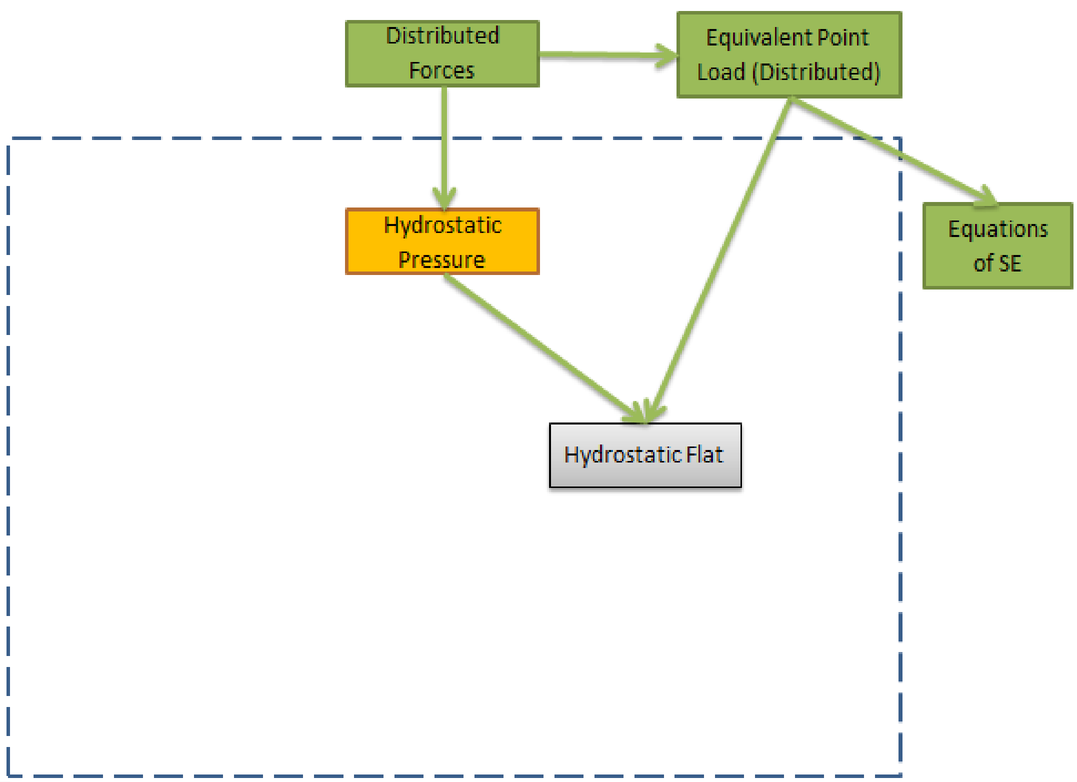


Figure 5.28: Sonya's CRESST Session 2 Explanation Concept Map

Case Summary:

Sonya was the only reported non-adopter of the Adaptive Map tool that was introduced to the tool in the research participant pool. For out of class learning, she reported using the detailed notes she took during lecture exclusively. Sonya did think that the content in the Adaptive Map was better than the paper textbook, but she did not like the concept map layout system and would have preferred a more linear navigation menu. When using the Adaptive Map tool during the CRESST sessions, Sonya moved slowly through the information, spending lots of time reading the more basic pages and taking extensive notes. The activity of taking and organizing notes (in which she created headings and then filled in details below the headings) may have served as a reflective activity that helped her connect new information to old. These observed behaviors may have been an established habit, a habit that she felt the Adaptive Map tool's layout interfered with.

Her explanations for both CRESST sessions were generally thorough and correct for the more basic information, and in the case of static determinacy in the first session and many of the more advanced topics in the second session, Sonya simply did not address the more advanced topics. These were the same topics she did not get to look at during the preparation.

Also of note, Sonya spent a significant portion of her second session reading information on distributed loads, which is prerequisite information for the fluid statics section. In her explanations she was able to correctly explain what distributed forces were and how they could be linked to the information in fluid statics.

Sonya also had low self-efficacy in engineering, which was apparent in the interview and on the NASA TLX surveys. This is also apparent from the low confidence she displayed in her explanations, saying "sorry" often and doubting the correctness of her statements.

5.6 The Traditional Textbook Student Profiles

This section presents the case profiles of the three research participants who were not introduced to the Adaptive Map tool and who used the traditional textbook during the data collection sessions.

5.6.1 Aaron

Background:

Aaron is a male student in the Mechanical Engineering Department. He is fluent in the English Language. Aaron states that he is in college to focus on academics and getting a good GPA so he can "get a better job right out of college". He says he may go for a master's degree as well, maybe in Industrial Systems Engineering, but his tone seems to indicate that this is a possible plan not certain one.

Aaron reports a course grade of "Hopefully a B," which is the second lowest reported course grade. He also reported a GPA of 2.90, which is also the second lowest reported GPA. Aaron's Statics Concept Inventory score of 7.4% is the lowest score of any research participant. Aaron seems to have a strong mastery orientation to learning, focusing on learning the content rather than looking good on assessments. This is indicated by his reported goal for the course,

> *"Definitely to use it to further my experience in college, and also outside as a resource. Maybe act as a tutor for others cause if they are struggling they can like come to me as a reference, cause I feel like I learned a lot."*

He reports preferring a combination of familiar and novel problems, familiar problems,

> *"So I know the material and in the one hand I understand that this is definitely the formula for this. This is definitely the angle for that."*

And novel problems because,

> *"…it is almost forcing you to know the material."*

Despite a strong mastery orientation to learning, Aaron places high value on grades because of his belief that a good GPA is the key to a good job.

Aaron reported mixed feelings on the course. He acknowledged that the course had the reputation that "everyone always said it was the worst course." And he said the tests were the worst part of the course. Despite this he said seemed to have positive feelings for the course outside of the tests stating that,

> *"I actually really liked the material. It was really basic concepts once you got down to simple steps, like it just clicked."*

He also reported positive feeling for the professor, stating that…

> *"Dr. Liao was a really good professor. He, like I said he did like baby steps and then more complex and so like if he took like a huge step and you were lost he would like work with you."*

Textbook Usage and Opinions:

Aaron was the heaviest textbook adopter, and reported using the textbook 2-3 times a week every week with only two reported "once a week" exceptions. During the final interview, Aaron reported "looking at the textbook at least 2-4 times a week" on average. He said this corresponded to the homeworks assigned every class as part of the course, and that if he did not have to look up the homework problems in the book he would have not used his textbook as much.

Aaron reported the role of the textbook to be one of the three sources of information in a course, where the other two sources are the lecture and the professor outside of class. Aaron said that he liked using the different sources, where he would listen to the professor in class and use,

> *"…the textbook so you can like look through and get a different perspective on the material."*

During the semester, Aaron reported using the textbook primarily to look up and then find information to solve homework problems. Aaron also reported using the book to study for exams. This set Aaron apart from the other two textbook group research participants in that they only used the textbook to look up homework problems.

Aaron's opinions of the book were mixed. He wrote down in the beginning that he thought it was a "good book." He found it easy to find topics in the book and he reported liking and using the end of chapter summaries. Aaron's main concern revolved around the overabundance of homework problems and the problems that caused.

> *"I feel like there was maybe like one to two pages of like textual work and then two pages of examples and then ten pages of homework problems. I feel like if you could even that out, like it would make it more, like simple. Instead of like cramming everything into a couple pages, to like spread out the text and make it a lot easier to understand. And sometimes I felt it was like hard to find the, like relate back in the text from where the homework was. And I felt like sometimes it wasn't like, like usually it's the text example problems and homework that like sometimes I had to go back further to actually like find the example for that problem."*

Aaron also felt that the book lacked simpler examples, despite having plenty of complex examples. He said he wished there was more of a mix that could build up to the more complex examples like Dr. Liao did. When asked for a good or bad experience, Aaron talked about the confusing and complex example problems, but said that they were better than nothing.

CRESST Session 1 Preparation:

Aaron began preparing for the first CRESST session by carefully reading from the first page and just working his way through the chapter linearly, taking notes as he went. He included section numbers in his notes for a short time but quickly discontinued this practice as he went on.

As Aaron went through the information, he spent a lot of time copying down example problems exactly as they appeared in the book. This can be seen in his notes on the Method of Joints, the Method of Sections, and space trusses. Because of the careful reading of the material and copying down the examples from the book, Aaron made slow progress through the chapter. As the end of the preparation time approached, Aaron did break from his linear progression and flip around within the chapter a little bit. He seemed to skim the sections on frames and machines, quickly taking notes as he went through this section.

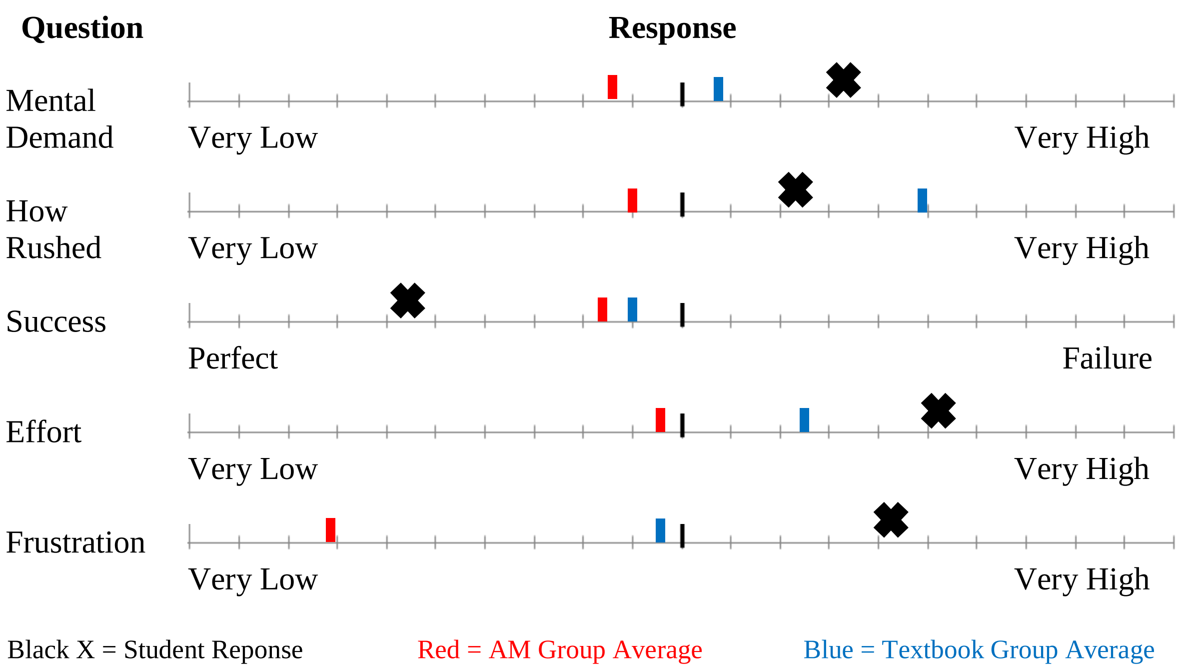


Figure 5.29: Aaron's CRESST Session 1 TLX Results

As seen in Figure 5.29, Aaron reported higher than average levels of cognitive load, backed up by his higher than average reported level of overall effort. Aaron also reported high levels of frustration, which is hypothesized to be linked to the change of pace required to finish within the twenty minute preparation time. Finally, Aaron reported a high level of self-reported success in the activity, despite the major misconceptions that are discussed in the following section.

CRESST Session 1 Explanation:

Aaron began instruction by saying that the chapter is based on structures, and that it is focused on the forces internal to the structure and that it deals with the action and reaction of connected members. This statement is pretty much read from his notes, and when asked to define a structure, Aaron seems to avoid defining what a structure is and instead gives some examples of structures.

Next Aaron moves onto trusses, and specifically plane trusses. Aaron gives a correct description of what trusses are, identified the key elements to be built from basic triangles, two force members (though he never actually says two force members he just describes them) and the connections, though he doesn't indicate all internal connections need to be pin or ball and socket joints for plane or space trusses respectfully, which is a key fact regarding the connections in trusses.

Next Aaron moves on to say that there are two methods for solving trusses, but only mentions and goes into the Method of Joints at this point. He explains the Method of Joints by going through an example he got from the book. Aaron omits the step of determining the external reaction forces before solving forces joint by joint, which is a procedural omission, but otherwise his example is procedurally correct. At the end of the example, Aaron goes into a special case proving that when three members come together and two are collinear, the forces in the collinear members are equal and opposite and the third member has no force in it. His explanation of the case is correct.

Next Aaron moves on to the Method of Sections, and again he quickly moves into a specific example to illustrate the method. He again omits the step of solving for external reaction forces first (a procedural omission) but other than that his example is correct. At one point in his explanation he refers to making a maximum of three cuts, and the following interaction showed a lack of understanding of why three is important.

> *"Interviewer: So, why, why is three kind of the magic number?*
>
> *Aaron: Um… I guess when you cut more you will have more unknowns than needed. And so three specifically you can, you can knock it out by doing just one equilibrium equation. If you do more you are going to end up with more unknowns and that just makes the problem tricky because you have to do simultaneous equations."*

Three is important because you can have up to three equations per section in a plane truss, and therefore that is the maximum number of unknowns you can solve for per section. He makes the connection between more cuts and more unknowns, but even with three cuts, you will often need to solve simultaneous equations.

Next Aaron moves on to discuss special a special case regarding K trusses, where you can use the Method of Sections with four cuts. Aaron identifies that you need two moment equations to solve for the extra unknown, which is incorrect; you need to make two cuts to solve for all the unknowns and there is a single moment equation for each.

After that Aaron discusses a "special case" that is simply using both methods together, starting with the Method of Sections and then moving outward with the Method of Joints. His description of this is brief, but is correct.

Next Aaron moves onto space trusses. He downplays the importance of space trusses, stating that,

> *"I do not believe that you need to know a lot about. I just wasn't taught that much and there wasn't much in the book."*

Aaron seems to understand that space trusses are the three dimensional counterpart to plane trusses and that you still "deal with" the Method of Joints, Method of Sections, and "structures." He states that there are forces in the X, Y, and Z directions for forces, which is correct. When later asked how the processes for the Methods of Joints and Methods of Sections differed he said he did not know how they were different and again downplayed the importance of space trusses, indicating they were not important for mechanical engineers.

> *"I didn't take too much time to look into it because, I didn't really think it was… I didn't really need to know that, unless you are going into aerospace or NASA, but I didn't think, especially with space trusses you didn't really need to know it."*

Aaron illustrated space trusses with an example drawn from the book, but had a major misunderstanding of the diagram, not understanding that the box drawn was actually the members in the truss.

After space trusses, Aaron began discussing frames and machines. He said that multi-force members were in frames and machines, which is the distinguishing factor, but did not offer an explanation of what a multi-force member was before going into how to analyze frames and machines. Aaron used two examples (one of a machine and one a frame) to explain frames and machines and to explain the process used to analyze frames and machines. Aaron said the key point analyzing frames and machines was to separate the frame or machine into separate bodies and to use Newton's Third Law to draw in the interactions. This is correct, but Aaron used an example of a machine of a pair of pliers that was separated into four bodies, rather than the appropriate two bodies. This shows some difficulty identifying the bodies to separate, though Aaron's understanding of the process of separating and using Newton's Third Law to draw the pairs of interactions seems to be correct. Along the way Aaron also makes the mistake of saying that any set of members can be analyzed independently, when only independently rigid sections can be analyzed with the equations of static equilibrium. This is a minor procedural error.

At this point Aaron stopped leading the discussion and the interviewer asked clarifying questions. First, the interviewer asked Aaron to distinguish between trusses, frames and machines and there was an unclear distinction given between the types of structures.

> *"Interviewer: Like what's the difference between frames, machines, and trusses?*
>
> *Aaron: I think they all like correlate together. A machine is like a specific instrument like you said in the diagram that, pliers. A frame could be, um, like an example a chair. And then a structure, like I believe that, like it is a truss. Like just a structure is much bigger, like a bridge or crane or something like that."*

He seems unaware that trusses frames and machines are all types of structures and unaware of the defining characteristics of each type of structure, though he could give some examples of each. When asked if the Method of Joints and Method of Sections could be applied frames and machines, Aaron said they probably could be applied (which is incorrect), though he didn't see any examples of this. Aaron attributed this to the fact that frames and machines were smaller than trusses.

Next the interviewer asked Aaron what two force and multi-force members were. He responded by again giving some examples. The examples he gave were in fact two force members, though he made an error drawing in the direction of the force in a curved two force member. When pushed about what makes something a two force member or multi-force member, Aaron stated that external forces on the member made it a two force member (which is incorrect).

Finally the interviewer asked Aaron to give more details on the Method of Joints (trying to test his understanding of the connection to the equations of equilibrium). Aaron in this interaction showed that he did in fact know how to create the equations of equilibrium within the Method of Joints (and presumably within the Method of Sections too).

Table 5.17: Aaron's CRESST Session 1 Rubric Scores

Category	Score
Principle Coverage	5/5 Moore
Prior Content	3/5 Moore
Conceptual Knowledge	2/5 Moore
Procedural Knowledge	4/5 Moore

As seen in Table 5.17 and Figure 5.30, Aaron covered all of the topics in the prescribed topic area. Aaron connected some relevant outside topics to the prescribed topic area, but had misconceptions about two force members and did not link it to any relevant prior content. In addition to having major misconceptions about two force members, Aaron seemed unable to distinguish between trusses and frames and machines, he had misconceptions about what space trusses were, and misconceptions about static determinacy. His misconceptions about two force members and trusses were regarded as major misconceptions. Procedurally, Aaron correctly described the Method of Joints and the Method of Sections. Aaron also correctly described the process for analyzing frames and machines, but was not able to correctly identify the bodies to separate in his example problem. This was regarded as minor procedural error.

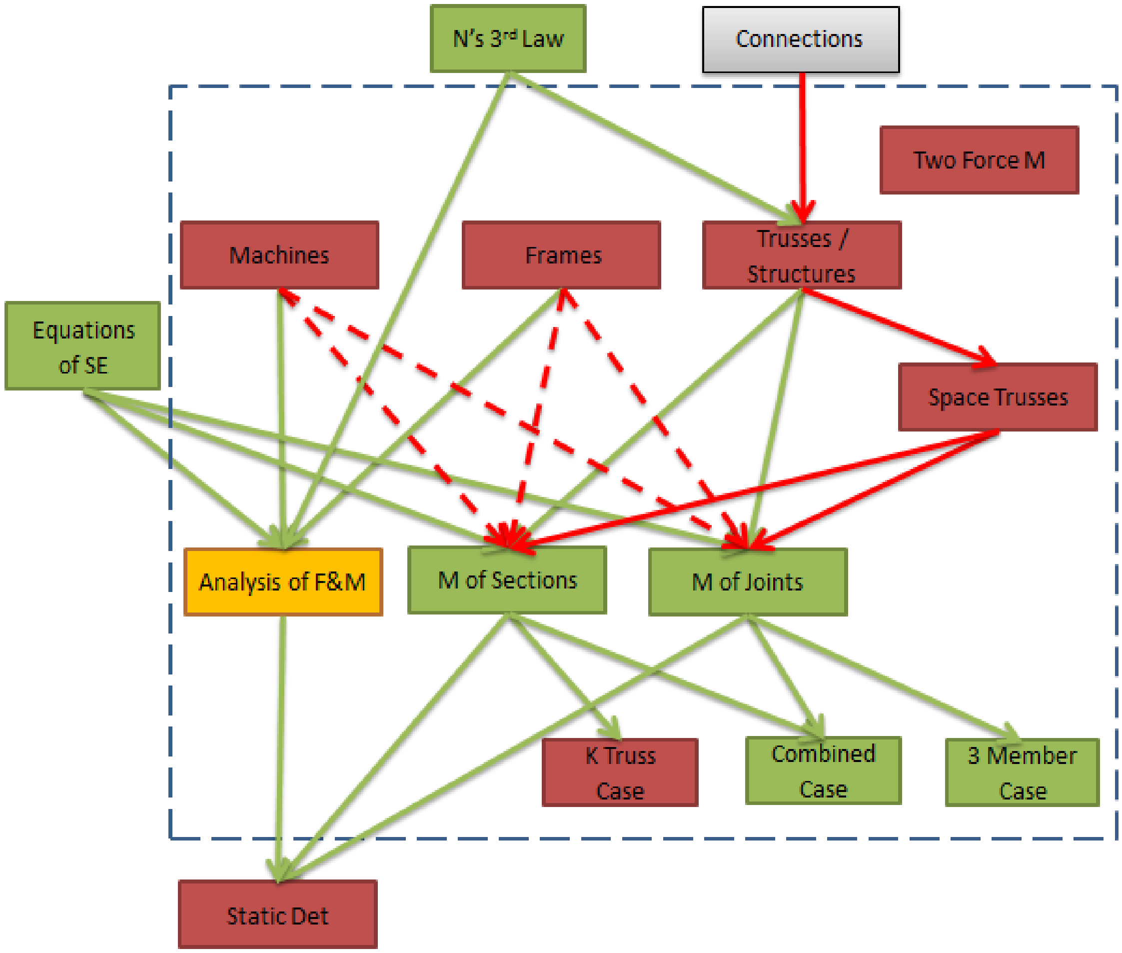


Figure 5.30: Aaron's CRESST Session 1 Explanation Concept Map

CRESST Session 2 Preparation:

Aaron started at the beginning of the fluid statics section, carefully reading the information and taking notes. Aaron spent a full seven minutes on the first page, and had taken nearly a full page of notes. He continued to read carefully through the section linearly for a while, taking detailed notes. At one point he did flip through the pages, appearing to count the pages left to the end of the section.

When given a four minute warning from the interviewer, Aaron flipped to the end of the chapter and read the end of the chapter summary. He took notes on this and then flipped back to the beginning of the section. The last few minutes of preparation time were spent flipping around the section, sporadically adding pieces to his notes.

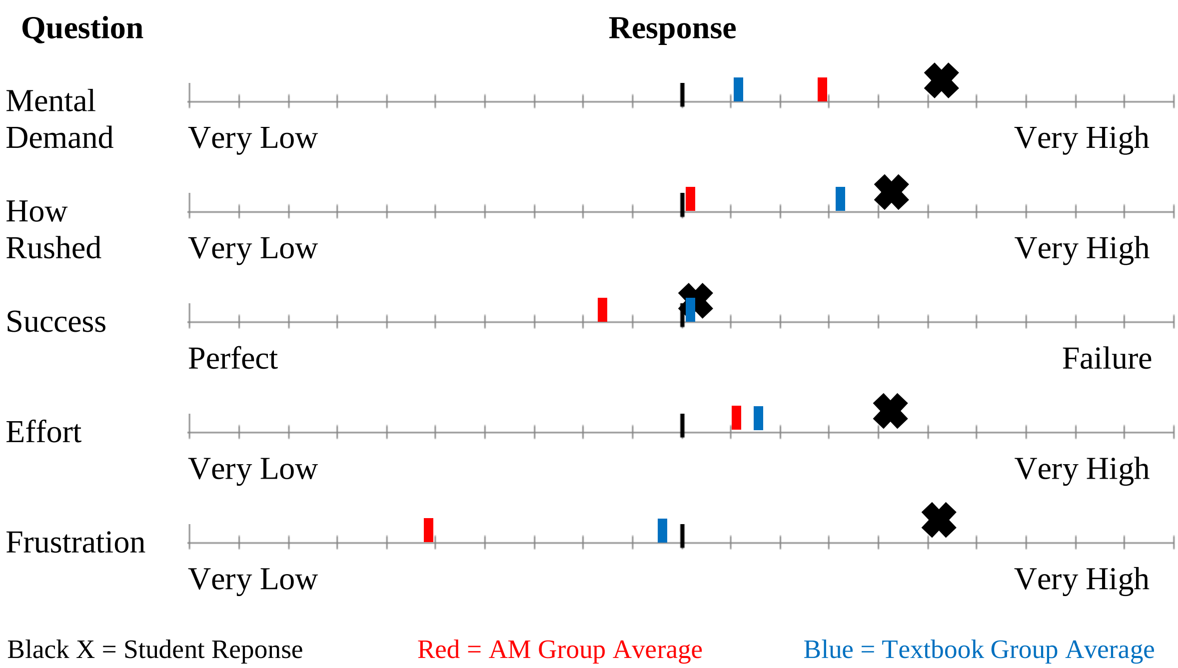


Figure 5.31: Aaron's CRESST Session 2 TLX Results

In Figure 5.31, we can see that Aaron reported a higher than average cognitive load level and a higher than average overall effort level. Also of note, Aaron reported much higher level of frustration that any other research participant for the second CRESST session.

