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Improving A Capstone Design Course Through Mindmapping

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ABSTRACT

Our full-year capstone design course, "Mechanical and Manufacturing Engineering Design Methodology and Application" focuses on both design methodology and design application. We redesigned the course to more effectively prepare students for the "application" aspect of design. The approach was essentially to implement a short inquiry-based learning exercise that was augmented by web-based teaching modules. This blended learning approach gave the students an immediate sense of team dynamics and project management skills necessary to complete this short exercise (and their year-long project). This paper discusses the design, testing, application and results of this two week design project and focuses specifically on mindmapping freeware. There will also be a discussion of how this project will be made accessible via an e-learning engineering design portal, which houses many projects such as the one described above.

Keywords: Mindmapping, design, blended learning

1. INTRODUCTION

Like other capstone design courses, our full-year "Mechanical and Manufacturing Engineering Design Methodology and Application" course is intended to provide students with an opportunity to learn design methodology and associated skills. In this course, students gain basic knowledge and concepts through lectures and tutorials on a variety of subjects important to the design process. The primary "vehicle" used for student learning at the heart of the course are team projects, where students gain experiential learning via a team-based, open-ended design project.

As implied by its title, this course focuses on both design methodology and design application. The first aspect of the course, design methodology, involves gaining an understanding of the Product

Development Process (PDP), the fundamentals of project management, and aspects of design theory (e.g., design for manufacture, design for the environment, robust design). Currently, this material is taught in the standard format of lectures and tutorials and is assessed using written tests.

The second and larger aspect of the course, design application, involves the application of design methodology to a team-based, open-ended design project. For example, projects from 2004/2005 include the design of a minefield mattress, a solar-powered bike, a material handling system, and a ski binding testing apparatus. Assessment of this aspect of the course is primarily through reports and design reviews (i.e., meetings between the student team, their sponsors, and their advisors) that are strategically placed throughout the academic year to correspond with each phase of the design process.

The problem that we have encountered is that students ofen enter the course with the expectation that it is about "doing a project" or become so deeply involved in their projects that they fail to see "the forest for the trees". More specifically, they often fail to see how the design process applies to the solution of general design problem, and specifically their project, and potentially miss the main message of the course.

As a result, the key issue addressed in this paper is how to more effectively enable students to put theory into practice and use the course methodology when moving on to the "application" aspect of the course. In particular, it is important that students are provided with a more meaningful presentation of the design process before they embark on their major project than they would obtain from lectures and tutorials alone.

To address this issue, we developed a short inquiry-based learning exercise, or "mini-project" that was augmented by web-based teaching modules, that provided student teams with a very compressed version of an open-ended design project at the beginning of the term before they had any preconceived notions about the design process. In this paper we focus on the development of this inquiry-based, blended learning (Fig. 1) exercise, and summarize our experience with e-learning tools in a trial project with our school's first-year Design and Communication class and in the subsequent mini-project in the capstone design course.

The paper begins with some background on the Mechanical and Manufacturing Engineering Design Methodology and Application capstone design course and its relationship to the proposed mini-project. This mini-project is meant to act as a bridge between the course methodology and application component. In Section 3, we describe our current class plan for the mini-project and identify the areas where e-learning tools appear to be most appropriate to support student and instructor activities. These e-learning tools will be used in addition to more traditional bridging methods. In Section 4, a number of course methodology and application bridging methods will be discussed, followed by a discussion of mindmapping software, one of the e-learning tools that will be used to support the

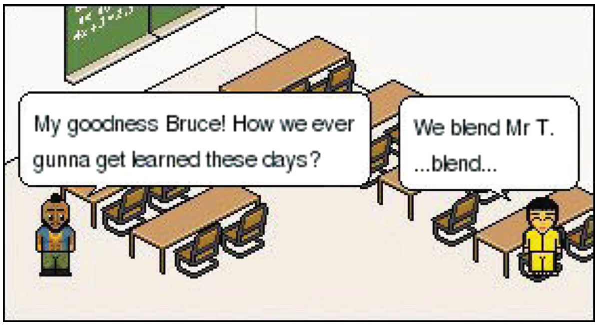

Figure 1: Blended Learning (from [1]).

mini-project. In Section 5, a pilot project and the lessons learned using mindmapping software conducted in a first year design course will be described as well as the mini-project conducted in the capstone course. Finally, in section 6, there will be a discussion of how this project will be made accessible via an e-learning engineering design portal, which houses many projects such as the one described above. The paper concludes with lessons learned and plans for our next iteration of the mini-project.