CRESST Session 2 Explanation:

Aaron begins by explaining what a fluid is and that it cannot support any shear forces. He provides correct explanations of Pascal's law and another derivation found in the book, but does not explain the significance of these proofs. After that he introduces the equation used to calculate hydrostatic pressure $P = Po + rho\ g\ h$. However, upon probing by the interviewer, Aaron only correctly identifies what one of the four variables represents (g in this case).

"Interviewer: Okay, can I ask some questions here. So we will start with this equation, so you have been talking about pressure, what is this P naught again?

Aaron: Initial pressure.

Interviewer: So like…

Aaron: So like before you apply the pressure how much the pressure is. On the object, like I guess when it is at rest.

Interviewer: Okay, then you said density, like density of what?

Aaron: The density of the object that the pressure is applying to.

Interviewer: Okay. Then g is?

Aaron: The acceleration force of gravity. Height is the height of the object."

Aaron next discusses hydrostatic pressure on a submerged rectangular surface. He correctly introduces two different formulas to calculate the resultant force *R*, but again does not seem to know what many of the variables stand for, including at least *b* and *h-bar*. When asked by the interviewer how this related to the hydrostatic pressure discussed earlier (*P = Po + rho g h*), Aaron was not able to correctly identify a connection.

Aaron then moved on to discuss hydrostatic pressure on cylindrical surfaces. Aaron states that this is similar to the hydrostatic pressure on a rectangular surface, except that you have two resultant forces. He gives equations to solve for these resultant forces, but again, when probed by the interviewer, he was unable to correctly identify what many of the variables stood for (including *dx* and *dy* at least). He also drew a diagram of a potential scenario (a cylinder submerged in water) that does not match the assumptions of the equations he was using.

Next Aaron discussed hydrostatic pressure on any shape, but gave an equation that was valid for any flat shape. The interviewer does not question Aaron's understanding of these variables, so it is unclear if he understands the equation - but most of the variables carry over from previous equations discussed.

Next Aaron discusses the topic of buoyancy. He immediately states that buoyancy is equal to the product of density, gravity and volume, which is correct. When questioned by the interviewer, Aaron is incorrect in his interpretation of the density and he flips back and forth on his definition of the volume, ending on an interpretation that is correct. Aaron also discusses the difference between the center of buoyancy and the center of gravity, though he is not able to correctly identify why they are different and he does not offer an explanation of the relevance of the center of buoyancy.

Next the interviewer asks how the topics presented here relate to distributed forces. Aaron starts with an incorrect connection, but then Aaron changes the explanation and indicates that fluid static pressures are distributed forces.

> *"Interviewer: I want to go back and ask questions about the beginning. So I told you earlier this relates to… this kind of builds on distributed forces, so how is fluid statics related to distributed forces?*
>
> *Aaron: It applies to like the load, it is applied in, so you have a distributed force to maintain the balance of the object. Like if it was submerged in water there has to be a force, uh a resultant force so I feel like… uh, I take that back. There is like a distributed force, like in loads, like there is a resultant forces and there is when it's submerged in water as well cause it's kind of like pressure is applied to the object. It's the same thing as like applying a force to a truss or a beam. That's how I think they relate."*

Table 5.18: Aaron's CRESST Session 2 Rubric Scores

Category	Score
Principle Coverage	5/5 Moore
Prior Content	2/5 Moore
Conceptual Knowledge	1/5 Moore
Procedural Knowledge	2/5 Moore

As seen in Table 5.18 and Figure 5.32, Aaron addressed all topics in the prescribed topic area. Aaron connected the discussed topic to distributed forces only after prompted by a question from the interviewer. Conceptually, Aaron did not indicate an understanding of any of the core concepts. Aaron relied heavily on equations and was unable to explain what variables many stood for in the equations or connect of most of the topic areas to one another. Procedurally, Aaron's lack of understanding of what most of the variables stood for in the equations meant that Aaron had major procedural errors in all of the topic areas.

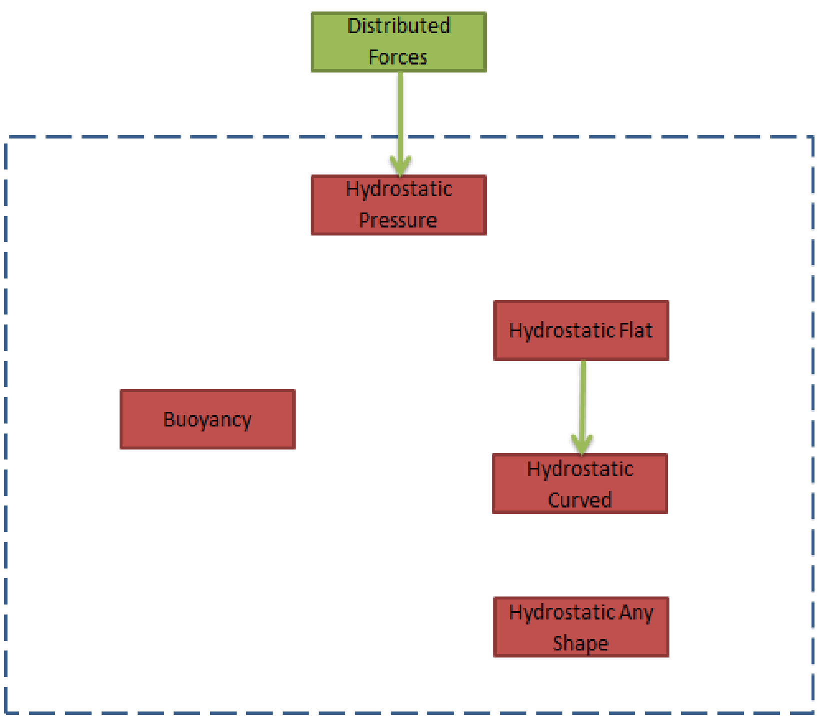


Figure 5.32: Aaron's CRESST Session 2 Explanation Concept Map

Case Summary:

Aaron was the only regular textbook user in the research participant pool, primarily using his textbook to help him solve homework problems. Aaron stated that he though the textbook was a "good book" overall, but wanted more in terms of explanations and worked example problems. In preparing for the CRESST sessions, Aaron seemed to move slowly and linearly through the material and had to speed up to get through the information in each twenty minute session. He relied on many examples and equations for his instruction, but often failed to grasp what the variables in those examples and equations represented. He also seemed to have difficulty identifying the key concepts in any given chapter. He spent little or no time explaining core concepts (such as the difference between trusses, frames, and machines) and spending lots of time on overly detailed information (such as how to solve K truss problems). Aaron also reported higher than average cognitive load and frustration for both CRESST sessions.

5.6.2 Carol

Background:

Carol is a female student in the Aerospace Engineering Department. Carol is fluent in the English Language. Carol is also a member of the Virginia Tech Corps of Cadets; meaning that she indicates a commitment to join the military upon graduation. Because of her commitment to the military, Carol did not have any concerns about getting a job upon graduation like many other students discussed.

Carol reports an expected course grade of "A or A minus" which is the second highest reported course grade. Carol also reported a GPA of 3.43, which is also above the self-reported average. Her Statics Concept Inventory score of 40.7% puts her above the average for the Statics Concept Inventory. Carol has a strong performance orientation to learning, indicated by a course goal of getting and A or A minus, her admitting that she is competitive and that she compares course performance to others, and her preference for solving problems that are familiar to her.

When asked about her opinions about the course, Carol seems to talk about the course as if it was an obstacle to overcome.

> *"Carol: Um, I didn't think it was hard, it was just… the only part that was hard about it was the little details, the little small algebra mistakes or the fact that one little thing could mess up your whole problem. One little number.*
>
> *Interviewer: So is it tedious?*
>
> *Carol: It was very tedious I think."*

Textbook Usage and Opinions:

Carol reported using the textbook about 2-3 times a week with only one exception on the weekly surveys, and she reported using the textbook "1-2 times a week" on average in the debriefing interview. She said this corresponded to the weekly homework assignments in the course. Carol reported using the textbook almost exclusively to look up the homework problems. She reported using the textbook once to look up information to solve the homework problems and once to study for a test. Other than these occasions she reported that she only looked up the homework problems and then used her notes for everything else.

Carol reported the role of the textbook as something that reiterates and expands upon what is taught in lecture.

> *"Um… I think it should be used as like a reference if something taught in the class isn't clear, something that can be used to like go back and look up whatever it is that you're not sure about. And learn more about it, learn more in depth about it."*

Overall, Carol reported only negative opinions of the textbook. She stated that "it was sometimes hard to find information" and that it "doesn't give many in depth examples". When discussing the difficulty in finding information, Carol brought up a specific example from her experience. She did not remember the subject, but she was solving a homework problem and could not find the information she needed in the chapter the homework problem was in.

"It wasn't, there wasn't really much that could help me in the book."

In terms of the more detailed examples, Carol suggested the best way to improve the book would be to add more advanced examples. She describes the worked examples given as more "general" and wanted examples that better matched the more advanced homework problems she was required to solve. Overall, it is clear from Carol's discussion of the tool that she wants a textbook that is optimized to help her solve homework problems, and she doesn't feel that this textbook fills this role.

CRESST Session 1 Preparation:

Because Carol arrived at the first session with a broken dominate arm which slowed down note taking, she was told she would be given more than the prescribed twenty minutes to prepare (she was given thirty minutes). When the preparation session began, Carol began reading the first page of the chapter. She moved slowly and linearly through the content, carefully reading each page and taking extensive notes. Carol was still able to write, though it seemed to take more time and effort because of her broken arm.

Upon getting to the section on the Method of Joints, it was noticed that Carol copied down an entire worked example problem in detail. About the time she finished copying the worked example was the twenty minute mark. At this point she seemed to notice the time and her pace changed. She moved more quickly through the rest of the chapter (about two thirds of the section remained), taking more limited notes. The entire rest of the chapter took her five minutes to go through. Upon getting to the chapter summary, she reported that she was ready.

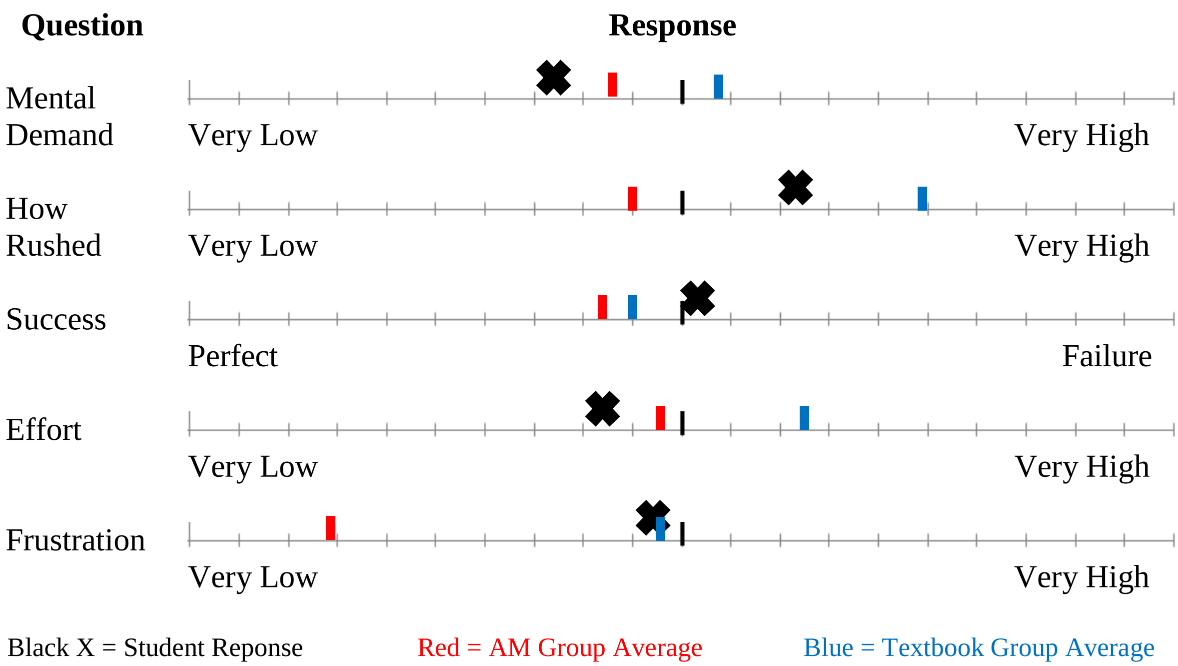


Figure 5.33: Carol's CRESST Session 1 TLX Results

As seen in Figure 5.33, Carol reported lower than average values for cognitive load and for effort for the textbook group. Other reported values are close to the averages.

CRESST Session 1 Explanation:

Carol begins with the statement,

> *"Okay, the first thing we will start with is plane trusses, um the base for this is a triangle, its three bars joined by pins and that makes a rigid frame. Um... a simple truss is a structure built from basic triangles..."*

Carol then explains that plane trusses are made entirely of two force members, and briefly but correctly explains what a two force member is. Carol also states some other necessary assumptions for plane trusses.

Next Carol begins explaining the Method of Joints, saying that the method looks at the concurrent forces on joints. Her explanation of the process is correct, except for two things. First, she omits the step of solving for the external reactions first, a procedural omission. Second, when probed for why moments are not used in the Method of Joints, Carol incorrectly says the moment equations can be used.

Carol then jumps to external redundancy and static determinacy. She says that the problem solver needs to make sure that there are at least as many equations as unknowns, though she does not discuss a way to predict this before writing out the equations.

Next Carol jumps back to discussing the Method of Joints. Carol goes through an example problem that she copied from the book. Here Carol does solve for the external reaction forces first and does not use moment equations, in contrast with the mistakes in the general process discussed earlier. Carol goes through the problem in detail and has no flaws in the worked example problem.

After discussion on the Method of Joints, Carol moves on to discussion on the Method of Sections, also indicating this is used for trusses. Carol uses an example to correctly illustrate the method. She spends much less time on this method, however; than on the Method of Joints. At the end of the explanation Carol also briefly mentions that the two methods can be applied together to analyze trusses.

Next Carol states that space trusses are 3D versions of plane trusses, and that they are analyzed in similar ways using the Method of Joints and Method of Sections. She correctly states that the two force equations are replaced three force equations, but she does not seem to understand that the one moment equation is replaced with three moment equations.

Next Carol correctly defines a frame or machine as something that contains at least one multi-force member. When asked what a multi-force member is however, Carol incorrectly identifies it as a member with more than one force at one connection point. The interviewer asks Carol if she could draw a multi-force member. Carol draws an example of a pulley that is correctly identified as a multi-force member.

Using the example drawn of a multi-force member, Carol expands the diagram out to a machine and begins explaining how to analyze a frame or machine. She correctly identifies the main point of separating the bodies and analyzing them separately, but Carol adds too many forces to the two force members in her example diagram. During the process of explaining how to analyze frames and machines, Carol also correctly ties in Newton's Third Law to the process.

After Carol finishes discussing the method used to analyze frames and machines, the interviewer asks Carol if there is a difference between a frame and machine. Carol says that there is, and she seems to understand that machines move but frames do not, but she is not able to formally define the difference between the two types of structures. Carol also correctly identifies that they are analyzed in the same way.

Carol says she has covered everything, so the interviewer asks more questions. The interviewer first asks what the chapter is about, what trusses, space trusses, frames, and machines are all called. She responds by saying,

> *"Carol: It's about trusses I guess. Members, force members.*
>
> *Interviewer: So you said it's about trusses, are frames and machines types of trusses then?*
>
> *Carol: Yes"*

Here Carol incorrectly identifies all structures as types of trusses.

Next the interviewer asks questions about two force members. During discussion it becomes clear that Carol is unclear what a two force member is an how to identify a two force member. Carol at one point states that no external forces can act on the two force member, and then when discussing an example from a truss, Carol makes an exception for external forces that do not line up with the line between the connection points.

Table 5.19: Carol's CRESST Session 1 Rubric Scores

Category	Score
Principle Coverage	5/5 Moore
Prior Content	4/5 Moore
Conceptual Knowledge	2/5 Moore
Procedural Knowledge	4/5 Moore

As seen in Table 5.19 and Figure 5.34, Carol addressed all topics in the prescribed topic area. Carol connected the discussion to relevant prior content, though she did discuss static determinacy without connecting the topic to the prescribed topic area. Carol has some major misconceptions about two force members, and has misconceptions about what trusses, frames, and machines are. Procedurally, Carol's explanations are correct but she makes an error in her example of analyzing frames and machines. This was deemed a minor mistake.

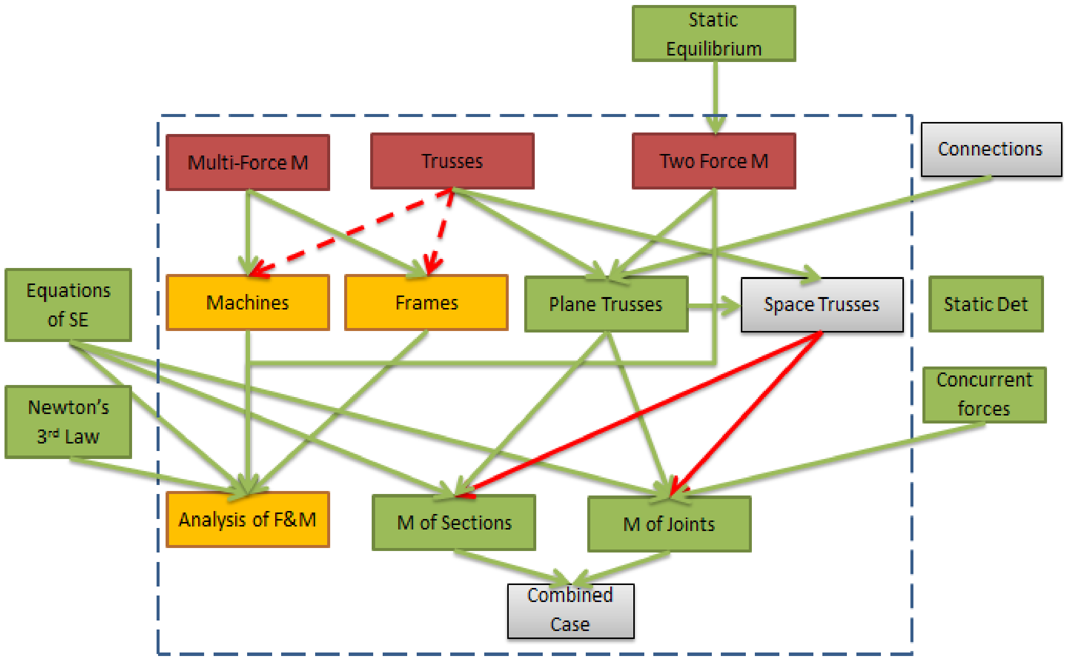


Figure 5.34: Carol's CRESST Session 1 Explanation Concept Map

CRESST Session 2 Preparation:

For the second session, Carol was again offered additional time to prepare because of a broken arm but only took the standard twenty minutes. She started by reading from the first page. She read through the information slowly and carefully, taking extensive notes. It was also noticed that Carol seemed to focus on copying down the equations, rather than explanations or examples.

After reading through the section for a while, Carol at one point flipped ahead to the end of the section. She seemed to be seeing how many pages were left in the section. After flipping through, she returned to where she left off and continued to work linearly and carefully through the section.

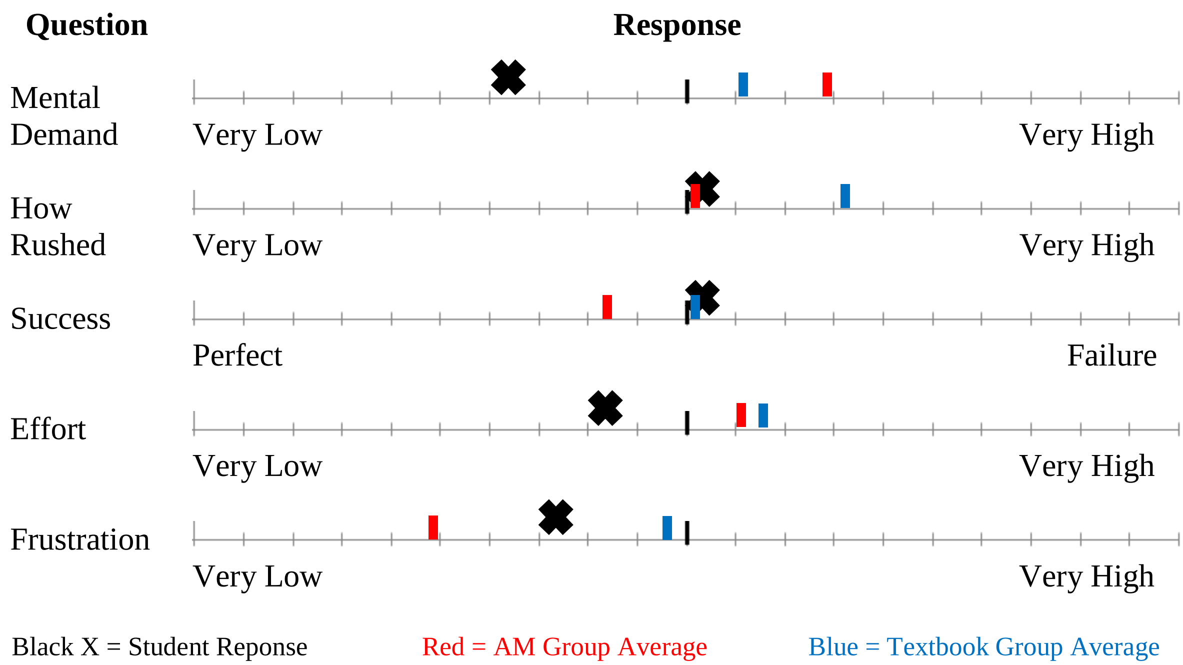


Figure 5.35: Carol's CRESST Session 2 TLX Results

As seen in Figure 5.35, Carol reported a lower than average value for cognitive load, which is supported by a lower than average value for overall effort. Reported values for the other metrics are around the average.

CRESST Session 2 Explanation:

Carol begins with the statement…

> *"Okay, we'll start with pressure, the pressure at any given point the same in all directions which is Pascal's law. If you were to calculate the equilibrium in the X and Y directions, the equation for this is P1 dy dx is equal to P3 ds dz sine theta or P2 dx dz is equal to P3 ds dz cos theta. And these, in order for these to be true, P1 must be equal to P2 which is equal to P3, which is equal to P. In the h direction..."*

The interviewer asks her what this means, but Carol's phone rings and interrupts the session before she can respond. Carol does not answer the question upon returning to the discussion.

Carol then goes on to explain the relationship between pressure and depth as *P = rho initial + rho g h*. Here she incorrectly identifies the *P naught* as *rho naught* and incorrectly identifies the two rho variables as "pressure constants," which is incorrect.

Next Carol moves on to discuss pressure on a submerged rectangular surface. Here Carol incorrectly states that the pressure is uniform across the surface, rather than varying with depth. She does correctly state however that the pressure needs to be converted to a single point load. Carol identifies formulas to determine the magnitude and placement of this point force, but when the interviewer questions her about what the variables represent in her equations, she is unable to correctly identify what a number of the variables represent in the equations. This would lead to major issues applying the formulas she has given.

Next Carol moves on to discuss hydrostatic forces on a cylindrical surface. She gives equations to solve for the magnitude of the equivalent point load, but does not address point of application. Carol moves through this topic too quickly to determine a measure of understanding.