2. THE CAPSTONE DESIGN COURSE

The fourth year design course in Mechanical and Manufacturing Engineering was developed to be in line with the Canadian Engineering Accreditation Board's (comparable to ABET's) main objectives for capstone design: to provide students with a significant design experience based on the knowledge and skills acquired in earlier course work, and give students exposure to the concepts of team work and project management [2]. As noted previously, this is accomplished through conventional lectures and tutorials on engineering design methodology, with the main focus of the learning process through full-year, open-ended design projects. These team-based projects are predominantly industry-sponsored, however there is also the opportunity for teams to work on faculty-sponsored or student-sponsored projects.

Given the nature of the projects in Mechanical and Manufacturing Engineering, the course is structured around a general Product Development Process (PDP) [3] as illustrated in Figure 2. In this course, deadlines associated with deliverables such as design reports and design reviews can be thought of as "gates" between the main stages of the PDP. In other words, student teams are required to use the feedback from their reports and reviews to not only help refine their final design report, but also guide their work in the subsequent stages of the product development process.

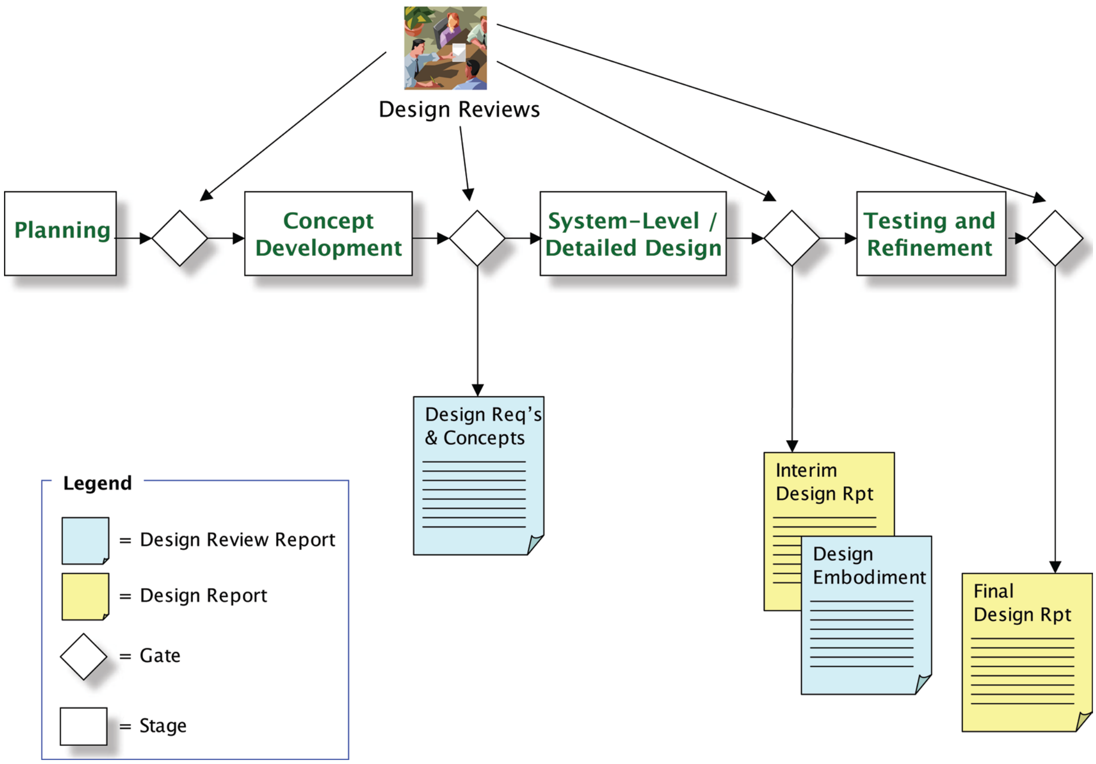

Figure 2: Capstone design course structure.

Our objective is that the students see the utility of this general methodology for engineering design during the process of their full-year project. However, our experience has been that, at best, this is recognized near the end of the course by the top-performing teams and at worst, it is viewed as a hindrance to team-members (i.e., "hoops" that they must jump through for grades).

The problem is not with the complexity of the PDP, as students appear to understand its basic principles when assessed via written tests. Instead, it appears the problem is with the application of the PDP and two basic misperceptions about design methodology. First, that the student team already has the answer to the design problem, and as a result, wants to cut to the chase rather than get bogged down in process. Second, that the PDP is a linear rather than an iterative process, as a first glance at Figure 2 would imply.

Our experience has shown that in both cases student teams discover the value of the PDP too late in the process. For example, in the first misperception, a whole set of promising solutions may have been discounted because the team rushed through the concept development phase while focused on an *idée fixe*. In the second misconception, teams may for example find themselves with a prototyping plan that does not serve to verify their product because they did not see the link between customer needs, target specifications, and prototype planning.

Although there remains some consolation to see teams discover the value of the PDP at the end of their project, it is our opinion that the students' learning experience (and course satisfaction) would be higher if they could see this from the start. In the next section we provide an overview of the previously introduced mini-project that is intended to address this issue.

3. THE MINI-PROJECT

Like the full-year project, the mini-project is designed as an inquiry-based learning approach to engineering education that involves the learner in his/her own education in order to acquire skills, critical thinking ability, and sound judgment. Through this approach, students not only gain engineering science and design knowledge, but also learn how to acquire and use it to solve real-life problems similar to their upcoming full-year project.

Unlike the full-year projects that are unique to each student team, a common project is used for the mini-project. Last year we took a Student's Union competition asking for ideas on how to improve campus life as the inspiration for our mini-project. Given the large size of our class and the short time frame for the mini-project, management becomes an issue. In order to facilitate this mini-project, a blended-learning approach is being developed that combines traditional classroom and laboratory work with e-learning technology. More specifically, we use a combination of online learning approaches via intra- and internet (e.g., interactive web pages, discussion forums, file transfer via Blackboard [4]) and specific software tools (e.g., the mind-mapping [5] software FreeMind [6]).

Students work on the mini-projects in the same team as they will be in for the full-year project over the course of 1–2 weeks during lecture and laboratory periods. A sample class plan is shown in Figure 3.

As can be seen in this figure, the lecture and laboratory periods are used primarily for hands-on student work (i.e., "exercises") on each phase of the project and presentations to their peers (i.e., "critiques"). All mini-project deliverables are in electronic form.

In order to manage the size of the class, and to keep everyone engaged, we randomly selected teams for the project critiques based on the material submitted electronically. The idea here is to allow individual teams to use their electronic submission to briefly summarize their progress at key stages of the project and field questions from their peers. These critiques also provided the instructor team the opportunity to comment on the teams' decisions in the context of the PDP.

Week	Day	Lecture	Lab	Deliverable
1	Wed.	Introduction to PDP; Introduction to the Mini Project exercise.	Mindmapping & FreeMind software tutorial; **Requirements** exercise	
1	Thur.			**Requirements** phase notes (in FreeMind) due on Blackboard.
1	Fri.	**Requirements** critique; **Concept Generation** exercise		
2	Mon.	**Concept Selection** exercise		
2	Tue.			**Concept Generation** and **Concept Selection** phases notes (in FreeMind) due on Blackboard
2	Wed.	**Concept Generation** and **Concept Selection** critique	**Design Embodiment** and **Prototyping** exercise	
2	Thur.			**Design Embodiment** phase notes (in FreeMind) due on Blackboard
2	Fri.	**Verification** exercise (e.g., competition)		
	Mon.	Mini Project critique and awards		

Figure 3: Mini-project class plan.

We feel that by supplementing the in-class work shown in Figure 3 with e-learning technology, students will not only be provided with the requirements of the mini-project exercise on-line, but will also be invited to publish and share their own content about this inquiry topic. In this case, student teams will share their views on the design process. For example, they may be asked to discuss the following:

1. What types of activities were undertaken during the development of your campus improvement idea and what was the approximate percentage of time devoted to each activity?
2. How would you change the design process with a view to improving the feasibility of your idea?
3. What are the best aspects of working on a team?
4. What are the worst aspects of working on a team?

The idea is to facilitate, in person (i.e., during class time) and on-line, discussions on design process issues that will serve as material for future lectures on design methodology. For example, the "activities" discussed in the first question should lead nicely into the activities involved in each phase of the design process, while discussion on the third and fourth questions should help teams identify their limitations. Additionally, it is hoped that this material will be more relevant to the students since is came from their own experiences.

Before discussing the e-learning technologies selected to facilitate the mini-project, a brief summary of current methods of linking or bridging design theory with design application will be discussed.