Next Carol begins to discuss hydrostatic pressure on any flat surface. Carol quickly skims through the derivation of a formula and states the final formula for the magnitude and point of application. However, when the interviewer asks what some of these variables represent, Carol misidentifies a number of the variables.

Carol then moves on to Buoyancy, starting with the interaction below.

> *"Carol: Finally for buoyancy, um, buoyancy has to act in the center... or along the center line of the object. And its equal and opposite to your mg. And it cancels it out. So buoyancy is that force which counteracts mg. So your force is rho times g, gravity times the volume.*
>
> *Interviewer: Okay, so this is the force that is making things float?*

Carol: Yes.

Interviewer: And rho is... sorry, what is rho again?

Carol: Pressure.

Interviewer: Okay, pressure and g is gravity?

Carol: Or, rho is the constant. The constant for water or whatever fluid you are in.

Interviewer: Okay. And V is?

Carol: Volume.

Interviewer: Okay, volume of what?

Carol: It's the volume of your liquid.

Interviewer: Okay, so the...

Carol: Or the volume of your object.

Interviewer: So which one?

Carol: Um... the volume of your liquid."

Here Carol shows two clear misconceptions, first that the buoyancy force is always equal and opposite to the weight, and second that the volume variable is either the volume of the liquid or the volume of the object, both of which are incorrect. When asked why buoyancy forces are always upward forces, Carol incorrectly attributed this to equilibrium, stating that the buoyancy force had to counteract the weight.

After this, Carol declared that she was done. The interviewer asked her how this information related back to distributed forces, as it was introduced as building on distributed forces. Carol responded,

"The pressure is like the same, like acting on the rectangles. So I guess that would be kinda like that."

Table 5.20: Carol's CRESST Session 2 Rubric Scores

Category	Score
Principle Coverage	4/5 Moore
Prior Content	2/5 Moore
Conceptual Knowledge	1/5 Moore
Procedural Knowledge	2/5 Moore

As seen in Table 5.20 and Figure 5.36, Carol covered all but one topic in the prescribed topic area. In terms of prior content, Carol incorrectly related static equilibrium to buoyancy and connected distributed forces to hydrostatic pressure only after prompted by the interviewer. Conceptually, Carol did not indicate an understanding of any of the core concepts. Carol relied heavily on equations and was unable to explain what variables many stood for in the equations or connect of most of the topic areas to one another. Procedurally, Carol's lack of understanding of what most of the variables stood for in the equations meant that Carol had major procedural errors in all of the topic areas.

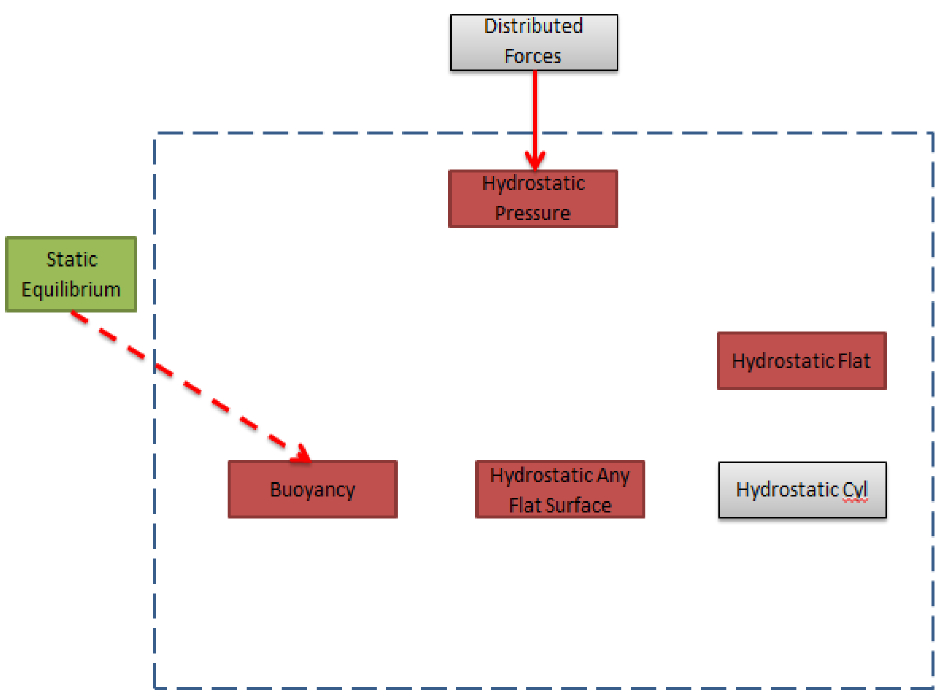


Figure 5.36: Carol's CRESST Session 2 Explanation Concept Map

Case Summary:

Carol was a textbook non-adopter, using her textbook almost exclusively to look up homework problems. Additionally, Carol had negative opinions of the textbook, stating that it was hard to find information and lacked more advanced and specific examples. In preparing for the CRESST sessions, Carol seemed to move slowly and carefully through the material, speeding up considerably when time was seen as running out. At no point did Carol get an overview of the information, though the end of chapter summary was available to her. She relied on examples and equations heavily in her explanations and had major misconceptions across both sessions. Additionally in the second CRESST session, Carol did not relate any of the topics to one another, which resulted in a very fragmented explanation.

5.6.3 Ryan

Background:

Ryan is a male student in the Aerospace and Ocean Engineering Department. Ryan states that he is specifically looking to get a degree in Ocean Engineering. Ryan is fluent in the English language and does not discuss his plans beyond college.

Ryan reports an expected course grade of "B+," which is the third highest reported course grade. His Statics Concept Inventory score of 44.4% is also the third highest out of all research participants. Ryan seems to have a mild mastery orientation to learning, though he sees grades as being critical to getting a job. This is shown in the interaction below.

> *"Interviewer: So what are your goals with respect to this course?*
>
> *Ryan: To get an A. [laughs]*

> *Interviewer: Okay, so grades are important to you in this course?*
>
> *Ryan: Well grades are important to employers."*

He later states that,

> *"I only care about learning the material so I can do well in my next course. Cause it is really cool stuff we learn in there. For the first time in engineering, you know coming in as a sophomore after last year as a freshman we just learned like math, and now like applying math to problems that could potentially be real."*

This indicates a mastery orientation, but a high utility to having good grades.

Ryan seemed to have positive opinions of many aspects of the course, particularly the instructor of the course.

> *"The statics course that I experienced was taught really well. As long as I paid attention I understood things I didn't have to go to office hours, or ask for help, or consult a textbook so I thought the class was taught really well and the tests were fair. And the amount of homework was enough."*

Textbook Usage and Opinions:

Ryan reported using the textbook about twice a week in the weekly surveys and in the final interview. He reported using it exclusively to look up homework problems that were assigned to him. Once he copied down the problems, he reported using his course notes to get the information needed to solve the problems.

When asked about the role of a textbook, Ryan said that a textbook should be able to act as a stand-alone learning tool if needed.

> *"A textbook should be able to teach you the material on its own, unless it's a supplementary textbook to the class. A textbook in my mind, I should be able to sit down with a textbook and learn everything I need to learn for a class without having to go to any lecture ever."*

Ryan went on to say that because the lectures were good enough, he didn't need the textbook for homeworks or tests. He did believe that this textbook would be good enough to fill that role if needed though.

When asked about his opinions of the textbook, Ryan reported that it was “a pretty standard textbook.” As stated above he thought the textbook could serve as a stand-alone learning tool if he did not already get the information he needed from lecture. Ryan felt that information was easy to find and that the example problems were easy to follow. He did report that he wished there were more worked examples though and that there were more instructions on how to analyze more specific scenarios.

CRESST Session 1 Preparation:

Ryan began preparing for the first CRESST session by quickly flipping through the chapter in the textbook. He seemed to be skimming though the information quickly, most likely reading the section headings. After flipping through the chapter, Ryan went back to the beginning of the chapter and began reading the material more thoroughly.

As Ryan went through the material linearly the second time, he spent more time carefully reading the pages and the example problems. Ryan also spent time looking at the worked examples and spent time copying down several of the diagrams into his notes.

By the end of the preparation session, Ryan was reading the chapter summary. While he read the chapter summary, Ryan filled in some details on his notes.

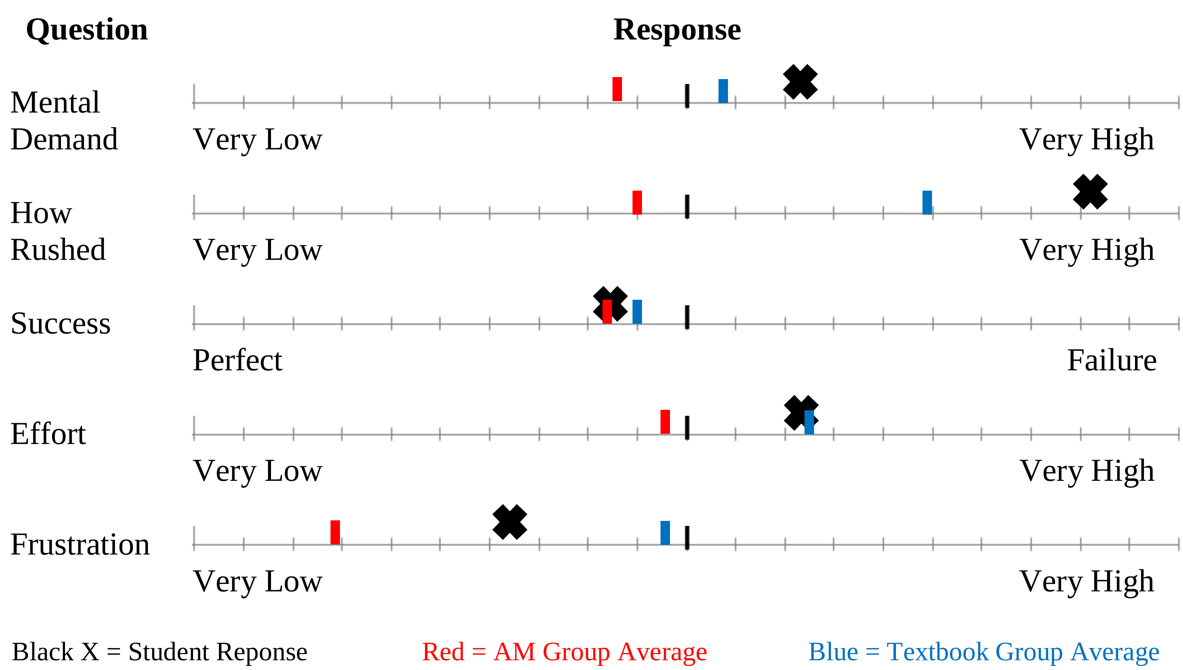


Figure 5.37: Ryan's CRESST Session 1 TLX Results

As seen in Figure 5.37, Ryan reported close to average levels of cognitive load and overall effort. Ryan reported feeling very rushed in the activity, reporting a higher value than any other research participant in CRESST session 1. Other metrics are reported close to the averages.

CRESST Session 1 Explanation:

Ryan began by saying "Okay, so today we are going to learn about trusses frames and machines," and then went on to correctly explain what a simple truss is. Next Ryan begins to explain how these trusses are analyzed to find the forces in the members. He explains two force members at this point, without mentioning the word two force members.

Next Ryan says that there are two ways to analyze trusses, and that he is going to start with the Method of Joints. Ryan gives a complete and correct walkthrough of the

Method of Joints, addressing the equations of static equilibrium where appropriate. For this he uses an example problem from his notes to illustrate the process.

Then Ryan moves onto the Method of Sections. He again uses an example to correctly illustrate the process and draws in the equations of static equilibrium to where appropriate.

Next Ryan introduced some specific scenarios for trusses, or "caveats, some shortcuts to learn, when dealing with special cases of problems," as Ryan puts it. He first indicates that when only two members come together and there is no load applied there, that both members are zero force members. This statement is true, but when asked why this is true Ryan just responds,

> *"I do not remember the proof, but it is proven by mathematics that if there is no load and only two members connected at a pin joint."*

Ryan moves on to explain that when three members come together and two are collinear, the two collinear members must exert equal and opposite forces and the third must be a zero force member. Again this statement is true, but when asked why Ryan again could not explain why this must be true. Finally Ryan went on to explain that when four members make a cross of two sets of collinear members the two collinear pairs must exert equal and opposite forces on each other. For a third time this statement is correct, but Ryan cannot explain why this is true.

Next Ryan starts explaining how to solve a K truss. He explains that four cuts need to be made, but does not explain that the truss needs to be cut one way and then another to solve for all of the unknowns. Before he finishes the explanation he says he needs to move onto frames and machines.

Next Ryan quickly addresses space trusses, which he says are just 3D versions of trusses. He says the class did not cover space trusses and that they will be covered in dynamics next semester. He then correctly states that the same procedures apply, just with more equations of equilibrium.

Ryan next moves on to explain what a frame is and in doing so how a multi-force member is different from a two force member. Ryan moves on to explain that to analyze these problems, you need to separate the members and analyze each one separately. This identifies the key element of the procedure, but Ryan gets lost when giving an example and is not able to correctly isolate members in the example problem he uses. He gets flustered and moves on to explaining Newton's Third Law and how this relates to analyzing frames. Ryan incorrectly associates Newton's Third Law with the equal and opposite forces on a two force member.

Ryan finishes his instruction and the interviewer goes on to start asking questions. The first thing the interviewer asks is the difference between frames and machines. Ryan explains the difference using examples, and attributes the difference to frames just accepting load and machines transferring loads.

The interviewer then asks what trusses frames and machines collectively are. Ryan answers that they are structures and then goes on to correctly explain what structures are.

Next the interviewer asks why the forces in two force members have to be equal and opposite. Ryan states that this is an assumption and that if the forces were not equal and opposite that the member would break. He continues to justify his reasoning as shown below.

"Ryan: Cause it would... I guess, I don't know it, hmm.... We assume that the sum of those forces is zero because the structure, the member itself is not bending. For our purposes.

Interviewer: Okay, so these have to be...

Ryan: They have to be to be equal and opposite, the laws say that."

The interviewer then asks why the forces have to be collinear and Ryan again says that if this was not true the member would bend or break.

Next the interviewer asks Ryan about static determinacy. Through the interaction, Ryan seems to figure out and relate static determinacy to the problems discussed earlier.

"Interviewer: And the last thing I want to talk about is static determinacy. What can you recall about static determinacy?

Ryan: A structure is statically determinate if everything sums to zero. There are enough members to hold all the loads and not too many of them. I think.

Interviewer: In solving problems like this how does that apply?

Ryan: We only solve statically determinate problems because, for some reason we do...? In my limited experience.

Interviewer: Could we solve statically indeterminate problems?

Ryan: No because we have more unknowns than equations.

Interviewer: Okay.

Ryan: Which I am pretty sure is the answer."

Finally the interviewer asks which methods apply to which kinds of structures. Ryan correctly states that the Method of Joints and the Method of Sections cannot be used for frames or machines, but he does incorrectly say that the method to analyze frames and machines could be used to analyze trusses.

Finally just before the recording is stopped, Ryan gives the following statement, indicating that the class was very much focused on the procedures for solving problems.

"Interviewer: Okay, I think we have covered everything, anything else you want to say before I stop the recording?

Ryan: Uh, the book and the lecture are different. He just said statically determinate and moved on and said this is what we do. And the book has all these terms and conditions and they were just there."

Table 5.21: Ryan's CRESST Session 1 Rubric Scores

Category	Score
Principle Coverage	5/5 Moore
Prior Content	3/5 Moore
Conceptual Knowledge	4/5 Moore
Procedural Knowledge	3/5 Moore

As seen in Table 5.21 and Figure 5.38, Ryan addressed all topics in the prescribed topic area. Ryan mentions and meaningfully relates some prior content, but he has some major issues relating Newton's Third Law to the subject area. Conceptually, Ryan was able to identify and represent two force members correctly, but incorrectly stated that they would break if the two forces were not equal and opposite. This was regarded as a minor misconception. Procedurally, Ryan had some major issues with the analysis of frames and machines. He was able to give the correct general procedure but gets lost and then abandons the example problem he is using. In this example it is clear that he is not able to correctly identify and separate the bodies in the frame. Ryan also mentions a number of "caveats" or special cases and has minor or major errors in most of these. Because they are not a central part of the material though, Ryan's error with the analysis of frames and machines is regarded as the only major procedural error.

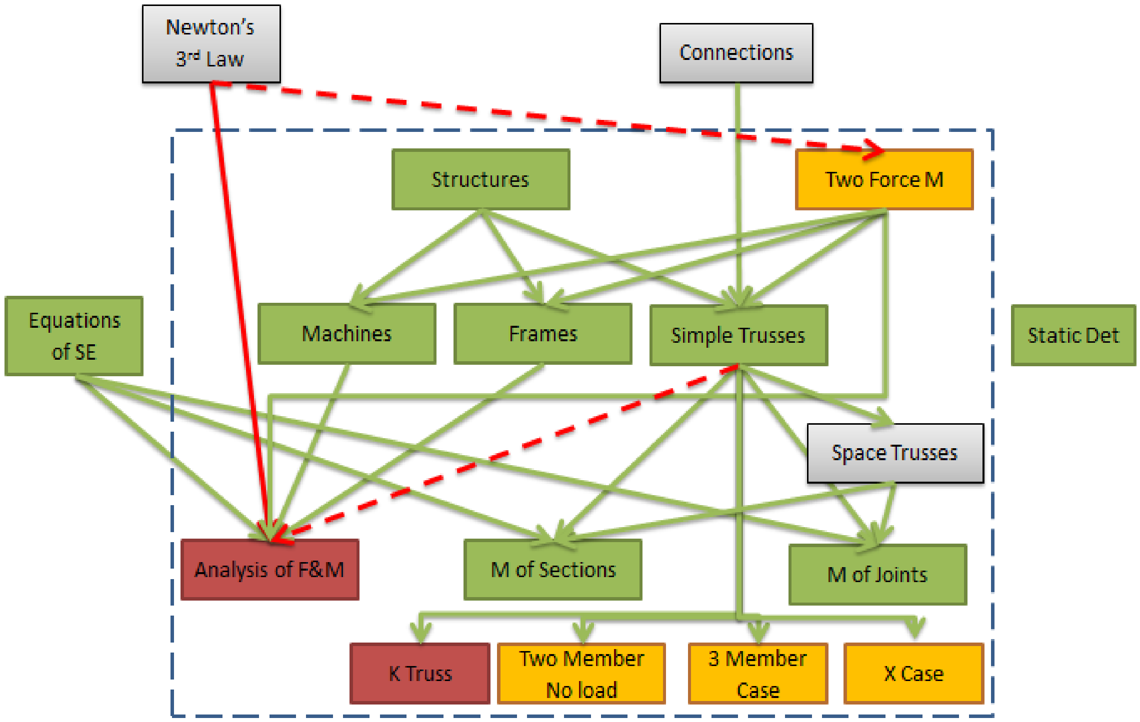


Figure 5.38: Ryan's CRESST Session 1 Explanation Concept Map

CRESST Session 2 Preparation:

Ryan began preparing for the second session by flipping around within the fluid statics section of the textbook. After flipping around in the section a little bit, Ryan went back to the beginning of the section and began carefully reading through the material linearly and taking notes.

Ryan continued to read through the section and copied some of the diagrams from the book. Ryan read through most sections quickly, probably moving too fast to read all of the content on the page. Somewhere towards the middle of the session, Ryan flipped to the end of the section and then went back to where he was reading. He appeared to be getting a sense of how many pages were left. After Ryan read the buoyancy section, he skipped ahead to the end of chapter summary and read through that. After reading the chapter summary, he went back to the first page of the section and read that page again quickly.

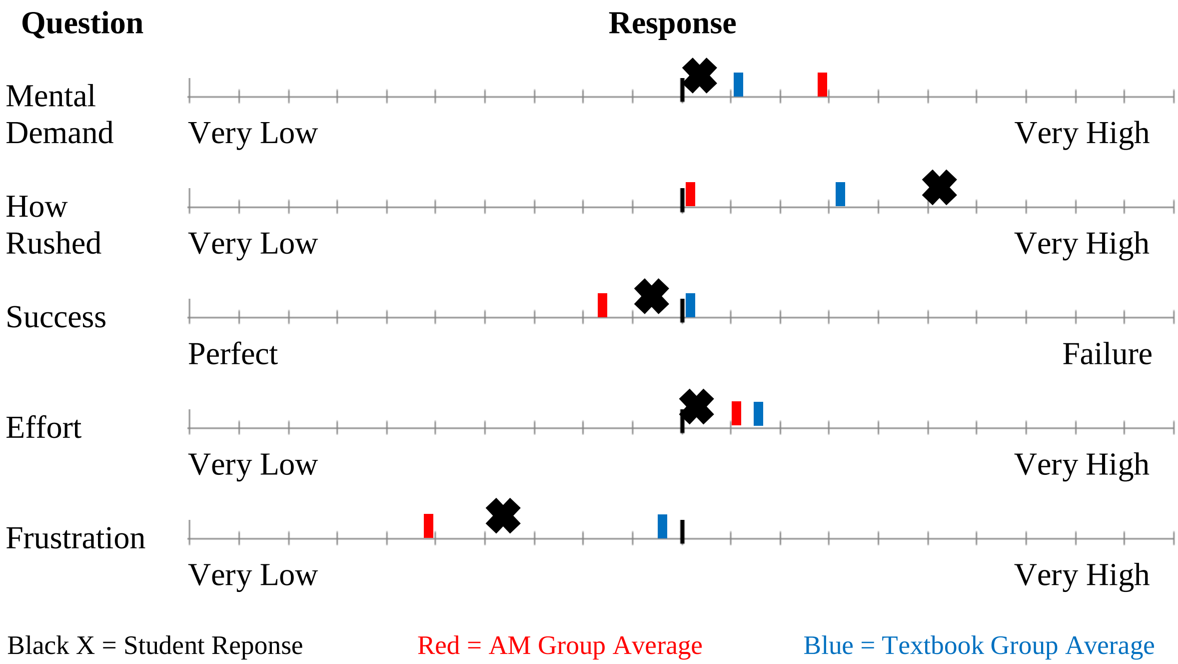


Figure 5.39: Ryan's CRESST Session 2 TLX Results

As seen in Figure 5.39, Ryan reported values cognitive load values close to the average of the textbook group. Other metrics are all also close to average values for the textbook group.

CRESST Session 2 Explanation:

Ryan begins with the statement

> *"Okay, so we are going to do fluid statics today, which builds off of distributed forces."*

From here Ryan explains what a fluid is and that fluid statics examines distributed forces that fluids in static equilibrium exert on surfaces in contact with the fluid.

Next Ryan ties in the equivalent point load to the fluid statics.

> *"And we can find the pressure at any point in the fluid because the pressure times area is how we are going to get the force on our object. So*

similar to how we have distributed loads, we would figure out where it is acting it times our area and that would be our force. Our R resultant."

This is a bit premature because Ryan has not yet explained how to get the pressure distribution that we are finding the equivalent point load of, but it is correct.

Next Ryan goes into Pascal's Equation, correctly explaining the relationship *P = P naught + rho g h*. He is able to correctly explain what all the variables stand for and provides a correct example. Then Ryan discusses absolute and gage pressure. He is able to explain how this distinction impacts the equation discussed above, but when asked why this would be useful, he is not sure.

Next Ryan begins discussing how to calculate the resultant force for a hydrostatic pressure on a flat surface. He correctly relates this back to the equivalent point loads work he has done with beams. During discussion he seems to have a good grasp of the process of determining the equivalent point load through integration. When questioned by the interviewer, Ryan does not seem to be able to relate the force distribution back to the equation for pressure discussed earlier.

"Ryan: Yeah. That's under some fluid, so it could be under water or a gas is acting on it. Being pushed on it. Some fluid is acting on it with a pressure distribution or a force distribution that is approximated by a trapezoid. A three dimensional trapezoid.

Interviewer: Alight so the height is? The height at any one point is equal to what?

Ryan: The height at any one point.... I'm not sure. It's some variable that I will call x.

Interviewer: How do you tell what x is though?

Ryan: Oh, so the height at any given point would be a function, of length.

Interviewer: How do we know that function though?

Ryan: Well if it's a trapezoid we could figure it out. Or it would be given to you. You would have to know, it would have to be given or somehow you would have to figure it out, based on the given information you would have to figure out that this is a function of the length and here it is."

Next he moves on to correctly explain how to find the point of application of the equivalent point load.

Then Ryan starts discussing buoyancy forces. He correctly identifies the relationship *F = rho g V*, and what all of the variables stand for. Then he goes on to say that the buoyancy force is always equal and opposite of the weight of the object, which is only true for objects in equilibrium. In his explanation however, Ryan states that this is true only for objects not in equilibrium,

"Ryan: And this is equal to the weight of the object. So we can the equivalency, the weight is equal to the buoyancy force.

Interviewer: So is this always true?

Ryan: This is true for an object that is being pushed down or up. An object not in equilibrium, fluid hydrostatic or aerostatic equilibrium. The weight would have to equal the buoyancy force."

When questioned by the interviewer further however, Ryan goes back to the correct association that buoyancy forces are based purely on the volume displaced and that objects not in equilibrium may have differing buoyancy and weight forces.

"Interviewer: Alright, so if we had a piece of metal and a piece of wood and you throw them in water, like the metal is going to sink, but if they are the same size the metal is going to be heavier. So is the buoyancy force bigger on the metal than on the wood?

Ryan: Um... yes. Wait, no because the buoyancy force is based on the volume displaced. So if you had two equally sized objects, one made of wood and one made of metal, the volume displaced would be the different, the volume displaced would be the same which would make the buoyancy force would be the same. Which is why the metal would sink and the wood would float... I think."

Next Ryan moves on to explain that the buoyancy force acts on the center of buoyancy, and correctly explains how to find the center of buoyancy. Ryan relates this to stability and upon questioning by the interviewer is able to explain what happens with a stable or unstable floating object.

After this, Ryan states that he is done. The interviewer asks what would happen if we tried to calculate the equivalent point load for fluid on a curved surface. Ryan states that he saw that in the book and states it is similar to the process for a flat surface. His explanation however is too short to judge his understanding of the process.

Table 5.22: Ryan's CRESST Session 2 Rubric Scores

Category	Score
Principle Coverage	4/5 Moore
Prior Content	5/5 Moore
Conceptual Knowledge	3/5 Moore
Procedural Knowledge	4/5 Moore

As seen in Table 5.22 and in Figure 5.40, Ryan addressed all topics in the subject area, but did not discuss hydrostatic pressure on the cylindrical surface long enough to determine understanding. Ryan grounded his discussion correctly and completely in the prior content. Conceptually, Ryan did not relate hydrostatic pressure to either hydrostatic pressure on a flat surface or to buoyancy, regarded as a major misconception. Procedurally, Ryan goes back and forth on whether or not the buoyancy force is always equal and opposite to the weight, which is regarded as a minor procedural error. The lack of connection between hydrostatic pressure and hydrostatic pressure on a flat surface, also leads to unanswered questions in calculating the equivalent point load, another minor procedural error.

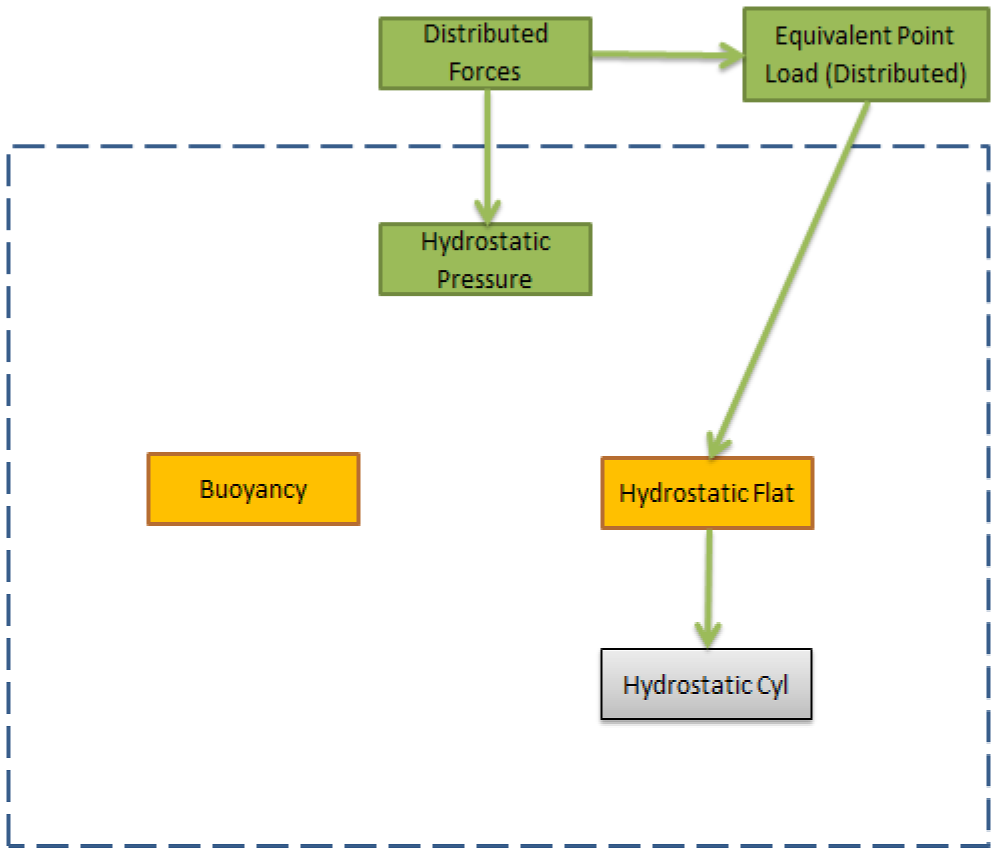


Figure 5.40: Ryan's CRESST Session 2 Explanation Concept Map

Case Summary:

Ryan was a textbook non-adopter. He used his textbook only to look up the homework problems for the regular homework assignments. His primary source of information for homework and studying out of class was the notes he took during lecture. He seemed to think that the textbook was pretty average and standard in terms of content and layout, and his feelings for the book were neutral. In preparing for the CRESST sessions, Ryan differed from the other textbook participants in that he flipped around a little bit in the section before marching linearly through the information. This may be an indication of using the section headings as an improvised advance organizer. In his explanations, Ryan seemed to have a deeper understanding of the material than other textbook participants. However, when questioned about why something worked that way or why it was true, Ryan would often respond with something like “I do not remember the proof. But it is proven by mathematics.” Like the other textbook participants, Ryan spent a lot of time in the first CRESST session discussing very specific scenarios.

5.7 Chapter Summary

Chapter 5 presents detailed descriptions of how six students in an authentic classroom environment used the Adaptive Map tool over the course of the semester, what effects the tool had on learning for these students, and what opinions these students had of the tool. Similar descriptions are also presented for three students using a traditional paper textbook to provide contrasting cases that the Adaptive Map cases can be compared to. Some of these cases, such as Anne, Lillian, Aaron, and Carol, matched the theoretically predicted usage patterns. Other cases, such as Ryan, Gabriel, and Sonya, provided unexpected and valuable information on how the Adaptive Map or traditional textbook are being used by students.

The following chapter will take the individual stories presented here and look for patterns or themes in the data. These cross-case themes will then be used to make broader claims about the success or failure of the Adaptive Map tool, and about the underlying theory behind the Adaptive Map tool.

6 Cross Case Analysis

Two primary themes or patterns emerged from the individual cases, as well as three secondary themes. Each of these themes had a number of underlying complexities, but was centered around one defining feature. The primary themes represent the issues most central to the design of the Adaptive Map tool, while the secondary themes represent observed patterns that were not central to the design of the Adaptive Map tool.

The two primary themes are:

1. Students using the Adaptive Map tool were more likely to engage in behaviors indicating advance organizer usage. Students using either aspects of the Adaptive Map tool or the traditional textbook as an advance organizer mimicked the expert's knowledge structures and had deeper and more connected knowledge. The students more likely to use the concept maps in the Adaptive Map tool as an advance organizer were those students who primarily used the tool to study or review information outside of class, while the students less likely to use the concept maps as advance organizers were those students who used the tool primarily to look up information to solve homework problems. A more detailed examination of this theme is presented in Section 6.1.

2. All students using the Adaptive Map tool were observed to leave the prescribed topic area at some point and explore the information in at least one of the two sessions, while there were no observed instances of students with the traditional textbook leaving the prescribed topic area. The students who spent the most time exploring outside information, tended to not address all the topics in the prescribed topic area, but better connected the topics they did cover. This is an indication of meaningful learning. Those students who did not explore any outside content were more likely to show signs of rote learning. A more detailed examination of this theme is presented in Section 6.2.

The three secondary themes are:

1. The simplicity of the language on the content pages was discussed as a draw for some of the students. This was a stronger a draw for students who learned English as a second language. The traditional textbook used more technical and exact language while the tone of the Adaptive Map tool was more conversational. This difference in tone is both a confounding factor and an area for future inquiry. A more detailed examination of this theme is presented in Section 6.3.

2. Students who reported very high levels of cognitive load had lower measures of learning for the corresponding activity. Low cognitive load did not necessarily

predict higher measures of learning, though. A manageable imposed load is then necessary but not sufficient for meaningful learning. These results match what is predicted by cognitive load theory. Students using the Adaptive Map tool did not appear to be more or less likely to report high levels of cognitive load than students using the traditional textbook. A more detailed examination of this theme is presented in Section 6.4.

3. The Adaptive Map tool was adopted for learning by students in the research participant pool, but website analytics show that few students outside of the research participant pool adopted the tool. Something that the research participants engaged in, beyond the initial recruitment introduction to the tool, caused those students to use Adaptive Map tool outside of the research sessions. It is suspected that by participating in the CRESST sessions, students in the research participant pool were forced to become familiar with the Adaptive Map tool. Only after becoming familiar with the Adaptive Map tool did students use the tool unsolicited. A more detailed examination of this theme is presented in Section 6.5.

To aid in future discussion, Figure 6.1 categorizes each participant in terms of how much time they devoted to behaviors that indicated the deliberate use of an advance organizer and how much time they devoted to examining information outside of the prescribed topic area (the two primary themes). This graphic represents the behaviors examined for each participant over both CRESST sessions. Students were generally consistent in their behaviors across both CRESST sessions, and the placement in the figure represents the aggregate of their behavior across both sessions. Participants using the Adaptive Map tool are underlined, while participants using the traditional textbook are in italics.

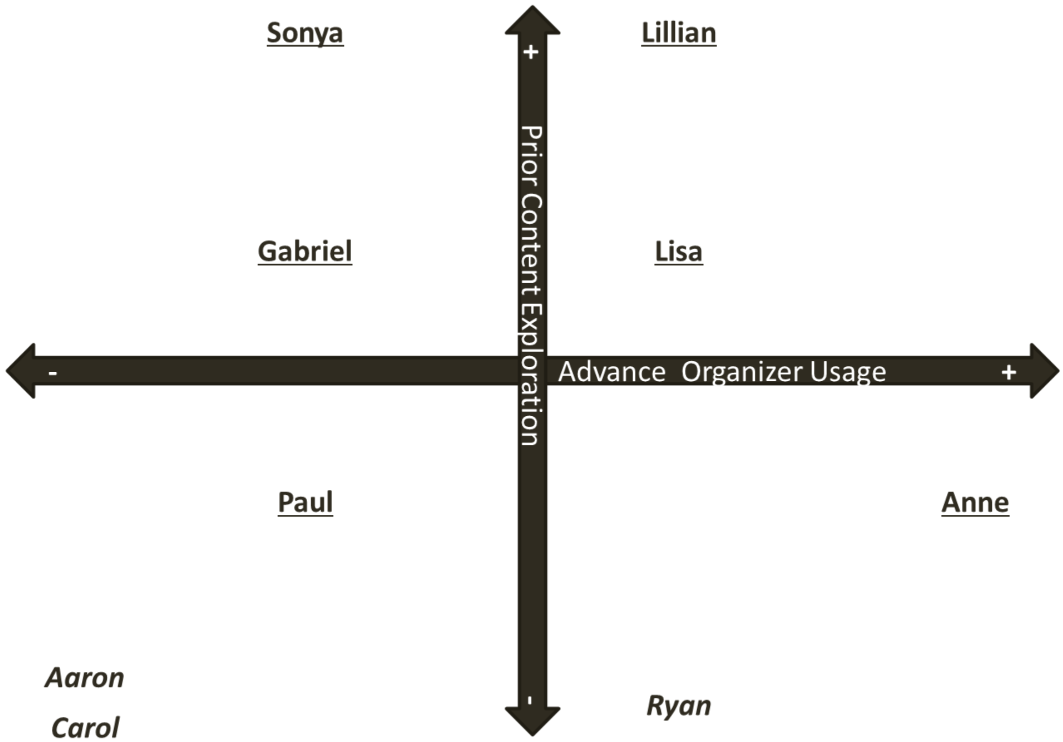


Figure 6.1: Categorization of Participants Prior Content Exploration and Advance Organizer Usage

Figure 6.1 shows that students using the Adaptive Map tool generally had higher measures of advance organizer usage and prior content exploration. The difference between the two tools is particularly stark along the prior content exploration axis, where there is a complete dichotomy between Adaptive Map users and traditional textbook users.

A summary of the categorization criteria used to classify students along the advance organizer usage scale and the prior content exploration scale is presented in Table 6.1. These were the metrics used to place the participants along the axes in Figure 6.1. Table 6.1 also reviews the categorization criteria used to determine the students' learning orientation and the students' adopter / non-adopter status.

Table 6.1: Student Participant Categorization Criteria

Criteria	Low	←	→	High
Advance Organizer Usage (Section 6.1.1)	**Very Low Advance Organizer User:** Showed no indication of viewing or processing an overview of the information in CRESST sessions.	**Low Advance Organizer User:** Showed some indications of viewing and processing small parts of an overview of the information in CRESST sessions.	**High Advance Organizer User:** Showed indications of processing a majority of an overview of the information in CRESST sessions.	**Very High Advance Organizer User:** Spent three minutes or more processing an overview of the information and viewed all parts of the overview in CRESST sessions.
Prior Content Exploration (Section 6.2)	**Very Low Prior Content Explorer:** Never left prescribed section during the CRESST sessions.	**Low Prior Content Explorer:** Skimmed at least one page outside of the prescribed section during at least one CRESST session.	**High Content Explorer:** Read (did more than skim) at least one page outside of the prescribed section during at least one CRESST session.	**Very High Content Explorer:** Spent a third or more of the preparation time across both CRESST sessions viewing information outside of the prescribed section.
Tool Adoption	**Non-Adopter:** Student did not use the Adaptive Map / textbook to learn information for the statics class outside of the CRESST sessions (not including looking up homework problems).		**Adopter:** Student used the Adaptive Map / textbook to learn information for the statics class outside of the CRESST sessions (not including looking up homework problems).	
Learning Orientation	**Strong Mastery Orientation:** Student placed low importance on grades, sought understanding of useful information, and preferred to solve novel problems that pushed their limits.	**Mild Mastery Orientation:** Student placed high importance on grades but only because of the perceived usefulness of high grades. Sought understanding as an internal measure of success.	**Mild Performance Orientation:** Student placed high importance on grades, and either compared performance to others and preferred to solve familiar problems.	**Strong Performance Orientation:** Student placed high importance on grades, compared performance to others and preferred to solve familiar problems.

Table 6.2 displays various measures related to student learning for each of the nine participants. The CRESST scores have been color coded for easier browsing (green for high scores to yellow for mid-range scores to red for low scores).

Table 6.2: Participant Learning Measures Summary

Group	Pseudonym (Learning Orientation)	Expected Grade	SCI Score	CRESST Session	Principle Coverage	Prior Content	Conceptual Knowledge	Procedural Knowledge
Adaptive Map Group	Anne (SP)	A	74.1%	1	5	4	3	4
				2	5	5	5	5
	Gabriel (SM)	B-C	18.5%	1	5	3	3	4
				2	3	3	2	2
	Lillian (SP)	B or B+ Hopefully	25.9%	1	3	4	4	4
				2	2	3	3	2
	Lisa (MP)	B	37.0%	1	4	4	5	4
				2	5	3	2	2
	Paul (MP)	B	59.3%	1	4	4	2	4
				2	5	3	3	4
	Sonya (MP)	B	33.3%	1	5	4	4	4
				2	2	5	4	4
Traditional Textbook Group	Aaron (SM)	Hopefully B	7.4%	1	5	3	2	4
				2	5	2	1	2
	Carol (SP)	A or A-	40.7%	1	5	4	2	4
				2	4	2	1	2
	Ryan (MM)	B+	44.4%	1	5	3	4	3
				2	4	5	3	4

6.1 Advance Organizers

The central design feature of the Adaptive Map tool is the concept map based navigation system. This feature was implemented for students to use as an advance organizer. The first theme to emerge from the data centered on the topic of if and how students used the concept maps in the Adaptive Map tool, or the section headings in the traditional textbook as an advance organizer. Section 6.1.1 discusses the observed behaviors that indicate the use or non-use of tool features as an advance organizer, Section 6.1.2 discusses the observed relationships between advance organizer usage and learning, and Section 6.1.3 discusses observed characteristics advance organizer users and non-users.

6.1.1 Behaviors that Indicate the Use or Non-Use an Advance Organizer

Students using both the Adaptive Map tool and the traditional textbook who scored high for advance organizer usage, spent time viewing an overview of the information in the assigned section before reading detailed instructional material in depth. In this way, they indicated that they processed an overview of the material before processing details of the content, the key goal of the advance organizer.

Anne serves as the clearest example of a student using the features of either tool as an advance organizer. At the beginning of both CRESST sessions, Anne spent a few minutes looking over the concept map of the cluster, hovering over the nodes and links to get details, and taking notes while examining the concept map. This is a clear indication that she spent time processing an overview of the content (in the form of a concept map), before she moved on to more detailed instruction on the topic pages. Anne's note taking began by spreading a few headings across the page to represent the main ideas and adding details under the headings as she read the topic pages.

On the other end of the spectrum, Aaron and Carol provide the clearest example of students not using an advance organizer. These students read the information in the traditional textbook carefully from beginning to end. As there was no overview present in the traditional textbook, they did not process an overview of the information at any point. Aaron and Carol both took detailed notes on each topic as it was addressed in the textbook.

All other participants fell somewhere between these two extremes in terms of the advance organizer usage. Lillian, Lisa, and Ryan were classified as moderate advance organizer users and Sonya, Gabriel, and Paul were classified as light advance organizer users.

Lillian and Lisa both spent time hovering over nodes and links in the concept map before opening topic pages just like Anne, but for a shorter duration. Lisa was an interesting case because she also returned to the concept map late in the preparation session and hovered over nodes and links after taking detailed notes. This changes the function of the concept map from an advance organizer to a reflective tool for Lisa. Ryan was interesting because he was an advance organizer user in the traditional textbook group. Ryan began each CRESST session by flipping through the section, presumably using the section headings to get an overview of the information to come. Like Lillian and Lisa, Ryan spent less time doing this than Anne spent looking over the concept map of the section.

Sonya, Gabriel, and Paul did not look over the concept map before opening a topic page, but at some point they did hover over a node or link on the concept map to get details. This was viewed as a minor use of the tool as an advance organizer, using the information in the concept map to get an overview of a subsection of the detailed information on the topic pages.

6.1.2 Learning and Advance Organizer Usage

After identifying the spectrum of advance organizer usage, the next step in the analysis was to relate this spectrum to the nature of the students' learning. Theoretically, advance organizers are supposed to help students mimic an expert's cognitive framework for the information (Ausubel, 1968; Luiten et al., 1980). By explicitly presenting this framework, students should be more inclined to meaningfully relate topics to one another as the expert has done and should rely less on rote learning strategies. This in turn should be reflected deeper conceptual understanding and a more connected cognitive framework. The researchers looked for evidence of this process occurring in the CRESST explanations, and then related these findings back to the observations of how students were actually observed to use the tool in preparation.

As a starting point, the explanations of a very high advance organizer user in the Adaptive Map group (Anne) and a very low advance organizer user in the traditional textbook group (Carol) are contrasted. Outside of the differences in advance organizer usage, these two students shared some characteristics that made them good candidates for comparison. Both students are high performers in the class. Anne has the highest expected course grade of “A” and Carol has the second highest expected course grade of “A or A minus”. In terms of the Statics Concept Inventory, Anne had the highest score (74.1%) and Carol had the fourth highest score (40.7%). Both were also above average by this measure. Finally, both students were also observed to spend a vast majority of preparation time within the prescribed topic area, leading to similar low prior content exploration scores. This limited the effect of the other observed theme of content exploration.

Figure 6.2 shows the differences in Anne and Carol’s CRESST explanation concept maps for the first CRESST session.

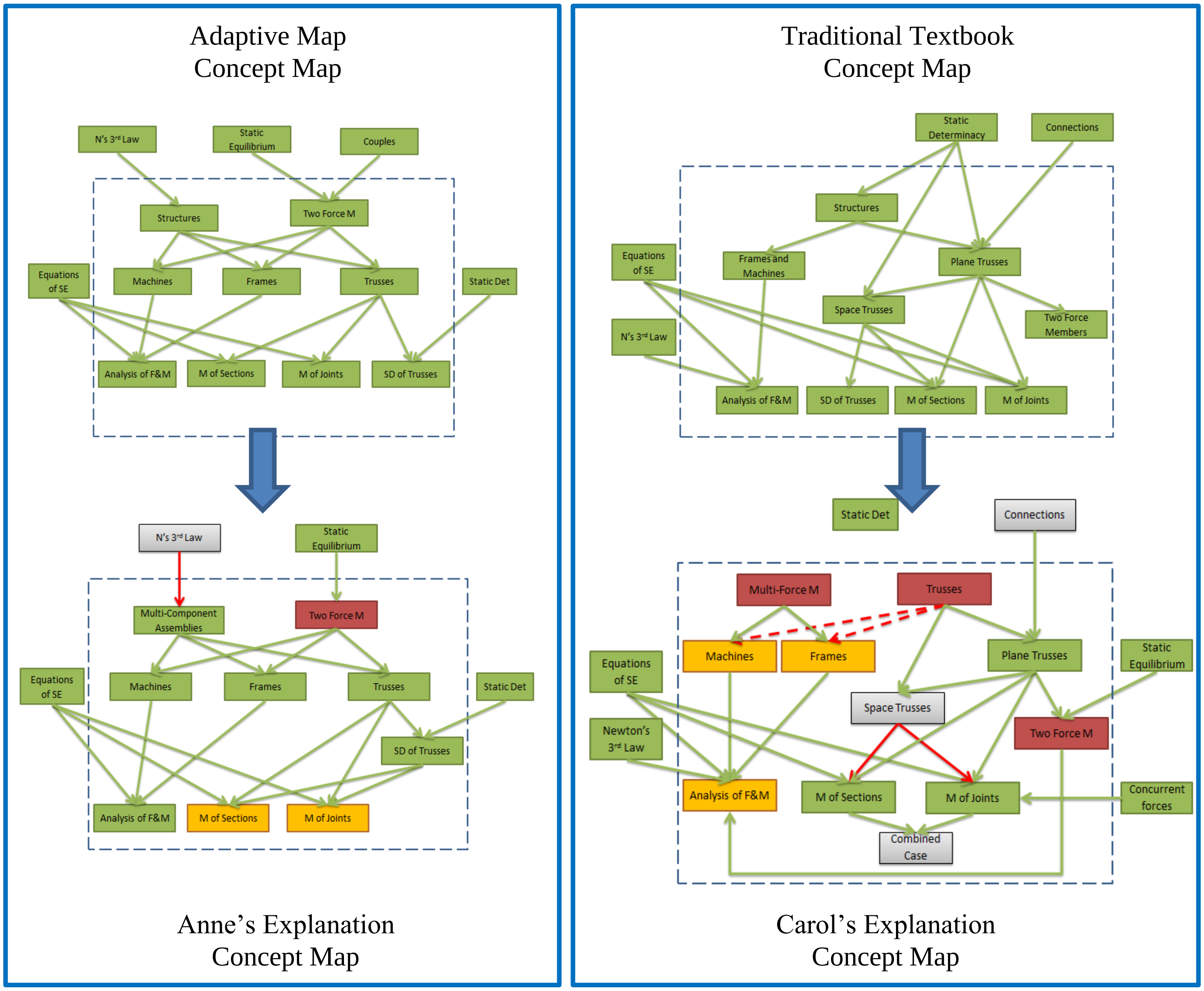


Figure 6.2: CRESST Session 1 Advance Organizer Comparison

As seen on the left in Figure 6.2, the map of Anne's first CRESST session very closely matches the map presented in the Adaptive Map tool. Anne connected static determinacy in trusses back to the method of joints and method of sections, but other than that her map matches the Adaptive Map tool perfectly. Carol's explanation of the first CRESST session also shares many commonalities with the concept map of the traditional textbook content, but the match is not as close. Carol added a number of connections in her discussion that were not present in the content of the traditional textbook. Some, like the connection between two force members and the analysis of frames and machines are correct, others such as the connection between trusses and frames and machines are incorrect. Overall, Carol's has added, modified, or omitted six nodes and six links (not including links to the differing nodes). This is far more than the two link difference present in Anne's case. This pattern applies more broadly to the whole spectrum of students in relation to advance organizer usage. **In general, the higher the student scored on the advance organizer usage scale, the higher the level of agreement between explanation concept map and the concept map of the source content itself.**

An indication that the concept maps in the Adaptive Map tool are serving as an advance organizer, rather than the content, is present in a mistake in Anne's discussion and concept map. Anne connected Newton's Third Law to multi-component assemblies just as shown in the cluster view of the multi-component assemblies, though her explanation of the connection does not match the explanation of the connection on the topic page itself. This is an indication that Anne processed the map and was using it to structure her understanding, even if it was misleading her in this case.