4. BRIDGING METHODS

During the lectures, product development processes, project management and design theory are addressed. The challenge to the students is to apply lessons learned to their team-based open-ended design project. Current methods typically used to monitor student research into design requirements, concept generation, detailing and verification stages of the design process are the use of logbooks, instructions sheets and case studies. This section will discuss the pros and cons of these four "bridging" methods. In our case, bridging refers to the process of connecting the methodology of design in the shape of lectures and tutorials to the actual application of design.

One method of keeping track of the design process is the student logbook. The advantage to the logbook is that it is portable and spontaneous. Largely a free format—students do have to date pages, add signatures when needed, and cross out blank spaces when pages are unused—students can take minutes, do calculations and sketch and discuss design ideas.

The fact that the logbook is an individual document is a pro and a con, in the sense that it does show an individual's contribution to the group but does not show the groups' progress as a whole. The disadvantage to the logbook is that it has less structure and can be random and unorganized. It is also a linear format which does not always allow for connections to be made to previous ideas or observations. Logbooks are very useful facilitators of individuals' work within a design team, but provide little in the way of communicating the team's overall work on the project.

In addition to requiring a logbook, an instructor might make use of "project requirements" sheets as additional bridging method. Project requirements documents (and also the corresponding rubrics) spell out what is required from the students for written reports, design reviews, etc. The sheets control the outcome, ease student stress (since they have a good idea of what the instructor wants), and help to ensure consistent assessment across multiple instructors. Unfortunately, there is a price associated with this structured approach: requirements sheets and rubrics may limit student creativity, can overly direct students, and are viewed, especially by students, as being rigid. Project requirement sheets are a balancing act; specific requirements help with assessment and provide structure for the students (which is typically appreciated by engineers) at the possible expense of creativity (which is sought after for designers).

Another bridging method is the use of case studies which show students previous processes that may mirror or trigger ideas for their future design attempts. The advantage of case studies is that they are "real" and allow students to learn by example, much like the court system's use of precedents. While case study will have the content the instructor is trying to get across, this content may be too diffcult to see. The content may also be too limited to show the overall process because it is too specific. In order to be a manageable learning tool, a case study also tends to be smaller than a realistic design, i.e., the type of design the students encounter later in the course and even later in practice.

A final bridging method is the use of concept maps to map the cognitive progress of a design. One form of a concept map is the mindmap, which associates concepts by linking them together in a tree structure. The advantage to the instructor is that he/she can show a general, non-specific project map. This map can be detailed for specific projects, triggering the appropriate questions at the appropriate stages.

FreeMind was selected as the e-learning software to help students perform a mindmap, and is, as the name suggests, a free download compatible with Linux, Mac OS X, and MS Windows (this was a requirement for the software). FreeMind proved to be flexible, intuitive, easy to use, and allowed concepts to be easily linked together in a graphical format (Fig. 4a). It is "a good way to organize information because it helps students to pull together information already known about a subject (Fig. 4b) and to comprehend new information as they learn" [12]. It is also image-oriented (Fig. 4c) and allows easy creation of pdf's, web pages and linked outlines. It forces organizational thinking, yet still allows for changes on-the-fly. The use of FreeMind allowed groups to create a team logbook. Each team member was able to contribute to the map, since the software was easy to use and easy to share. It made each team member aware of the 'state' of the design process. Often design teams will divide tasks to the extend that half the team is not up to speed on the finer details. This may be acceptable during a longer design project where there is time to catch up, but in the case of a 2-week project the entire team has to be 'on board'.

A test design project using this software was conducted in a first year design course. The next section discusses the findings from this pilot project and introduces our first iteration of the capstone mini-project.

5. A SHORT INQUIRY-BASED DESIGN EXERCISE FOR FIRST AND FOURTH YEAR STUDENTS - EXPERIENCES

First Year

A pilot project was conducted in a first year design course using FreeMind mindmapping software. Of interest was whether the use of mindmaps would result in a more thorough approach to a design problem. Buzan [5], describes a mindmap as "a graphic technique, which harnesses the full