Examining the second CRESST session, more drastic differences in Anne and Carol's explanations are present. These more drastic differences may be attributable to the fact that the second CRESST session covered unfamiliar content, leaving the research session as the sole chance to learn the assigned information. Figure 6.3 represents Anne and Carol's explanations of the second CRESST session and their corresponding source tool's concept map.

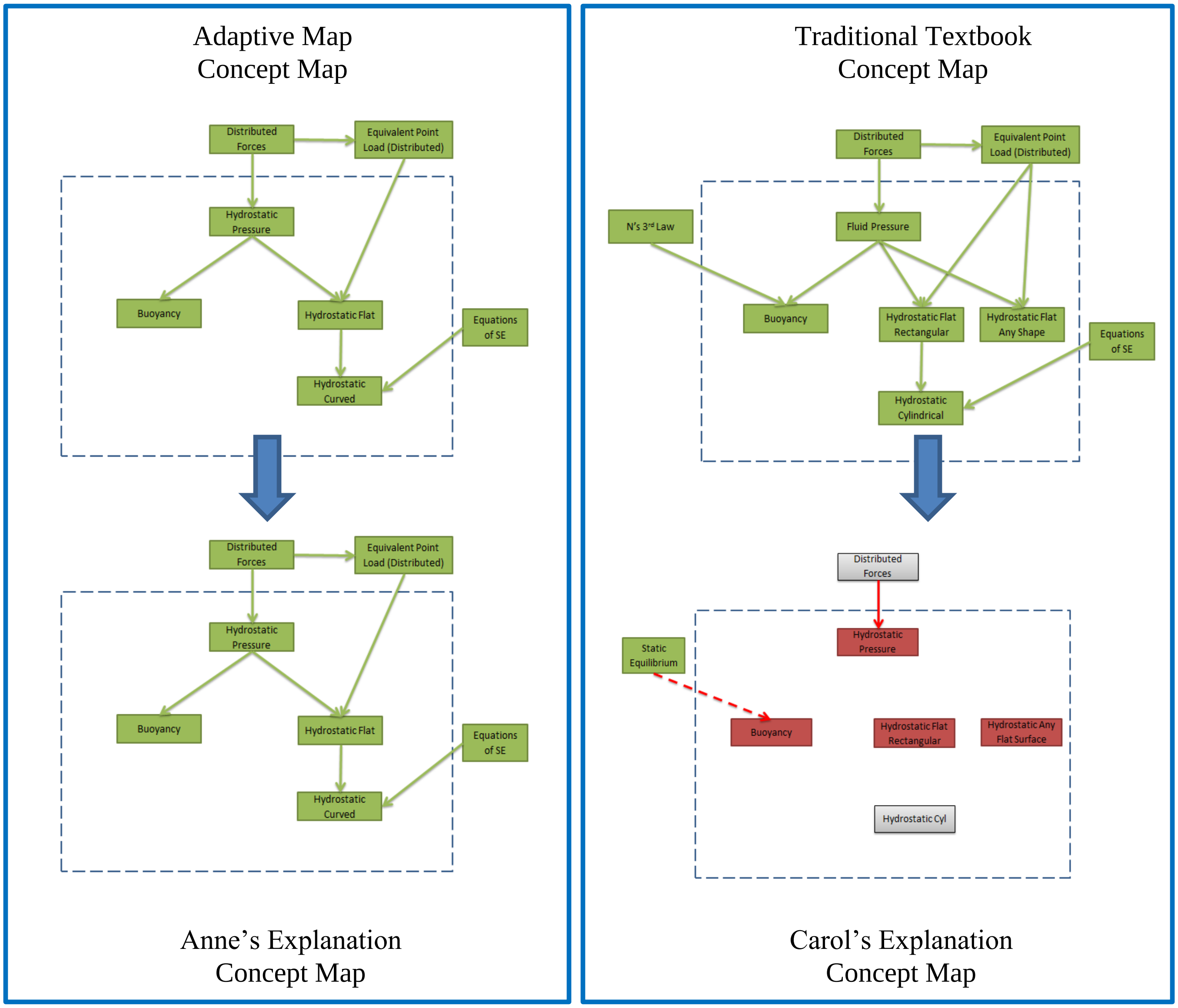


Figure 6.3: CRESST Session 2 Advance Organizer Comparison

As seen on the left of Figure 6.3, Anne's explanation perfectly matched the cluster view in the Adaptive Map tool. Anne was able to correctly explain all the topics and meaningfully relate the topics to one another in a way that was identical to the original expert who created the map. Carol's explanation, on the other hand, had a number of major flaws. She wrote down and used a number of equations, but was usually unable to apply them because of misconceptions and misunderstanding of what the variables represented. Carol also failed to relate the topics to one another, despite these connections being covered in the textbook. This stark difference is an indication of meaningful learning by Anne and rote learning by Carol. Anne was able to correctly respond to questioning, while Carol often made mistakes when questions. Also, Anne had a completely interconnected set of knowledge, while Carol discussed a number of disjointed topics.

Expanding beyond Anne and Carol, we can examine the other two traditional textbook participants to illustrate the observed differences between advance organizer users and advance organizer non-users. Aaron and Ryan used the same tool to prepare, so differing content cannot explain the differences in their explanations, but they did differ in their approach to preparing the explanations. Aaron prepared in a similar way to Carol for the second CRESST session. He jumped straight into the reading detailed content and was classified as an advance organizer non-user. Ryan, on the other hand, started preparing for the second CRESST session by flipping through the section skimming the content he was tasked with covering. Presumably he was using the section headings as a sort of improvised advance organizer, a high level overview of the information in the assigned section. Figure 6.4 shows Aaron and Ryan's Session 2 explanation maps and the concept map of the common content they used to prepare.

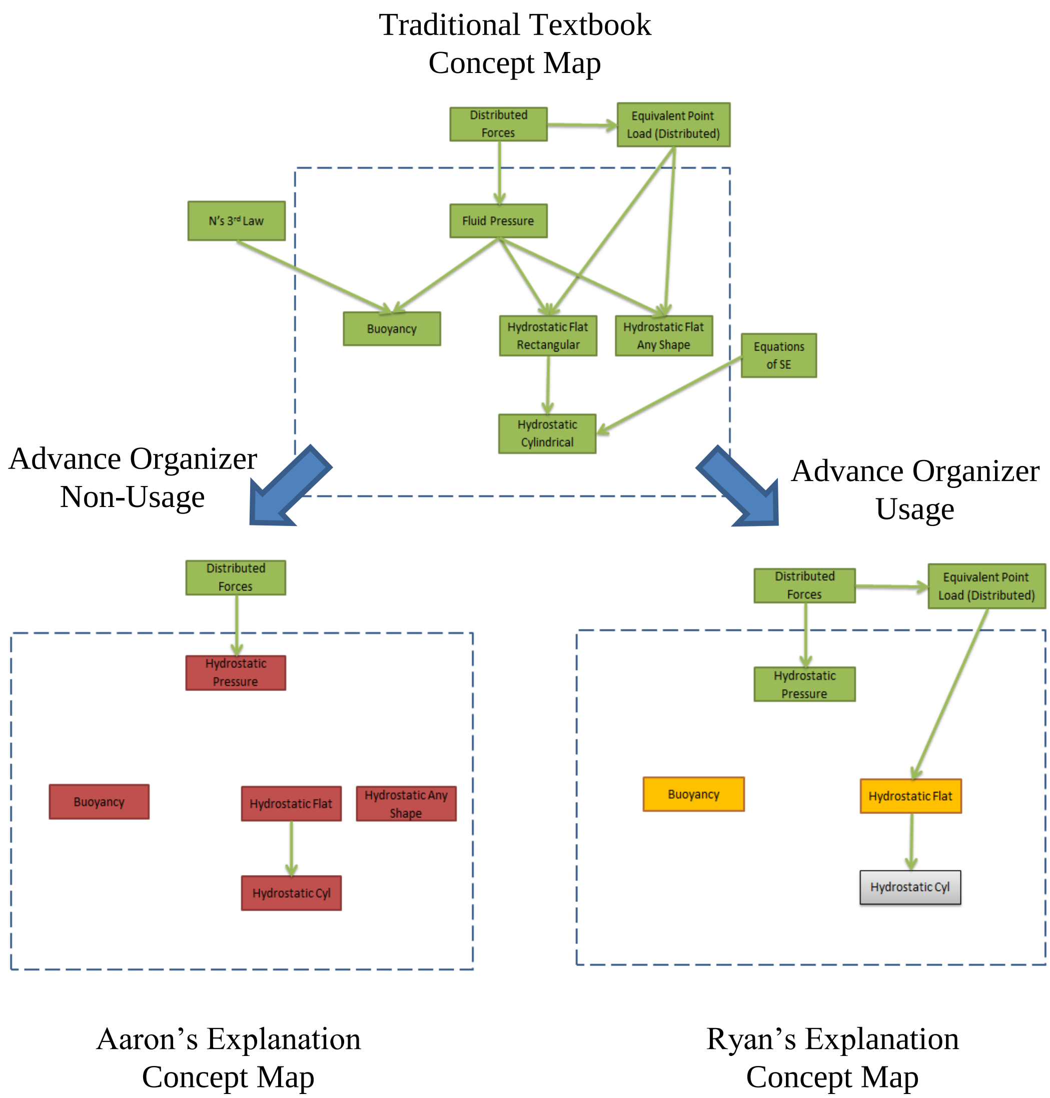


Figure 6.4: CRESST Session 2 Additional Advance Organizer Comparison

As seen in Figure 6.4, Ryan's explanation in the second CRESST session was more correct and more the topics were connected. Aaron, like Carol, exhibits characteristics of rote learning, while Ryan has a better understanding of the material. This is an indication that advance organizer usage, not the content, explains the rote learning behavior.

The patterns observed so far continue to generalize across all nine cases in the case study. **Meaningful learning should lead to greater measures of conceptual understanding, and we find evidence of a relationship between advance organizer usage and conceptual understanding through the CRESST scoring rubrics across**

both tools. Splitting the group of participants into high advance organizer users (Anne, Lillian, Lisa, and Ryan) and low advance organizer users (Sonya, Gabriel, Paul, Aaron, and Carol), one can compare scores on the CRESST scoring rubrics. Table 6.3 represents the average scores (all participants and both sessions) for each of the four categories. Again student were classified as high or low advance organizer users based on their behaviors across both sessions.

Table 6.3: Comparison of Advance Organizer Users and Non Users (Scores out of five)

	High Advance Organizer Users	Low Advance Organizer Users
Principle Coverage	4.13	4.30
Prior Content	3.88	3.30
Conceptual Knowledge	3.63	2.40
Procedural Knowledge	3.50	3.40

Table 6.3 shows that the conceptual understanding scores of high advance organizer users are more than a full point higher than the low advance organizer users. Though there are not enough participants for statistical significance, this finding supports the claim that advance organizer adoption leads to more meaningful learning. Prior content measures are also half a point higher for the advance organizer users, indicating that the high advance organizer users grounded their discussion in outside topics more effectively than the low advance organizer users. Measures of principle coverage and procedural knowledge do not appear to differ between the two groups.

Comparing the CRESST rubric scores of students using the Adaptive Map tool to students using the traditional textbook produces similar results to what is seen in Table 6.3. Students using the Adaptive Map tool were far more likely to score highly on the advance organizer usage scale though, indicating that the tool used and advance organizer usage score are not independent factors. The students who defied the average for advance organizer usage (Ryan who had a high advance organizer score despite being in the traditional textbook group and Gabriel and Paul who had the low advance organizer scores despite the being in the Adaptive Map group) also defied the averages for measures of conceptual understanding. **This leads to the conclusion that the Adaptive Map tool supports students' use of an advance organizer, but it is the behavior of using an advance organizer that is the true predictor of higher conceptual understanding scores.**

6.1.3 Other Characteristics of Advance Organizer Users and Non-Users

After identifying the relationship between advance organizer usage and student learning, further analysis was conducted to identify other characteristics that relate to advance organizer usage behaviors. By identifying these characteristics, the researcher hoped to understand why students chose to use the Adaptive Map tool as intended or why they chose not to. Relationships were searched between advance organizer usage and i) the frequency of tool use, ii) primary tasks performed while using the tool, iii) mastery versus performance learning orientation, and iv) overall course performance.

Only one factor had a clear and strong relationship to advance organizer adoption: the primary task performed while using the tool outside of the CRESST sessions. In the Adaptive Map group, the three heaviest users of the concept maps as advance organizers (Anne, Lillian, and Lisa) were also the three participants who reported using the Adaptive Map tool primarily to review information outside of class and to study for exams. This was not true for the three users who used the concept maps as advance organizers the least (Gabriel, Paul, and Sonya). Gabriel and Paul used the tool primarily to look up information to solve homework problems, and Sonya did not use the tool at all outside of the research sessions.

Though it is impossible to assign causality in this relationship based on the gathered data, it is suspected that students who engaged in using the tool to help solve homework problems engaged in a search with a specific and very focused end goal in the content. This directed search led them to use features such as the search bar, which both Gabriel and Paul mentioned as a draw to the tool. By using such features, these participants were largely ignoring the context of the concept map and jumping straight to the details they needed. Those users who were using the tool to study, however, were engaged in a more open ended search. They had no final destination in information they were looking for and gave more attention to the context provided by the concept map as they moved through the material. With a preference for this type of navigation, and with more practice with this type of navigation, students who used the Adaptive Map tool to review and study regularly gave more attention to the concept maps during the CRESST sessions. It was thought that this may relate to mastery versus a performance orientation to learning; however these usage patterns did not align with the learning orientations measured in the debriefing interview. This may be a type of localized learning orientation at work, though further investigation is needed to pursue this hypothesis.

6.2 The Adaptive Map and Content Exploration

A second major theme that emerged from the data was that students using the Adaptive Map tool were more likely to explore content outside of the assigned section and that those students who spent more time exploring outside content learned in a way that better matched expert learning. All student participants, using either the Adaptive

Map tool or the traditional textbook, were given a clearly defined section of the content to study and explain for each CRESST session. **It was noticed that all traditional textbook users read the information in the prescribed section exclusively; they never looked at pages in other chapters or even other sections in the same chapter in the case of the fluid statics section. All Adaptive Map users on the other hand looked at least one page that was outside of the prescribed topic area in at least one of the CRESST sessions. These pages were usually on topics prerequisite to the prescribed topic area, hence the name "prior content exploration."** Some Adaptive Map users, such as Lillian and Sonya, spent a third or more of their preparation time reading pages outside of the prescribed topic area. Additionally, some of the Adaptive Map participants were questioned about the time they spent outside of the prescribed topic area. All participants who were questioned were aware they were outside of the prescribed topic area. This indicates an intentional exploration of outside content that the traditional textbook students did not engage in.

Students were classified in terms of how much attention they seemed to give outside content.

- Student who spent a third or more of their time looking at topic pages outside of the prescribed topic area were classified at the highest level of prior content exploration.
- Those who carefully read through at least one outside topic page were place at the next highest level.
- Those who skimmed at least one outside page were at the third highest level.
- Those who never looked at anything outside of the prescribed topic area were at the lowest level.

The classification of each student in terms of their prior content exploration rating can be seen in Figure 6.1. Section 6.2.1 discusses the observed relationships between content exploration and learning, and Section 6.2.2 discusses the observed characteristics content explorers and non-explorers.

6.2.1 Learning and Prior Content Exploration

After identifying the spectrum of content exploration, the next step in the analysis was to relate this spectrum to the nature of the students' learning. Increased prior content exploration was not an intended effect of the Adaptive Map tool, so no theoretical effect was predicted, though differences did emerge from the data.

Sonya (Section 5.5.6) and Lillian (Section 5.5.3) spent the most time exploring prior content so they will serve as exemplars of content explorers, while Ryan (Section 5.6.3) and Paul (Section 5.5.5) will serve as the exemplars of non-explorers. Ryan (traditional textbook user) never left the prescribed topic area, while Paul (Adaptive Map user) engaged in some prior content exploration, but, on average across both sessions, less than any other participant in the Adaptive Map group. None of the identified participants for this section fell on the extremes of advance organizer usage or overall course performance. By not having any other extremes, this selection helped to isolate the effects of the prior content exploration factor.

The first pattern that can be noticed when looking at the behaviors of Sonya and Lillian is the lower levels of principle coverage across both CRESST sessions. In CRESST Session 1, Lillian only briefly touched upon frames, machines or the analysis of frames and machine, and for CRESST Session 2, neither of them touched on more advanced topics such as buoyancy or hydrostatic pressure on a curved surface. Looking back at the preparation, we can see that this matches the preparation for the session. Lillian and Sonya did not open all the pages in the prescribed session, and these pages they didn't open were not addressed in the explanation. Ryan and Paul, our exemplars of the low levels of prior content exploration, had higher measures of principle coverage. This also matches their preparation behaviors, where Ryan and Paul viewed more of the relevant content pages.

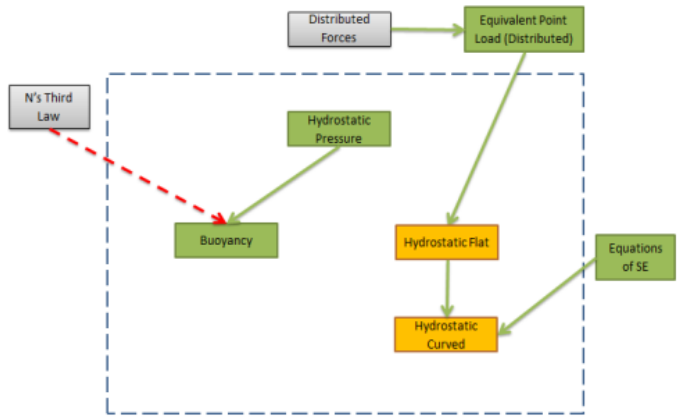
Table 6.4 compares the CRESST rubric scores for high prior content explorers (Gabriel, Lillian, Lisa, and Sonya), and the low prior content explorers (Anne, Paul, Aaron, Carol, and Ryan). These scores represent the averages of all participants in each group across both sections. The table confirms that the higher levels of content exploration correspond to lower measures of principle coverage across all participants, with scores more than a full point lower for high prior content explorers.

Table 6.4: Comparison of Content Explorers and Non Content Explorers (Scores out of five)

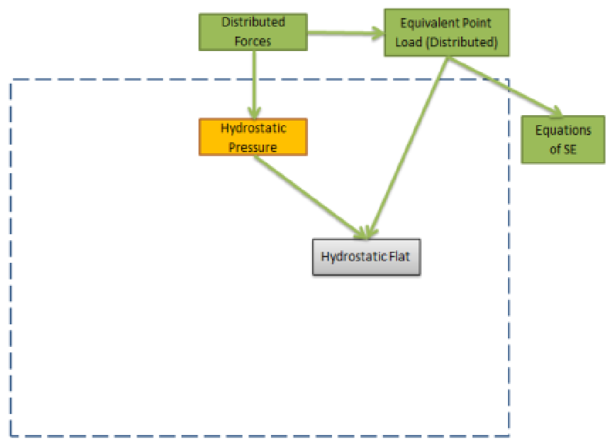
	High and Very Prior Content Explorers	Low and Very Low Prior Content Explorers
Principle Coverage	3.63	4.70
Prior Content	3.63	3.50
Conceptual Knowledge	3.38	2.60
Procedural Knowledge	3.25	3.60

A second noticeable point in Table 6.4 is the higher measures of conceptual knowledge. This observed gain in conceptual learning may be an artifact of the scoring rubric and may be related to the lower observed measures of principle coverage. Lower levels of principle coverage seem like a negative aspect of content exploration, but this may actually point to positive aspect of content exploration. Students who explore the content are mastering lower level topics before moving on to higher level topics. Explorers simply do not address many of the higher level concepts, and not covering these advanced topics lowers the principle coverage scores but not the conceptual knowledge scores (which are only based on the topics that were addressed). On the other hand, non-explorers tend cover all the topics but make more conceptual mistakes. Both groups may correctly understand a comparable number of topics, but the explorers tend to build a solid base of foundational knowledge and then have no understanding of the more advanced topics and the non-explorers tend to push through all of the topics even if they have misconceptions about some of the lower level topics.

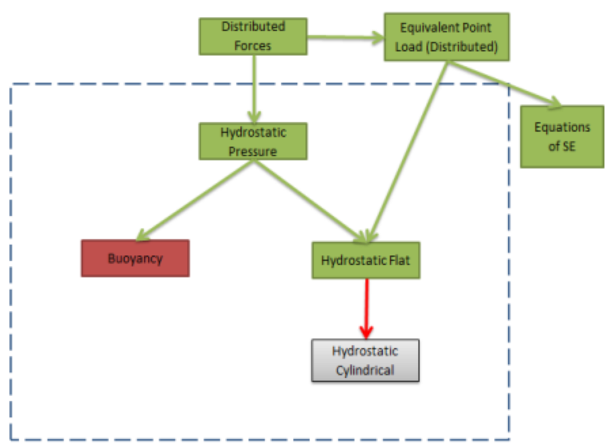
Figure 6.5 helps to illustrate this relationship by showing Paul (Adaptive Map, non-explorer), Sonya (Adaptive Map, explorer) and James's (Traditional



Paul's Explanation Concept Map
(Adaptive Map, Non-Explorer)



Sonya's Explanation Concept
Map (Adaptive Map, Explorer)



James's Explanation Concept
Map (Textbook, Expert)

Figure 6.5: CRESST Session 2 Prior Content Exploration Comparison

Textbook, expert) CRESST session 2 concept maps. Both Sonya and Paul have identical measures of advance organizer usage so this helps isolate the effects of content exploration.

As is seen in Figure 6.5, Paul (non-explorer) covered more of the topics in the prescribed section than Sonya (explorer). Both have errors and missing nodes and links, but Paul's errors are distributed over the map while Sonya's are concentrated with the more advanced topics on the bottom of the map. Sonya gave a more complete and correct explanation of the base of the knowledge, making errors and stopping once she reached more advanced topics. Paul on the other hand seemed to push through the information and move to more advanced topics even with misconceptions in lower level topics. Sonya's approach seemed to more closely match James's (the expert's) approach to learning, where mistakes were concentrated at more advanced topics. **In this way, the Adaptive Map tool appears to encourage students to learn by mastering lower level topics before moving on to more advanced topics. This method of learning better matches the expert's approach to learning new material.**

6.2.2 Characteristics of Content Explorers and Non-Explorers

After identifying the relationship between content exploration and student learning, the next step was to identify why students chose to engage in prior content exploration. The most obvious and influential factor was the tool the students were using. **Those students using the Adaptive Map tool did engage in prior content exploration while those students using the traditional textbook did not engage in prior content exploration.** This is a clear indication that the Adaptive Map tool promotes prior content exploration.

Next we can look within the Adaptive Map tool participants to examine why some students chose to engage in a large amount of prior content exploration and others just engaged in a little. Relationships were searched for between prior content exploration and the i) frequency of tool use, ii) primary tasks performed while using the tool, iii) mastery versus performance learning orientation, and iv) overall course performance. Only one factor was found to correlate to the amount of prior content exploration: the Statics Concept Inventory score. Anne and Paul had the highest Statics Concept Inventory scores of any research participants. They also spent the least amount of time exploring prior content. Other Adaptive Map participants including Gabriel, Lillian, Lisa and Sonya had scores below that Statics Concept Inventory average for all research participants. This observed relationship can be explained by a need for exploration. Those students coming into the CRESST sessions who already had an understanding of the course content (such as Anne and Paul), had less need to look backward at previously covered material. Other students who didn't know the prior content as well coming into the CRESST sessions were more likely to look back at the topic pages leading up to the prescribed topic area.

6.3 Language Complexity

Of the five students who adopted the Adaptive Map tool outside of the research sessions (Anne, Gabriel, Lillian, Lisa and Paul), three participants (Anne, Gabriel, and Lillian) mentioned the simplicity of the language as a draw of the Adaptive Map tool. Of these three students, two self-identified as non-native English speakers (Anne and Gabriel). This finding helped researchers identify an unintentional difference in the two tools - the language complexity of the content material. This difference in language complexity serves as both a confounding factor in the research and as an interesting avenue for future research.

Though the tools cover the same topics, the language in the traditional textbook (Meriam & Kraige, 2007) has a more formal and precise tone, and the language on the Adaptive Map topic pages has a more informal and conversational tone. The interaction between language complexity and the reading comprehension of non-native speakers has been examined in the literature, where some researchers have found language simplicity increases the reading comprehension of non-native speakers (Droop & Verhoeven, 1998; Luxia & Chuming, 1988) and other researchers have found no increase in reading comprehension (Johnson, 1981). This research does not seek to explore this relationship, though the accommodation of non-native speakers is an aspect of textbook design that should be addressed in future research and by textbook developers.

6.4 Cognitive Load and Learning

There were students in both groups who reported high levels of cognitive load (15 or above on the 20 point scale), such as Aaron, Gabriel, and Paul. As predicted in the literature (Paas et al., 2004), these high levels of cognitive load corresponded to lower measures of student learning (both conceptual and procedural). Theoretically, the high cognitive load imposed on these students by reading and taking notes on the assigned section interfered with learning of the content.

Of the students who reported high levels of cognitive load, two are in the Adaptive Map group and one is in the traditional textbook group. The percentage of students reporting high cognitive load is consistent across groups, so the Adaptive Map tool seems to impose a similar cognitive load to a traditional textbook. High cognitive load in one

CRESST session does seem to correspond to high cognitive load in the other CRESST session though, so students were consistent in their reported level of cognitive load across the two tasks.

The most obvious relationship between these participants with high cognitive load is low overall course performance as measured by expected course grade and reported GPA. This may be part of a positive feedback loop, where struggling students experience higher cognitive loads which hinders learning, leading to the student to fall even further behind.

All students who reported high cognitive load levels also always fell on the lowest end of advance organizer usage for their group (either Adaptive Map or traditional textbook). This would seem to indicate a relationship between advance organizer usage and lower cognitive load. Students who used an advance organizer reported lower levels of cognitive load, though there are other students on the low end of the advance organizer spectrum, such as Carol and Sonya that did not report high cognitive load levels. It is suspected that using an advance organizer is one way, but not the only way, to help manage cognitive load.

6.5 Adaptive Map Adoption

Out of the six students in the Adaptive Map group, five reported using the Adaptive Map tool on a regular basis outside the research sessions (about once a week or more). Students reported using the Adaptive Map tool to review information covered in class, to study for upcoming tests, to look up information to solve homework problems, and even to preview information before class. This high rate of unsolicited and authentic usage for a variety of learning activities indicates that the tool was an effective learning aid, at least in the eyes of the students themselves.

The Adaptive Map tool was also introduced to approximately 450 other engineering statics students at the beginning of the fall semester 2012. Website analytics software (Google, 2012) on the Adaptive Map website provided a way to track web traffic through the main page of the Adaptive Map tool. A graph of the website traffic over the course of the Fall 2012 semester is presented in Figure 6.6.

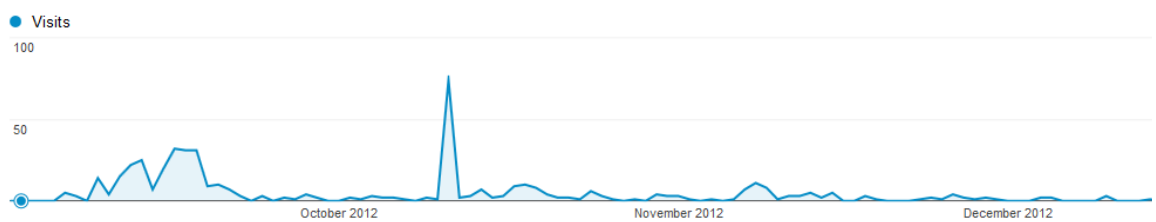


Figure 6.6: Adaptive Map Web Traffic During the Fall 2012 Semester

Figure 6.6 shows a few spikes in usage, but an overall low level of website traffic. These two spikes in usage respectively correspond to the software heuristic analysis conducted by non-statics students (discussed in Section 3.5.2), and the introduction of the tool to a second 300 person section of engineering statics. The initial introduction to a 150 person section of statics from which all research participants were drawn occurred just prior to the analytics software being activated. Other than the two spikes in student usage, the number of website visitors was limited to numbers that approximately matched the self-reported usage numbers of the research participants. This indicates that few, if any students used the Adaptive Map tool outside of the group of research participants.

All but two of the research participants also reported not using the Adaptive Map tool before the first research session, which was two to three weeks after they were introduced to the tool. This indicates an initial resistance to adopting the adaptive map, where students were reluctant to spontaneously adopt the tool. Only after becoming familiar with the tool through the first research session did students use the tool outside of the research sessions.

6.6 Chapter Summary

The two primary themes identified in sections 6.1 and 6.2 serve as the critical findings of this study. Students who exhibited behaviors that indicate the use of an advance organizer and students who spent more time exploring relevant prior content both had higher measures of learning, specifically conceptual understanding, than students who did not. Both of these behaviors were more prevalent in students using the Adaptive Map tool, indicating that the Adaptive Map tool supports these behaviors. Through supporting these behaviors then, the Adaptive Map tool is successful in its stated goal of promoting conceptual understanding in the context of digital content repositories.

The following chapter of the dissertation uses the findings presented in this chapter to directly address the original research questions, and to identify the relevance of the findings to the theory and practice of engineering education.

7 Conclusions

The overall purpose of this study was to explore how information visualization techniques could be used to design content repositories that better promote the formation of conceptual understanding.

As discussed in Chapter 1, this work is motivated by the prevalence of textbooks in engineering education practice and the scarcity of research into the use and design of effective textbooks. The transition from a paper based textbooks to digital textbooks also presents new design opportunities, making now an ideal time reexamine how to design content repositories such as the textbook.

As discussed in Chapter 2, many engineering students have difficulty developing a deep conceptual understanding of core engineering subjects. Expert-generated concept maps, serving as advance organizers, present one way to helps students develop this deep understanding. Map-shock, a reaction to large scale concept maps, prevents expert-generated concept maps from being useful overview of large sets of information though. Cognitive Load Theory helps better explain map-shock, and the information visualization literature discusses ways to manage cognitive load.

As discussed in Chapter 3, the literature on concept mapping and the literature on information visualization were synthesized to establish design guidelines for a large-scale concept map navigation and visualization tool. These design guidelines were then used to develop a prototype tool that could be used to evaluate the design guidelines. Theoretically, the prototype tool should use large-scale, expert-generated concept maps as advance organizers to better promote the formation of conceptual understanding while not imposing map shock on the tool user.

As discussed in Chapter 4, a multiple case study was used to examine how students used the prototype tool in an authentic classroom setting and what effect the tool had on student learning. Nine students, each serving as a case, used either the Adaptive Map tool or the traditional textbook over the course of the fall 2012 semester in engineering statics. For each student, data was collected on usage behaviors, cognitive load, and student learning.

The case profile for each of the nine cases was presented in Chapter 5, examining each student's experiences with the Adaptive Map tool or traditional textbook over the course of the semester. The primary themes that emerged from the data, discussed in Chapter 6, were that students using the Adaptive Map tool were more likely to show signs of using an advance organizer and that they were more likely to examine topics that were outside of the assigned section. Both of these behaviors were linked to more expert-like learning outcomes.

The purpose of the final chapter of this dissertation is to relate the findings of the research, presented in Chapters 5 and 6, back to the theoretical framework and the original research questions and then to identify the contributions that this work offers to the broader engineering education research and practice communities. Sections 7.1 through 7.4 use the results presented in Chapters 5 and 6 to answer the four original sub-research questions presented in Section 1.3. Section 7.5 ties the answers to the sub-research questions together to answer the primary research question and offers future design guidance for the Adaptive Map tool and more broadly for other digital learning tools. Section 7.6 discusses the contributions that this work offers to the theory and practice of engineering education, and Section 7.7 discusses the limitations of this work and areas for future research. Table 7.1 summarizes the research questions this work seeks to answer, as presented earlier in Section 1.3.

Table 7.1: Review of the Research Questions

Primary Research Question: **How can large-scale concept map visualization tools be realized in a way that promotes conceptual understanding and manages cognitive load?**
Sub-Research Question 1: How are students engaging in learning activities with the proposed tool? How does this differ from the learning behaviors students engage in with traditional textbook?
Sub-Research Question 2: How do these observed learning behaviors promote or hinder the formation of conceptual understanding?
Sub-Research Question 3: Are students experiencing cognitive overload during any of the observed learning behaviors, and if so how is this affecting the learning process?
Sub-Research Question 4: What factors contribute to students adopting or not adopting the proposed tool for learning activities?

7.1 Student Usage Behaviors

This section seeks to answer the questions "How are students engaging in learning activities with the proposed learning tool?" and "How does this differ from the learning behaviors students engage in with traditional textbook?" Two primary themes in student behavior were identified in Chapter 6, which will serve as the core of the discussion in this section. The primary themes were,

1. Students using the Adaptive Map tool were more likely to engage in behaviors indicating advance organizer usage. Students using either aspects of the Adaptive Map tool or the traditional textbook as an advance organizer mimicked the expert's knowledge structures and had deeper and more connected knowledge. The students more likely to use the concept maps in the Adaptive Map tool as an advance organizer were those students who primarily used the tool to study or review information outside of class, while the students less likely to use the concept maps as advance organizers were those students who used the tool primarily to look up information to solve homework problems.

2. All students using the Adaptive Map tool were observed to leave the prescribed topic area at some point and explore the information in at least one of the two sessions, while there were no observed instances of students with the traditional textbook leaving the prescribed topic area. The students who spent the most time exploring outside information, tended to not address all the topics in the prescribed topic area, but better connected the topics they did cover. This is an indication of meaningful learning. Those students who did not explore any outside content were more likely to show signs of rote learning.

Each of these themes will be discussed briefly and related back to the theoretical framework.

7.1.1 The Adaptive Map Tool and Advance Organizer Usage

The first observed difference in student learning behaviors was the use of advance organizers to precede the learning of detailed content information. As predicted in the literature (Ausubel, 1968; Luiten et al., 1980), students who used an advance organizer exhibited higher levels of conceptual understanding of the content associated with the advance organizer (see Section 6.1.2 for details).

The Adaptive Map tool featured a concept map navigation tool designed to be used as an advance organizer while the traditional textbook did not feature an advance organizer. As would be expected, students using the Adaptive Map tool were more likely to show signs of using an advance organizer than students using the traditional textbook. Some students using the Adaptive Map tool, such as Anne (Section 5.5.1), Lillian (Section 5.5.3) and Lisa (Section 5.5.4), used the concept maps as the designers intended. They looked over the concept maps, presumably processing the maps as an overview of the content in the section, and then proceeded to read the detailed content instruction in the tool. Some students using the traditional textbook, such as Aaron (Section 5.6.1) and Carol (Section 5.6.2), used the textbook as predicted. They jumped strait into the detailed content instruction provided by the book without any attempt to get an overview of the information before reading the detailed instruction.

Exceptions to this pattern existed however, there were students using the Adaptive Map tool who largely ignored the concept maps and therefore did not use them as an advance organizer, and there was a student in the traditional textbook group that used the section headings as a sort of improvised advance organizer. The presence or absence of an advance organizer is correlated to but does not perfectly predict the use of an advance organizer. Since the Adaptive Map tool featured a prominent advance organizer as part of the tool, students in the Adaptive Map group were more likely to use an advance organizer than the students in the traditional textbook group (See Figure 6.1 for a more detailed comparison).

Additionally, advance organizer usage within the Adaptive Map group was found to be related to student learning behaviors outside of the research sessions. Those students who used the Adaptive Map tool primarily to study or review were more likely to use the concept maps as an advance organizer, while those students who used the Adaptive Map tool to aid in solving homework problems were more likely to ignore the concept maps and therefore not use them as an advance organizer (see Section 6.1.3 for details).

7.1.2 The Adaptive Map Tool and Content Exploration

The second observed difference in student learning behaviors was the exploration of the content that only the Adaptive Map users exhibited. Content exploration refers to students viewing text and images outside of the section they were assigned to study for the research session. Without exception, students using the Adaptive Map tool left the section they were assigned to study and students using the traditional textbook did not leave the section they were assigned to study. Additionally, through questioning it was determined that students in the Adaptive Map group were aware that they were leaving the assigned section and that left the assigned section intentionally (see Section 6.2 for details).

Two additional observations also shed light on why students may have engaged in this behavior. First, this exploration was almost always focused on prerequisite topics to topics in the assigned section. For example a student would read about what a distributed force was before reading about hydrostatic pressure, a type of distributed force. Second, the degree of content exploration seemed to be related to performance on the Statics Concept Inventory, with the highest performers engaging in the least amount of content exploration outside of the assigned section. These two factors would seem to suggest that students lacking in the relevant prior knowledge for the assigned sections (those performing poorly on the Statics Concept Inventory) used the Adaptive Map tool to seek out and learn the relevant prior concepts before moving on to learn the assigned section.

7.2 The Adaptive Map and Conceptual Understanding

This section seeks to answer the second sub-research question: "How do these observed learning behaviors promote or hinder the formation of conceptual understanding?" This discussion will focus on the relationship between conceptual understanding and two behaviors discussed in Section 7.1.

7.2.1 Advance Organizer Usage and Conceptual Understanding

As discussed in Section 7.1, students using the Adaptive Map tool were more likely to use an advance organizer than students using the traditional textbook. This learning behavior was found to have a clear positive effect on the student's conceptual understanding of the topics within the assigned content material. Students who engaged in a high degree advance organizer usage such as Anne (Section 5.5.1), Lillian (Section 5.5.3), Lisa (Section 5.5.4), and Ryan (Section 5.6.3), had fewer misconceptions about core concepts in the content area and were better able to answer questions about core concepts in the content area. Additionally, students in the Adaptive Map group who engaged in a higher degree of advance organizer usage were more likely to connect the topics in ways that matched the concept maps in the Adaptive Map tool. This indicates that students are mimicking the cognitive structures of the expert who created the concept map, the theoretical basis of using concept maps as advance organizers.

Students with lower levels of advance organizer usage, such as Gabriel (Section 5.5.2), Paul (Section 5.5.5), Sonya (Section 5.5.6), Aaron (Section 5.6.1), and Carol (Section 5.6.2), had more misconceptions and were more likely to incorrectly answer or avoid questions about the core concepts. The concept maps of the Adaptive Map users in this group were more varied and were less likely to connect topics in ways that matched the concept maps in the advance organizer. The students at the lowest end of this spectrum, Aaron and Carol, showed clear signs of rote learning and a complete lack of conceptual understanding of the topics in fluid statics (See Figure 6.3 for an example of this).

Despite the clear differences in conceptual understanding, the students with a high degree of advance organizer usage did not score higher than the students with a low degree of advance organizer usage on measures of procedural knowledge. This indicates that advance organizer usage has a targeted positive effect on conceptual understanding with little or no effect on procedural knowledge.

7.2.2 Content Exploration and Conceptual Understanding

Also as discussed in Section 7.1, students using the Adaptive Map tool were far more likely to explore content outside of the assigned section than students using the traditional textbook. The effect that content exploration has on the student formation of conceptual understanding is complicated, but positive.

The clearest relationship between content exploration and student learning is the measure of principle coverage. Students who had spent a larger portion of their time viewing topics outside of the assigned topic area did not view and then did not discuss a larger number of topics within the assigned topic area. Strictly from a perspective of time management this makes sense, since there was a limited amount of time allotted to the students to prepare.

As discussed in Section 6.2, the vast majority of content exploration addressed topics that were prerequisite to the assigned topic area and students with lower scores on the Statics Concept Inventory engaged in more content exploration than students with high Statics Concept Inventory scores. A probable explanation for this is that students who already had a firm grasp of the more foundational concepts spent less time exploring because they already understood that information, while those who struggled with foundational concepts had more of a need to review the prerequisite topics that the more advanced topic built upon. This contrasted with the traditional textbook users who seemed to push through all of the assigned content even if they had major misconceptions about lower level concepts. The expert in this study (James, Section 5.4) addressed learning unfamiliar content in a way that better matched the content explorers. James mastered lower level topics before moving on to more advanced topics.

The Adaptive Map tool facilitated students to learn in a more expert like fashion by encouraging them master lower level topics before moving on to more advanced topics. Students who lacked the understanding necessary to master the lower level topics in the assigned section spent time catching up by viewing topic pages prerequisite to these lower level concepts. This behavior was observed as a higher level of prior content exploration.

7.3 The Adaptive Map and Cognitive Load

This section seeks to answer the third sub-research question: "Are students experiencing cognitive overload during any of the observed learning behaviors, and if so how is this affecting the learning process?" The Adaptive Map tool was designed to promote conceptual understanding through large scale concept maps by managing cognitive load, and the design in this respect was successful. The Adaptive Map group did not report higher levels of cognitive load than the traditional textbook group, indicating that using the Adaptive Map tool is no more mentally demanding than using a traditional textbook.

Also, as discussed in Section 6.4, those students who reported the highest levels of cognitive load also had lower measures of conceptual and procedural knowledge. This matches what is predicted by theory, as high cognitive load is supposed to hinder learning (Paas et al., 2004). Low measures of cognitive load did not necessarily always lead to higher measures of learning, though, showing that managing cognitive load is necessary but not sufficient to promote learning.

The students who reported high cognitive load, reported a high cognitive load across both sections. These students also all had lower than average measures of course success (expected course grade and GPA). This may indicate that these students were falling behind, which induces high cognitive load when learning new material, which then hinders learning. This cycle would make it more and more difficult for students to catch up. If this is indeed the case, a system for identifying and giving extra help to struggling students early on may be helpful.

7.4 Reasons for Adoption

This section seeks to answer the fourth sub-research question: “What factors contribute to students adopting or not adopting the proposed tool for learning activities?” This question is important because students must use an instructional tool for it to be effective, and students must choose to use a tool that is primarily an outside of the classroom tool like the Adaptive Map. Adoption rates for the Adaptive Map tool were high within the research group, but few if any students outside of the research participants chose to adopt the Adaptive Map tool. As discussed in Section 6.5, this is suspected to be an initial resistance to using an unfamiliar tool. Students in the research group were forced to become familiar with the tool, and then only after this did they use the tool spontaneously.

To increase the initial adoption rates of the Adaptive Map tool, two possibilities exist. The first is to integrate the tool into a class. By having the tool used in class or by having students look up homework problems in the book, students would be encouraged to use the tool during the first few weeks of class despite the initial resistance to becoming familiar with the unfamiliar interface. A second avenue to improve adoption rates is to further improve the usability of the interface. The traditional textbook has the advantage of familiarity, so students have to spend very little time learning to navigate and use a new traditional textbook. With novel interface systems, such as the Adaptive Map tool, having intuitive navigation and encoding design is essential to having students quickly and effortlessly learn to use the new system. Further work to improve the navigation and encoding design of the Adaptive Map tool will also be a key element to improving adoption rates. Improved design for the initial screens such as the overview (which is the first screen that students see) will be particularly important.

Features of the tool that students identified as useful during the closing interview varied, indicating a number of draws to adopt the Adaptive Map tool. The two most commonly identified useful features of the Adaptive Map tool were the concept map based layout system and the simple and more casual tone in the writing.

The concept map based navigation system is the central design feature of the Adaptive Map tool, and the fact that multiple students identified this as a useful feature of the tool speaks to the willingness of students to try this non-linear way of organizing information. Some students such as Paul (Section 5.5.5) and Sonya (Section 5.5.6) though, stated that they disliked the concept map based navigation system, indicating that not all students liked the change from a linear layout. With the Adaptive Map tool departing from the layout of a traditional textbook in a big way, some resistance to change is expected, but the majority of students in the Adaptive Map group (4/6 participants) identified the change in layout as a positive design feature.

The tone of the written topic pages was also addressed as a draw to the Adaptive Map tool. The topics addressed and the split between explanations and worked problems was kept consistent across tools, but the more simple and conversational language used in the Adaptive Map topic pages served as an unintentional difference between the Adaptive

Map and the traditional textbook. As discussed in Section 6.3, multiple students, particularly the ESL students, identified the language as easier to understand and therefore a draw to the Adaptive Map tool.

Functions such as the ability to search and the ability to customize the display (change font size, default zoom, etc.) were also identified less frequently as draws of the Adaptive Map tool.

7.5 Design Implications for Digital Learning Materials

This section seeks to draw together the answers to the four sub-research provided in Sections 7.1-7.4 to answer the primary research question "How can large-scale concept map visualization tools be realized in a way that promotes conceptual understanding and manages cognitive load?" This is a design question that has no one correct or final answer, but the findings of this work provide valuable information for the designers of such systems.

The first claim that can be made is that research hypothesis and theoretical framework were observed to be applicable in practice. Students using the Adaptive Map tool often used the concept map visualizations as advance organizers. Signs of map-shock were not present while students used the Adaptive Map tool, indicating that the interface helped students manage the cognitive load imposed while viewing a large 90+ node concept map. Furthermore, the high degree of content exploration observed in the Adaptive Map group indicates that while the interface design limited amount of information displayed at any one time, it did not hinder the cross-cluster navigation of that information. Linking these behaviors back to the back to the desired goal of the tool, students using the concept maps as advance organizers demonstrated higher measures of conceptual understanding than those students who did not exhibit advance organizer usage behaviors.

These results show potential for the use of interactive concept map based systems as a means to more effectively navigate and learn from large stores of information. The design presented in this work serves as a prototype for similar non-linear organization systems for digital textbooks and a basis for further design work in this area. There is room for further design and optimization of the system, as well as room to apply such as system to other large stores of data.

Some suggestions for the development of such systems can be offered based on the findings of this work. These suggestions are provided below

- **Deliberately design and present an overview of the information:** The core of the Adaptive Map design was created to serve as an advance organizer. Decisions on how to display an understandable overview of the information were deliberately addressed in creating the tool. The students who were most successful in learning the information were the students who utilized this overview. The student with the traditional textbook who was most successful in learning the information skimmed the section headings to get an improvised overview of the information. The action of viewing and processing an overview before reading detailed content information has been shown to have a positive effect on student learning (see Section 7.1.2 for details). Designs should encourage students to view and process an overview of the information before addressing detailed content information, and the overview presented should easy to understand and process by novices to the content area.

- **Make relevant information easily accessible:** All students using the Adaptive Map tool viewed relevant information covered earlier in the course. Students using the traditional textbook did not. The action of looking back at this relevant information benefited in the learning process (see Section 7.2.2 for details). The Adaptive Map tool made it very easy to visit this information quickly and then return, while the traditional textbook required more searching to find relevant content in previous chapters. Tools should make it easy for users to locate and visit relevant topics in other areas and then to easily return to their original location. This facilitates students' visiting and reviewing these topics and helps students connect the new topics to the relevant prior content.

- **Help users manage cognitive load:** A central design goal of the Adaptive Map tool was to help users manage their cognitive load when examining large stores of information. The tool, for the most part was successful, but those students who did report high cognitive load levels when using either the Adaptive Map tool or the traditional textbook later had lower measures of learning across all categories. Care must be taken to not clutter the screen with visuals and overwhelm the users, as this will hinder learning.

- **User goals affect usage behaviors and habits:** During the CRESST sessions all students were given the same task and used one of two possible tools. All students who used the Adaptive Map tool did not use it in the same way, though. How students used the tool during the research sessions was correlated to the activities they used the tool for outside of the research session (see Section 6.1.3 for details). It is presumed that the differing activities and goals while using the Adaptive Map tool outside of class led students to use the tool in different ways. These usage patterns then developed into usage habits, which were carried into the research sessions. The user's goals and behaviors outside of the research sessions affected the user's behaviors within the research sessions. It is important to look beyond the behaviors students exhibit using a tool in order to determine how and why students developed those usage habits with the tool.

- **Make novel design features intuitive and give students time to adjust:** The Adaptive Map tool had mixed results when measuring student adoption (see Section 6.5 for details). The tool was introduced to approximately 450 students, but remained unused over the course of the semester by all but a handful of these students. That handful of students was comprised entirely, or at least primarily, of the students in the research group. Of the six students who were in the research group, five of them ended up using the Adaptive Map tool on a regular basis outside of the research sessions. It does not seem that the adopters of the tool volunteered for the research study, though it is the research participants who became the adopters (again see Section 6.5 for details). These students had to become familiar with the unfamiliar Adaptive Map tool through the research, and then adopted it. Students outside of the research did not have to become familiar with the tool, and this resistance to learning the new interface prevented them from adopting the tool. Two avenues to improve adoption would be to i) integrate the digital tool into the class through usage in the classroom or through embedding homework problems in the tool to give students time to learn the new interface, or ii) make the interface design more intuitive so that it takes students less time to learn to use the new interface.

7.6 Contributions to Research and Practice in Engineering Education

The work presented here contributes directly and indirectly to both the practice of engineering education and to the body of literature in engineering education. This section seeks to identify these contributions, both large and small.

7.6.1 Contributions to the Engineering Education Research Community

The goals, the design, and the evaluation of the Adaptive Map tool are all grounded in the literature, and this work contributes back to that body of knowledge in engineering education. Some specific contributions that this work offers are:

1. This research synthesized work done with concept mapping and work done with information visualization in a way that was not done before. This work proves that information visualization techniques can be applied to improve aspects of student learning (Sections 2.5, 3.3.1, and 7.5). This work opens the door to a number of other fruitful collaborations between the engineering education and information visualization communities.

2. This research offered a detailed account of two behaviors, advance organizer usage (Section 6.1) and prior content exploration (Section 6.2), that were linked to the formation of conceptual understanding in students using content repositories. By encouraging these behaviors through content repository design or class assignments, future content repositories can be better utilized as an out-of-classroom learning tool.

3. This work confirmed aspects of Cognitive Load Theory within the context of learning with content repositories (Section 6.4), a context not yet addressed by cognitive load literature.

4. The process of capturing expert knowledge in the form of a broad but detailed concept map was develop and tested (Section 3.2.2). This process could be used or adapted to capture expert knowledge for an advance organizer as is done here, it could be adapted for students as a reflective end of the course learning activity, or it could be used by instructors to better plan a course and coordinate with instructors in prerequisite or post-requisite courses.

5. Concept mapping was adapted to serve as a compact but richly detailed evaluation of student transcripts for the CRESST research methodology (Section 4.4.5). This methodology still needs further development to improve inter-rater reliability, but this evaluation method has the potential to serve as a richly detailed but still compact summary of student learning.

7.6.2 Contributions to the Practice of Engineering Education

The core of this research centered on a working prototype that has proven to be effective in facilitating student learning. This work can contribute to the practice of engineering education in a number of immediate and long term ways. Some specific contributions that this work offers are:

1. This work has resulted in the creation of a tool to help promote conceptual understanding of engineering statics concepts. The tool is freely available online and could easily be integrated in existing engineering statics classes with minimal effort.

2. The software used to run the Adaptive Map program is open source and freely available. Documentation for this software is also provided with the software itself. Since care was taken to ensure content and software remained independent, subject matter experts can easily develop their own content for the tool, expanding the impact beyond engineering statics.

3. This work highlights the importance of prefacing detailed instruction with an easy to understand overview of that information. This finding is easily applied to lectures, in addition to digital textbooks.

4. This work also highlights the importance of referencing and reviewing the relevant prior content before learning the ideas that build upon those more basic concepts. Again this is easily applied to lecture, where a short review of information covered in previous weeks or even semesters may have a significant effect on student learning.

7.7 Limitations and Future Work

This study fills a number of gaps in the literature regarding the application of information visualization, advance organizers, concept mapping, and cognitive load theory, but as is often the case with research, the work raised at least as many new questions as it helped to answer.

This work looked at a single course with a single instructor. This specially selected population helped limit the number of outside factors that had to be considered during analysis. Results are suspected to generalize to the broader population of all engineering students, but further work is needed to examine how the Adaptive Map tool or other similar learning tools are used by different students, in different classes, with different instructors. The context of this study served as an authentic usage scenario for the Adaptive Map tool, but only by testing the tool within a variety of authentic scenarios can we truly make generalizable claims about the interactions between the tool and the student population.

Additionally, this study compared a single digital tool to a single traditional textbook. The specifics of the content and the layout of these two tools are invariably tied to the results of this study, and further studies examining a variety of digital interfaces and a variety of traditional textbooks is needed to determine exactly what features of these two tools are particularly salient to the student learning experience.

The author is also interested in exploring the effects of a cross-course concept mapping tool. The content in the Adaptive Map tool is currently limited to a single course, engineering statics. Expanding the content to closely related mechanics courses such as dynamics and mechanics of deformable bodies would allow not only the ability to study the effect of the tool with differing subject materials, but would also allow for cross course connections to be created and used by students. Students were more likely to explore relevant prior content with the non-linear layout in the Adaptive Map tool, and cross-course connections would allow students to easily review relevant topics addressed in previous courses before addressing the more advanced topics in later courses that build on them.

This study is also limited by its qualitative nature and its small sample size. Because of the large number of unanswered questions about how students would use the tool and what effect the tool would have in practice, a multiple case study was well suited to the situation. The qualitative approach allowed for a richer analysis of the students using the adaptive map tool with the resources available for this work. As with all research methods though, this qualitative approach had limitations as well as advantages. The findings of an experimental, quantitative analysis involving a large number of participants could be used to investigate causal relationships related to tool use and to further validate and investigate some of the themes observed in the case study.

Additional qualitative analysis could also be used to further knowledge in this area of research. The research presented here covered a broad scope because little was known about how the Adaptive Map tool would be used in practice. The themes of advance organizer usage and prior content exploration were identified as key elements in the analysis, but a deeper, more detailed analysis of these patterns could shed light on how these activities help students learn and what causes students to engage in these behaviors.

Additionally, the coding procedures and the explanation concept map creation procedures had low levels of inter-rater reliability. Though acceptable levels of code-recode and map-remap reliability were achieved, further refinement of these procedures is needed if similar methods are to be used in future investigations. The explanation concept mapping procedure in particular ended up being a key element of the analysis and a refinement of this procedure resulting in higher levels of inter-rater reliability would be a valuable contribution to the engineering education community.

Another area for future work is to more fully investigate the effects of learning orientation on content repository usage. Within the context of this study no patterns emerged related to learning orientation, but the limited sample size may be limiting the ability to relate learning orientation to student tool usage patterns. A study with a larger sample size may shed light on the suspected relationship between learning orientation and content repository usage.

In Section 2.2.2, the author introduced Ausubel's classification framework for learning experiences, where all learning experiences are classified along the reception/discovery and rote/meaningful axes. Both the Adaptive Map tool and the traditional textbook present information to the students in a more or less final form classifying them as reception learning tools. Where students' experiences differ is how students navigate the information. Students with the traditional textbook are guided on a single path through the information, while students with the Adaptive Map have to actively choose the next topic to pursue. This distinction is similar to Ausubel's reception/discovery axis in some ways, but content exploration plays no part in Ausubel's original distinction between receptions and discovery learning. A deeper examination of how to content exploration relates to Ausubel's framework could help inform the design of future learning tools.

The final area for future research is the variety of improvements for future generations of the Adaptive Map tool. This tool serves as an exemplar of the navigation system that can be integrated with a number of other digital learning tools. Obvious areas for improvement are the addition of multimedia and interactive elements on the topic pages. Another idea is to add a method to integrate homework problems and a method to track and assess student progress in various areas, showing students and the instructor which areas of the map where students are performing well in and which areas need improvement. The final identified area for expansion of the project is integrating social aspects to the program, allowing students to take and share notes, comment on the content, and to modify and share modifications of the layout itself.

This research showed that there is potential to concept map based navigation systems for digital content repositories and potential for collaboration between the engineering education and information visualization communities. The findings here serve as the base for future research and for future educational tools.

References:

Adesope, O. O. (2006). *Dynamic Concept Maps as Knowledge Representation Tools for Learning* (MS.). Simon Fraser University, Ottawa.

Alpert, S. R. (2005). Comprehensive Mapping of Knowledge and Information Resources: The Case of Webster. In S.-O. Tergan & T. Keller (Eds.), *Knowledge and Information Visualization* (Vol. 3426, pp. 220–237). Berlin, Heidelberg: Springer Berlin Heidelberg.

Ambrose, S. A. (2010). How Does the Way Students Organize Knowledge Affect Their Learning. In S. A. Ambrose, M. W. Bridges, M. DiPietro, M. C. Lovett, & M. K. Norman (Eds.), *How Learning Works: Seven Research-Based Principles for Smart Teaching* (1st ed.). San Francisco, CA: Jossey-Bass.

Ames, C. (1992). Classrooms: Goals, structures, and student motivation. *Journal of Educational Psychology*, *84*(3), 261.

Ames, C., & Archer, J. (1988). Achievement goals in the classroom: Students' learning strategies and motivation processes. *Journal of Educational Psychology*, *80*(3), 260–267.

Anderson, L. W., Krathwohl, D. R., Airasian, P. W., Cruikshank, K. A., Mayer, R. E., Pintrich, P., … Wittrock, M. (2000). A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives.

Ausubel, D. P. (1960). The Use of Advance Organizers in the Learning and Retention of Meaningful Verbal Material. *Journal of Educational Psychology*, *51*(5), 267–272.

Ausubel, D. P. (1963). *The Psychology of Meaningful Verbal Learning*. New York, NY: Grune & Stratton.

Ausubel, D. P. (1968). *Educational Psychology; a Cognitive View*. New York, NY: Holt, Rinehart and Winston.

Ausubel, D. P., & Fitzgerald, D. (1961). The Role of Discriminability in Meaningful Learning and Retention. *Journal of Educational Psychology*, *52*(5), 266–274.

Ausubel, D. P., & Fitzgerald, D. (1962). Organizer, General Background, and Antecedent Learning Variables in Sequential Verbal Learning. *Journal of Educational Psychology*, *53*(6), 243–249.

Ausubel, D. P., & Robinson, F. G. (1969). *School Learning: An Introduction to Educational Psychology*. New York, NY: Holt, Rinehart and Winston, Inc.

Ausubel, D. P., & Youssef, M. (1963). Role of Discriminability in Meaningful Paralleled Learning. *Journal of Educational Psychology*, *54*(6), 331–336.

Baddeley, A. (1994). The Magical Number Seven: Still Magic After All These Years? *Psychological Review*, *101*(2), 353–356.

Baker, E. L., Aschbacher, P. R., Niemi, D., & Sato, E. (1992). *CRESST Performance Assessment Models: Assessing Content Area Explanations*. CRESST.

Baker, E. L., Niemi, D., Novak, J., & Herl, H. (1992). Hypertext as a Strategy for Teaching and Assessing Knowledge Representation. In S. Dijkstra, H. P. M. Krammer, & J. J. G. van Merrienboer (Eds.), *Instructional Models in Computer-Based Learning Environments*. Springer.

Bederson, B. B., & Hollan, J. D. (1994). Pad++: A Zooming Graphical Interface for Exploring Alternate Interface Physics. In *Proceedings of the 7th Annual ACM Symposium on User Interface Software and Technology* (pp. 17–26). Marina del Rey, CA: ACM.

Blankenship, J., & Dansereau, D. (2000). The Effect of Animated Node-Link Displays on Information Recall. *The Journal of Experimental Education*, *68*(4), 293–308.

Bloom, B. S. (Ed.). (1956). *Taxonomy of Educational Objectives: The Classification of Educational Goals*. New York, NY: D. McKay Co., Inc.

Cañas, A. J., Carff, R., Hill, G., Carvalho, M., Arguedas, M., Eskridge, T. C., … Carvajal, R. (2005). Concept Maps: Integrating Knowledge and Information Visualization. In S.-O. Tergan & T. Keller (Eds.), *Knowledge and Information Visualization* (Vol. 3426, pp. 205–219). Berlin, Heidelberg: Springer Berlin Heidelberg.

Card, S. K., Mackinlay, J. D., & Shneiderman, B. (Eds.). (1999). *Readings in Information Visualization: Using Vision to Think*. Morgan Kaufmann.

Card, S. K., Pirolli, P., & Mackinlay, J. D. (1994). The Cost-of-Knowledge Characteristic Function: Display Evaluation for Direct-Walk Dynamic Information Visualizations. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 238–244). Boston, MA: ACM.

Carey, J. W., Morgan, M., & Oxtoby, M. J. (1996). Intercoder agreement in analysis of responses to open-ended interview questions: Examples from tuberculosis research. *Cultural Anthropology Methods*, *8*(3), 1–5.

Chang, K.-E., Sung, Y.-T., & Chiou, S.-K. (2003). Use of Hierarchical Hyper Concept Map in Web-Based Courses. *Journal of Educational Computing Research*, *27*(4), 335–353.

Clement, J. (1982). Students' Preconceptions in Introductory Mechanics. *American Journal of Physics*, *50*(1), 66–71.

Cline, M. S., Smoot, M., Cerami, E., Kuchinsky, A., Landys, N., Workman, C., … Bader, G. D. (2007). Integration of biological networks and gene expression data using Cytoscape. *Nature Protocols*, *2*(10), 2366–2382. doi:10.1038/nprot.2007.324

Coffey, J. W. (2005). LEO: A Concept Map Based Course Visualization Tool for Instructors and Students. In S.-O. Tergan & T. Keller (Eds.), *Knowledge and Information Visualization* (Vol. 3426, pp. 285–301). Berlin, Heidelberg: Springer Berlin Heidelberg.

Corbin, J., & Strauss, A. (2007). *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory* (3rd ed.). SAGE Publications, Inc.

Creswell, J. W. (2009). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (3rd ed.). Thousand Oaks, CA: Sage Publications.

Creswell, J. W. (2013). *Qualitative Inquiry and Research Design: Choosing Among Five Approaches* (3rd ed.). Los Angeles: SAGE Publications.

Dansereau, D. F. (2005). Node-Link Mapping Principles for Visualizing Knowledge and Information. In S.-O. Tergan & T. Keller (Eds.), *Knowledge and Information Visualization* (Vol. 3426, pp. 61–81). Berlin, Heidelberg: Springer Berlin Heidelberg.

Davenport, J. L., Yaron, D., Koedinger, K. R., & Klahr, D. (2008). Development of Conceptual Understanding and Problem Solving Expertise in Chemistry. In *Proceedings of the 30th Annual Cognitive Science Society* (pp. 1699–1704). Washington, DC.

Dick, W., Carey, L., & Carey, J. O. (2008). *The Systematic Design of Instruction* (7th ed.). Pearson.

Droop, M., & Verhoeven, L. (1998). Background Knowledge, Linguistic Complexity, and Second-Language Reading Comprehension. *Journal of Literacy Research*, *30*(2), 253–271.

Ellson, J., Gansner, E., Koutsofios, L., North, S. C., & Woodhull, G. (2002). Graphviz—Open Source Graph Drawing Tools. In P. Mutzel, M. Jünger, & S. Leipert (Eds.), *Graph Drawing* (pp. 483–484). Springer Berlin Heidelberg.

Fenton, A. (2012). *Weft QDA*. Retrieved from http://www.pressure.to/qda/

Fletcher, G., Schaffhauser, D., & Levin, D. (2012). *Out of Print: Reimagining the K-12 Textbook in a Digital Age*. Washington, D.C.: State Educational Technology Directors Association (SETDA).

Gaines, B. R., & Shaw, M. L. G. (1995). Concept Maps as Hypermedia Components. *International Journal of Human Computer Studies*, *43*(3), 323–362.

Ginsburg, H. (1997). *Entering the child's mind: the clinical interview in psychological research and practice*. Cambridge ; New York: Cambridge University Press.

Glaser, R. (1984). Education and thinking: The role of knowledge. *American Psychologist*, *39*(2), 93–104.

Google. (2012). *Google Analytics*.

Greeno, J. G., Riley, M. S., & Gelman, R. (1984). Conceptual Competence and Children's Counting. *Cognitive Psychology*, *16*(1), 94–143.

Halloun, I. A., & Hestenes, D. (1985). The Initial Knowledge State of College Physics Students. *American Journal of Physics*, *53*(11), 1043–1055.

Hart, S. G. (2006). NASA-task load index (NASA-TLX); 20 years later. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 50, pp. 904–908).

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Human Mental Workload*, *1*, 139–183.

Hartson, R., & Pyla, P. S. (2012). *The UX Book: Process and Guidelines for Ensuring a Quality User Experience*. Elsevier.

Herman, I., Delest, M., & Melançon, G. (1998). Tree Visualisation and Navigation Clues for Information Visualisation. *Computer Graphics Forum*, *17*(2), 153–165.

Herman, I., Melançon, G., & Marshall, M. S. (2000). Graph Visualization and Navigation in Information Visualization: A Survey. *IEEE Transactions on Visualization and Computer Graphics*, *6*(1), 24–43.

Hornbæk, K., Bederson, B. B., & Plaisant, C. (2002). Navigation Patterns and Usability of Zoomable User Interfaces With and Without an Overview. *ACM Transactions Computer-Human Interaction*, *9*(4), 362–389.

Jamieson, L. H., & Lohmann, J. R. (2009). *Creating a Culture for Scholarly and Systematic Innovation in Engineering Education: Ensuring US Engineering Has the Right People with the Right Talent for a Global Society*. Washington, D.C.: American Society of Engineering Education.

Jamieson, L. H., & Lohmann, J. R. (2012). *Innovation with Impact: Creating a Culture for Scholarly and Systematic Innovation in Engineering Education*. Washington, D.C.: American Society of Engineering Education.

Johnson, P. (1981). Effects on Reading Comprehension of Language Complexity and Cultural Background of a Text. *TESOL Quarterly*, *15*(2), 169–181.

Karagoz, M., & Cakir, M. (2011). Problem Solving in Genetics: Conceptual and Procedural Difficulties. *Educational Sciences: Theory and Practice*, *11*.

Kirsh, D. (2000). A Few Thoughts On Cognitive Overload. *Intellectica*, *1*(30), 19–51.

Lamping, J., Rao, R., & Pirolli, P. (1995). A Focus+Context Technique Based on Hyperbolic Geometry for Visualizing Large Hierarchies. In *Proceedings of the SIGCHI Conference on Human factors in Computing Systems* (pp. 401–408). Denver, CO: ACM Press/Addison-Wesley Publishing Co.

Leppavirta, J., Kettunen, H., & Sihvola, A. (2011). Complex Problem Exercises in Developing Engineering Students' Conceptual and Procedural Knowledge of Electromagnetics. *IEEE Transactions on Education*, *54*.

Lim, K. Y., Lee, H. W., & Grabowski, B. (2009). Does Concept-Mapping Strategy Work for Everyone? The Levels of Generativity and Learners' Self-Regulated Learning Skills. *British Journal of Educational Technology*, *40*(4), 606–618.

Luiten, J., Ames, W., & Ackerson, G. (1980). A Meta-analysis of the Effects of Advance Organizers on Learning and Retention. *American Educational Research Journal*, *17*(2), 211 –218.

Luxia, Q., & Chuming, W. (1988). Background knowledge and language complexity in reading comprehension——a report of an experiment [J]. *Foreign Language Teaching and Research*, *2*, 005.

MacQueen, K. M., McLellan, E., Kay, K., & Milstein, B. (1998). Codebook development for team-based qualitative analysis. *Cultural Anthropology Methods*, *10*(2), 31–36.

Mathematics Learning Study Committee; National Research Council. (2001). *Adding It Up: Helping Children Learn Mathematics*. (J. Kilpatrick, J. Swafford, & B. Findell, Eds.). Washington, D.C.: The National Academies Press.

Matheson, D., & Achterberg, C. (1999). Description of a Process Evaluation Model for Nutrition Education Computer-Assisted Instruction Programs. *Journal of Nutrition Education*, *31*(2), 105–113.

McCormick, R. (1997). Conceptual and procedural knowledge. *International journal of technology and design education*, *7*(1), 141–159.

McGill, D. J., & King, W. W. (1989). *Engineering Mechanics: Statics* (2nd ed.). PWS Kent Publishers.

Meriam, J. L., & Kraige, L. G. (2007). *Engineering Mechanics: Statics* (6th ed., Vol. 1). John Wiley & Sons Inc.

Midgley, C., Maehr, M. L., Hruda, L. Z., Anderman, E., Anderman, L., Freeman, K. E., … Middleton, M. J. (2000). *Manual for the Patterns of Adaptive Learning Scales* (pp. 48109–1259). Ann Arbor, MI: University of Michigan.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Sage Publications, Incorporated.

Miller, G. A. (1956). The Magical Number Seven, Plus or Minus Two: Some Limits On Our Capacity For Processing Information. *Psychological Review*, *63*(2), 81–97.

Montfort, D., Brown, S., & Pollock, D. (2009). An Investigation of Students' Conceptual Understanding in Related Sophomore to Graduate-Level Engineering and Mechanics Courses. *Journal of Engineering Education*, *98*(2), 111–129.

Moore, J. P., Pascal, M., Williams, C. B., & North, C. (2013). Translating Educational Theory Into Educational Software: A Case Study of the Adaptive Map Project. Presented at the ASEE Annual Conference, Atlanta, GA.

Moore, J. P., Pierce, R. S., & Williams, C. B. (2012). Towards an "Adaptive Concept Map": Creating an Expert-Generated Concept Map of an Engineering Statics Curriculum. Presented at the ASEE Annual Conference, San Antonio, TX.

Munzner, T. (2009). A Nested Model for Visualization Design and Validation. *IEEE Transactions on Visualization and Computer Graphics*, *15*(6), 921–928. doi:10.1109/TVCG.2009.111

National Academy of Engineering. (2004). *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, D.C: National Academies Press.

National Academy of Engineering. (2005). *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*. Washington, DC: National Academies Press.

National Research Council. (2003). *Beyond Productivity: Information, Technology, Innovation, and Creativity*. (W. J. Mitchell, A. S. Inouye, & M. S. Blumenthal, Eds.). Washington, DC: National Academy Press.

Nesbit, J. C., & Adesope, O. O. (2006). Learning With Concept and Knowledge Maps: A Meta-Analysis. *Review of Educational Research*, *76*(3), 413 –448.

Nickerson, R. S. (1985). Understanding Understanding. *American Journal of Education*, *93*(2), 201–239.

Niemi, D. (1996). Assessing Conceptual Understanding in Mathematics: Representations, Problem Solutions, Justifications, and Explanations. *The Journal of Educational Research*, *89*(6), 351–363.

North, C. (2001). Multiple Views and Tight Coupling in Visualization: A Language, Taxonomy, and System. In *Proceedings of the International Conference on Imaging Science, Systems, and Technology Workshop of Fundamental Issues in Visualization* (pp. 626–632). CSREA Press.

North, C. (2005). Information Visualization. In *Handbook of Human Factors and Ergonomics* (3rd ed.). New York, NY: John Wiley & Sons Inc.

North, S. C. (1996). Incremental Layout in DynaDAG. In F. J. Brandenburg (Ed.), *Graph Drawing* (Vol. 1027, pp. 409–418). Berlin/Heidelberg: Springer-Verlag.

Novak, J. D. (2002). Meaningful Learning: The Essential Factor for Conceptual Change in Limited or Inappropriate Propositional Hierarchies Leading to Empowerment of Learners. *Science Education*, *86*(4), 548.

Novak, J. D. (2010). *Learning, Creating, and Using Knowledge: Concept Maps as Facilitative Tools in Schools and Corporations*. New York, NY: Taylor & Francis.

Novak, J. D., & Cañas, A. J. (2008). *The Theory Underlying Concept Maps and How to Construct and Use Them* (Technical Report No. Cmap Tools 2006-01 Rev 01-2008).

Novak, J. D., & Musonda, D. (1991). A Twelve-Year Longitudinal Study of Science Concept Learning. *American Educational Research Journal*, *28*(1), 117–153.

O'Donnell, A. M., Dansereau, D. F., & Hall, R. H. (2002). Knowledge Maps as Scaffolds for Cognitive Processing. *Educational Psychology Review*, *14*(1), 71–86.

Olds, B. M., Streveler, R. A., Miller, R. L., & Nelson, M. A. (2004). Preliminary Results From the Development of a Concept Inventory in Thermal and Transport Science. In *Proceedings of the Annual Conference of the American Society for Engineering Education*. Presented at the ASEE Annual Conference, Salt Lake City, UT.

Ormrod, J. E. (2008). *Human Learning* (5th ed.). Upper Saddle River, N.J: Pearson/Merrill Prentice Hall.

Paas, F. (1992). Training Strategies For Attaining Transfer of Problem-Solving Skill in Statistics: A Cognitive-Load Approach. *Journal of Educational Psychology*, *84*(4), 429–434.

Paas, F., Renkl, A., & Sweller, J. (2004). Cognitive Load Theory: Instructional Implications of the Interaction Between Information Structures and Cognitive Architecture. *Instructional Science*, *32*(1/2), 1–8.

Paas, F., Tuovinen, J. E., Tabbers, H., & Van Gerven, P. W. M. (2003). Cognitive Load Measurement as a Means to Advance Cognitive Load Theory. *Educational psychologist*, *38*(1), 63–71.

Paas, F., & Van Merriënboer, J. (1994). Variability of Worked Examples and Transfer of Geometrical Problem-Solving Skills: A Cognitive-Load Approach. *Journal of Educational Psychology*, *86*(1), 122–133.

Paas, F., Van Merriënboer, J., & Adam, J. (1994). Measurement of Cognitive Load in Instructional Research. *Perceptual and Motor Skills*, *79*(1 Pt 2), 419–430.

Patton, M. Q. (2002). *Qualitative Research and Evaluation Methods* (3rd ed.). Thousand Oaks, CA: Sage Publications, Inc.

Piaget, J. (1978). *Success and understanding*. (A. J. Pomerans, Trans.). Cambridge, MA: Harvard University Press.

Pietriga, E. (2005). A Toolkit For Addressing HCI Issues in Visual Language Environments. In *2005 IEEE Symposium on Visual Languages and Human-Centric Computing* (pp. 145 – 152). Presented at the 2005 IEEE Symposium on Visual Languages and Human-Centric Computing.

Prawat, R. S. (1989). Promoting Access to Knowledge, Strategy, and Disposition in Students: A Research Synthesis. *Review of Educational Research*, *59*(1), 1–41. doi:10.2307/1170445

Purchase, H. (1997). Which Aesthetic Has the Greatest Effect on Human Understanding? In G. DiBattista (Ed.), *Graph Drawing* (Vol. 1353, pp. 248–261). Berlin/Heidelberg: Springer-Verlag.

Purdue University. (2011). ciHUB.org.

Rao, R., & Card, S. K. (1994). The Table Lens: Merging Graphical and Symbolic Representations in an Interactive Focus + Context Visualization for Tabular Information. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 318–322). Boston, MA: ACM.

Reif, F., & Allen, S. (1992). Cognition for Interpreting Scientific Concepts: A Study of Acceleration. *Cognition & Instruction*, *9*(1), 1.

Riley, W. F., & Sturges, L. D. (1996). *Engineering Mechanics: Statics* (2nd ed.). John Wiley & Sons Inc.

Riley, W. F., Sturges, L. D., & Morris, D. H. (1995). *Statics and Mechanics of Materials: An Integrated Approach*. John Wiley & Sons Inc.

Rittle-Johnson, B., Siegler, R. S., & Alibali, M. W. (2001). Developing Conceptual Understanding and Procedural Skill in Mathematics: An Iterative Process. *Journal of Educational Psychology*, *93*(2), 346–362.

Russell, T. L. (1999). *The No Significant Difference Phenomenon*. North Carolina State University.

Salata, M. W. A. (1999). *Concept Maps as Organizers in an Introductory University Level Biology Course* (PhD.). University of Virginia, Charlottesville, VA.

Schuetze, C. F. (2011, November 23). Textbooks Finally Take a Big Leap to Digital. *The New York Times*.

Scott, J., Peter, M., & Harlow, A. (2012). An electronics Threshold-Concept Inventory. In *2012 IEEE International Conference on Teaching, Assessment and Learning for Engineering (TALE)* (pp. T1A–11–T1A–14). Presented at the 2012 IEEE International Conference on Teaching, Assessment and Learning for Engineering (TALE).

Shaw, R.-S. (2010). A Study of Learning Performance of E-learning Materials Design With Knowledge Maps. *Computers & Education*, *54*(1), 253–264.

Shneiderman, B. (2010). *Designing the User Interface: Strategies for Effective Human-Computer Interaction* (5th ed.). Boston, MA: Addison-Wesley.

Spence, R. (2007). *Information Visualization: Design for Interaction* (2nd ed.). Harlow, England: Pearson.

Spurlin, J. E., Rajala, S. A., & Lavelle, J. P. (Eds.). (2008). *Designing Better Engineering Education Through Assessment: A Practical Resource for Faculty and Department Chairs on Using Assessment and ABET Criteria to Improve Student Learning* (1st ed.). Sterling, VA: Stylus Pub.

Steif, P. S. (2004). An Articulation of the Concepts and Skills Which Underlie Engineering Statics. In *Proceedings of the 34th Annual Frontiers in Education Conference* (p. F1F–5). Presented at the Frontiers in Education, Savannah, GA.

Steif, P. S., & Dantzler, J. A. (2005). A Statics Concept Inventory: Development and Psychometric Analysis. *Journal of Engineering Education*, *94*(4), 363–372.

Steif, P. S., & Hansen, M. A. (2007). New Practices for Administering and Analyzing the Results of Concept Inventories. *Journal of Engineering Education*, *96*(3), 205–212.

Streveler, R. A., Litzinger, T. A., Miller, R. L., & Steif, P. S. (2008). Learning Conceptual Knowledge in the Engineering Sciences: Overview and Future Research Directions. *Journal of Engineering Education*, *97*(3), 279–294.

Sweller, J. (1988). Cognitive Load During Problem Solving: Effects on Learning. *Cognitive Science*, *12*(2), 257–285.

Sweller, J. (2005). Implications of Cognitive Load Theory for Multimedia Learning. In R. E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning*. New York, NY: Cambridge University Press.

Wachter, L. N. (1993). *An Investigation of the Effects of Hierarchical Concept Mapping as a Prefatory Organizer on Fourth-Grade Students' Comprehension and Retention of Expository Prose* (PhD.). Pennsylvania State University.

Wallace, D. S., & West, S. C. (1998). The Effect of Knowledge Maps That Incorporate Gestalt Principles on Learning. *Journal of Experimental Education*, *67*(1), 5–16.

Ware, C. (2004). *Information visualization: perception for design*. Morgan Kaufmann.

Wiegmann, D. A., Dansereau, D. F., McCagg, E. C., Rewey, K. L., & Pitre, U. (1992). Effects of Knowledge Map Characteristics on Information Processing. *Contemporary Educational Psychology*, *17*(2), 136–155.

Willerman, M., & Mac Harg, R. A. (1991). The Concept Map as an Advance Organizer. *Journal of Research in Science Teaching*, *28*(8), 705–711.

Yin, R. K. (2009). *Case Study Research: Design and Methods* (4th ed.). Los Angeles, Calif: Sage Publications.

Appendix A: Sample Weekly Usage Survey

Adaptive Map Use Survey
Week of 10/21-10/27

Name:

How often did you use the adaptive map tool during the week of Sunday October 21st through Saturday October 27th ? (Do not include use during the research sessions)

- ☐ Not at all
- ☐ Once
- ☐ Two or three times
- ☐ More than three times

If you used the Adaptive Map tool, for what purposes did you use the Adaptive Map Tool? Check all that apply.

- ☐ To look over information prior to it being covered in class.
- ☐ To review information covered in class.
- ☐ To study for an exam.
- ☐ To look up homework problems.
- ☐ To look up information needed to solve homework problems.

Appendix B: The CRESST Explanation Codebook

Broad Codes:

Title	Description	Inclusion Criteria	Exclusion Criteria	Example
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."
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."

Sub-Codes:

Broad Code	Title	Description	Inclusion Criteria	Exclusion Criteria	Example
Procedural	Correct	The procedural content is completely correct.	Any procedural segment that contains no technical errors.	The procedural segment contains at least one technical error.	"P: So, um... the method of joints is... you pick a joint, like you pick joints separately to analyze and to write the equations of equilibrium."
	Incorrect	There are one or more errors in the procedural content.	Any procedural segment that contains at least one technical error.	The procedural segment contains no technical errors.	"P: Then the last topic that I saw that was important was buoyancy. And that equals F equal the density times the gravity times the volume of the water that it's in."
Prior Knowledge	Correct and Connected (Conceptual)	Explanation is technically correct and related and is conceptually focused.	Any prior knowledge segment that is technically correct and is correctly related to the prescribed topic area. Prior knowledge is a concept that is addressed to explain or derive a claim.	The prior knowledge segment is either technically incorrect or is not correctly related to the prescribed topic area.	"P: …when you go to the next member you can't assume that any more, it has to be equal and opposite because of Newton's Second Law... Newton's Third Law."
	Correct and Connected (Procedural)	Explanation is technically correct and related and is procedurally focused.	Any prior knowledge segment that is technically correct and is correctly related to the prescribed topic area. Prior knowledge is a procedure that is applied in the given context.	The prior knowledge segment is either technically incorrect or is not correctly related to the prescribed topic area.	"After that you can use the ... you can use the equations of equilibrium to solve for the forces that you are looking for"
	Incorrect and/or Not Correctly Connected	Explanation is incorrect or incorrectly related.	Any prior knowledge segment that is either technically incorrect or incorrectly related to the prescribed topic area.	The prior knowledge segment is technically correct and is correctly related to the prescribed topic area.	"P: If the one force not add up to zero then it would not be equilibrium. I: Okay. P: And the reason that one force is always opposite the other is that it has to satisfy Newton's third law.

	Not Connected	Explanation is correct but nor related.	Any prior knowledge segment that is technically correct, but not related to the prescribed topic area.	Any attempt is made to relate the prior knowledge to the prescribed topic area.	"P: Um... so, the multi-component assemblies basically consists of three parts, or three um, yeah three parts. These are trusses frames and machines, but all of them are based on the Newton's Third Law which says that for every action there is an equal and opposite reaction so that is the base of all the three types of assemblies.
Conceptual	Relationship to Other Concepts	Conceptual discussion relating concepts to one another.	Conceptual discussion where the participant is relating the current concept to another concept or procedure in the prescribed topic area.	No relationships discussed. Conceptual discussion contains a technical error. Conceptual discussion relates concept only to prior knowledge.	"P: So... let's start with trusses. When we analyze trusses, we have two methods the method of joints and the method of sections."
	Questioning Answer	Conceptual discussion where the participant correctly answers questioning	Conceptual discussion where the participant is subjected to and correctly answers questioning.	No questioning occurs. Conceptual discussion contains a technical error.	"I: So, when you talked about static determinacy in trusses, this [points to static determinacy equations] , what happens if this is not true? P: Then you cannot use method of joints or method of sections to analyze. I: Okay, what would happen if you tried to? P: You won't be able to solve it. I: Okay, why not? P: Because there will be more unknowns for you to solve [laughs]?
	Correct Unclear	Conceptual discussion that is correct, but questioning and relating do not occur.	Conceptual discussion where the participant does not relate information to other topics and is not questioned.	Relationships discussed. Questioning occurs. Conceptual discussion contains a technical error.	"P: The final one is frames and machines. At least one of its members, of the frame or machine, is a multi-force member. Which a multi-force member is one with three or more forces on it."

	Questioning Avoid	Conceptual discussion where the participant avoids or cannot answer questioning.	Conceptual discussion where the participant is subjected to and either states they cannot answer the question or diverts discussion to avoid answering the question.	No questioning occurs. Conceptual discussion contains a technical error.	"I: Okay so with the space trusses you can use the method of joints and the method of section? P: Yes, that does apply. I: Are they different in any way? P: That I'm not sure. I didn't take too much time to look into because…"
	Questioning Examples	Conceptual discussion where the participant answers questioning by giving an example.	Conceptual discussion where the participant is subjected to questioning and answers by giving an example, rather than directly answering the question.	No questioning occurs. Conceptual discussion contains a technical error.	"I: Let's go back to two force members, so what is a two force member? P: Two force members is... I guess we can back to the diagram of the pliers. If there was a pin BD, and a line there. That would be a two force member."
	Incorrect	Conceptual discussion where the participant is technically incorrect in at least one way.	Conceptual discussion where the participant is technically incorrect in at least one way.	Conceptual discussion contains no technical errors.	"I: Sorry, can I go back and ask a more basic question? So what is a multi-force member? P: It's when there is more than one force, is more than one force on one joint."

Appendix C: CRESST Scoring Rubric

Subject Name:

Rater Name:

Date:

Criteria	1 (worst)	2	3	4	5 (best)
Principle Coverage	Student did not cover any relevant principles	Student covered less than half the relevant principles	Student covered more than half the relevant principles	Student missed one important principle	Student covered all relevant principles
Prior Content	Student showed no indication of relevant prior knowledge	Some indication of prior knowledge, but significant misconceptions exist. Unable to relate any principles to prior knowledge	Some indication of prior knowledge, but significant misconceptions exist and/or two or more mistakes connecting prior knowledge	Student showed one misconception in prior knowledge or made one mistake connecting prior knowledge	Student showed no prior misconceptions and was able to meaningfully relate principles to relevant prior knowledge
Conceptual Knowledge	No indication of understanding of the central concepts addressed.	Two or more serious misconceptions / lack of understanding about the concepts addressed	One serious or three or more minor misconceptions / lack of understanding about concepts addressed	One or two Minor misconceptions / lack of understanding about the concepts addressed	Complete understanding of the addressed concepts
Procedural Knowledge	No indication of understanding of the central procedures addressed	Two or more serious flaws in the procedures addressed	One serious or three or more minor flaws in the procedures addressed	One or two minor flaws in the procedures addressed	Complete comprehension of the addressed procedures

Structures/Multi-Component Assemblies Rubric Addendum

Central Principles

- Structures / Assemblies
- Two Force Members
- Trusses
- Frames
- Machines
- Method of Joints
- Method of Sections
- Analysis of Frames and Machines

Relevant Prior Knowledge:

- Understanding of Newton's Third Law and its relevance to connected bodies
- Understanding of static equilibrium and couples in explaining why forces must be equal opposite and collinear for two force members.
- Understanding of the equations of static equilibrium and how to determine them.
- Understanding of how to solve the equations of static equilibrium.
- Understanding the reactions that various connections exert.

Core Concepts:

- Understanding the difference between a (frame or machine) and a truss.
- Understanding what the conditions are for a two force member to exist.
- Understanding of how two force members are represented in FBDs.
- Ability to correctly identify and separate bodies for analysis

Minor Concepts:

- Understanding of what a structure/assembly is.
- Understands that two force members must have collinear forces.
- Understanding the difference between a frame and a machine
- Understanding of how analysis of space trusses (3D systems) differs from the analysis of plane trusses (2D systems).
- Understands the equations of equilibrium can only be applied rigid assemblies.

Core Procedures:

- Method of joints involves getting the equations of equilibrium for each of the joints (just forces, not moments).
- Method of sections involves splitting the truss into sections and analyzing each body as a separate body for analysis, cut members reveal internal forces.
- Analysis of frames and machines involves separating the bodies out and analyzing them all separately.

Minor Procedures:

- For both method of joints and method of sections you first treat the truss as a rigid body and analyze to find the external reactions.
- Understands which procedures are applicable to which types of structures.
- Indicates that starting on the end of a truss where there are less unknowns is preferable.
- Knows that you must have at least as equations as unknowns (static determinacy).

Fluid Statics Rubric Addendum

Central Principles

- ☐ Hydrostatic Pressure
- ☐ Hydrostatic Pressure on a Flat Plate
- ☐ Hydrostatic Pressure on a Curved or Cylindrical Surface
- ☐ Buoyancy

Relevant Prior Knowledge:

- ☐ Understanding of what a distributed force is and that hydrostatic pressure is a type of distributed force.
- ☐ Understanding of what an equivalent point load is and in the Hydrostatic Pressure on a Flat Plate section understands how this process is finding the equivalent point load.
- ☐ Understanding of the equations of static equilibrium and how they apply to the equivalent point loads.

Core Concepts:

- ☐ Understands that pressure increases linearly with depth.
- ☐ Understands pressure always acts normal to the surfaces
- ☐ Understands that pressure forms the force distribution for later analysis.

Minor Concepts:

- ☐ Able to distinguish between absolute and gage pressure.
- ☐ Understands that increasing pressure with depth causes buoyancy force.
- ☐ Understands that buoyancy force depends upon submerged volume.

Core Procedures:

- ☐ Is able to apply the formula $P = Po + \rho gh$ to find the magnitude of the pressure. Minor mistake for misunderstanding of one variable other than h.
- ☐ Is able to correctly solve for the equivalent point load on a submerged flat rectangular surface.
- ☐ Is able to solve for the equivalent point load on a submerged cylindrical or curved surface.
- ☐ Is able to apply the formula $F = \rho gV$

Minor Procedures:

- ☐ Is able to correctly solve for the equivalent point load on a submerged flat non-rectangular surface.

Appendix D: NASA TLX Survey

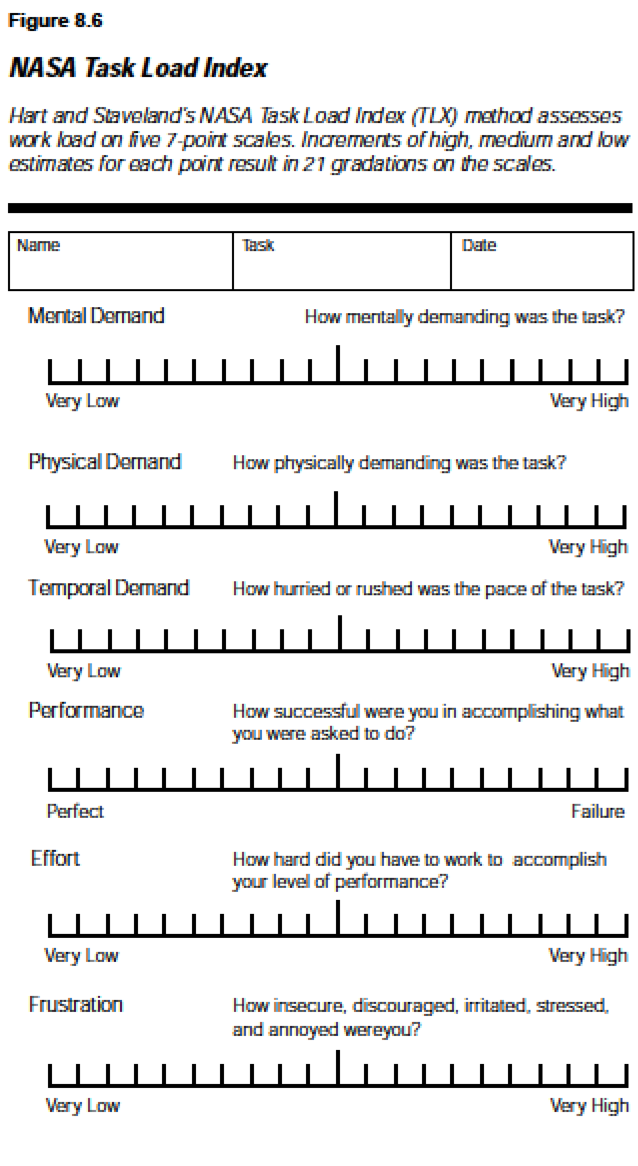


Figure 8.6

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Appendix E: Debriefing Interview Guide

Start with informal conversation unrelated to the study to put the interviewee at ease. Remind the interviewee of…

The purpose of the project
Discuss the general layout/purpose of the interview
The consent procedure/agreement

Before the interview, ask students to write down any thoughts on their (the adaptive map / your textbook) for about 2 minutes. Collect the sheet and use this this to formulate possible probes to explore during the interview.

Ask if they are ready to begin recording

Start recording:
We'll start by looking at how you used (the adaptive map / your textbook) this semester. (5 mins)
Please describe how you used (the adaptive map tool / your textbook) in engineering statics this semester.

Probes:
Did you use the (adaptive map / textbook) to look over the information that would be covered later in class and if so how often?
Did you use the (adaptive map / textbook) as a reference while solving homework problems and if so how often?
Did you use the (adaptive map / textbook) to review for exams and if so how often?

On average, how many times per week would you say you used (the adaptive map tool / your textbook)?

(Just for the adaptive map group) How often did you use your paper textbook in comparison the adaptive map tool?

What was the most common reason for using (the adaptive map / your textbook)?

Now we are going to switch gears a little bit and talk about your opinions of (the adaptive map / your textbook). (10 mins)

What are your feelings about (the adaptive map / your textbook)?

Probes:
What do you think makes it effective or not effective as a learning tool?
What did you like about it?
What didn't you like about it?

What do you think the role of “the textbook” should be in a class?

How easy do you feel it is to find the information you need in (the adaptive map / your textbook)?

Probe:

What would be an example of either a really good or a really bad experience in searching for some bit of information?

(Just for the adaptive map group) Do you feel that the adaptive map tool gave you a better or worse “big picture” of what is covered in engineering statics?

What would you change about (the adaptive map / your textbook) to make it better?

Finally, we’ll end with a few general background questions. (5 mins)

What were your opinions of the engineering statics course? (try and keep this to a minute or so)

What are you goals with respect to this course?

Probes:

Why are you taking this course?
How important are grades important to you?
Do you prefer solving problems that you already know how to solve or solving problems that you do not know how to solve?
Do you compare your performance on HW and exams to others?
What do you feel like if you receive a low grade on an assignment?

What grade do you expect to get in engineering statics?

Thank you, that’s all the questions I had. Before I stop recording is there anything else you would like to clarify or that you think would be helpful for me?