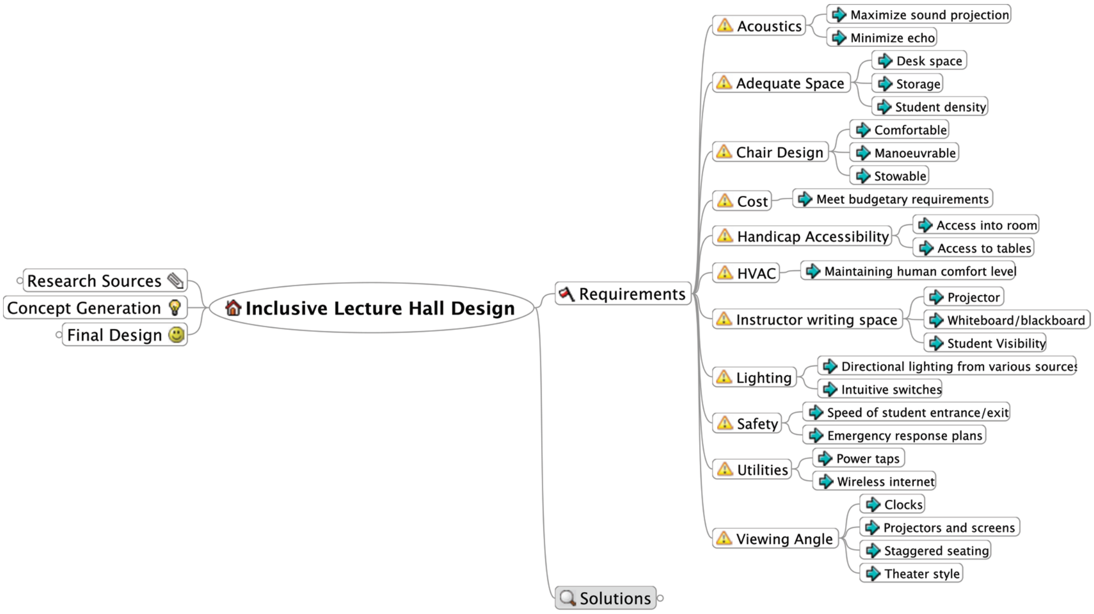

Figure 4a: Student mindmap.

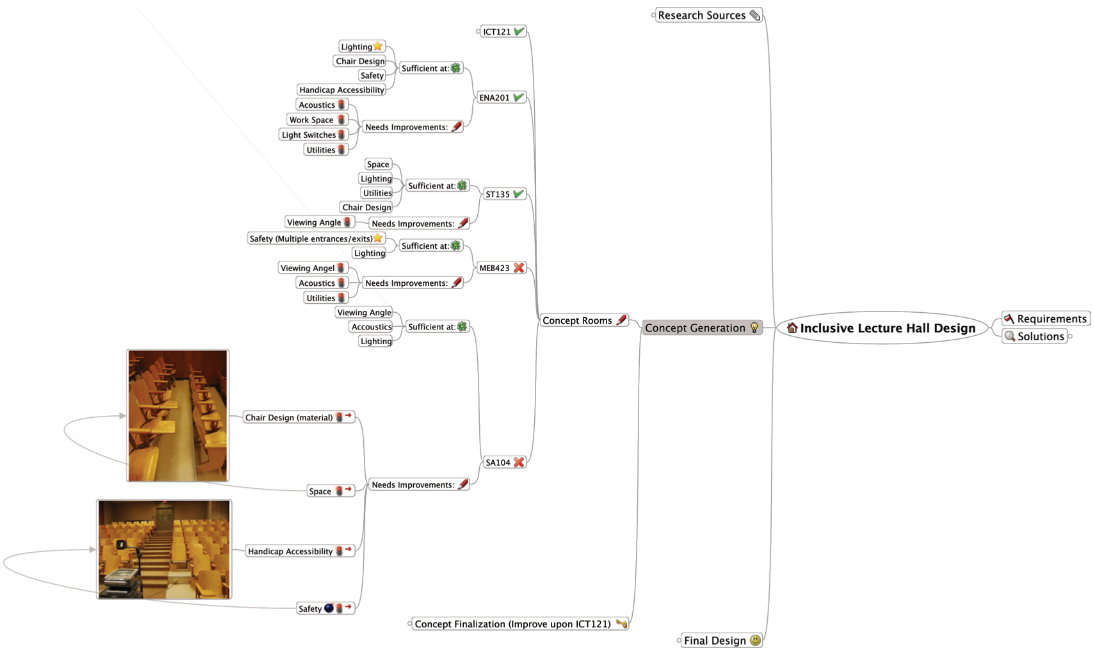

Figure 4b: Student mindmap.

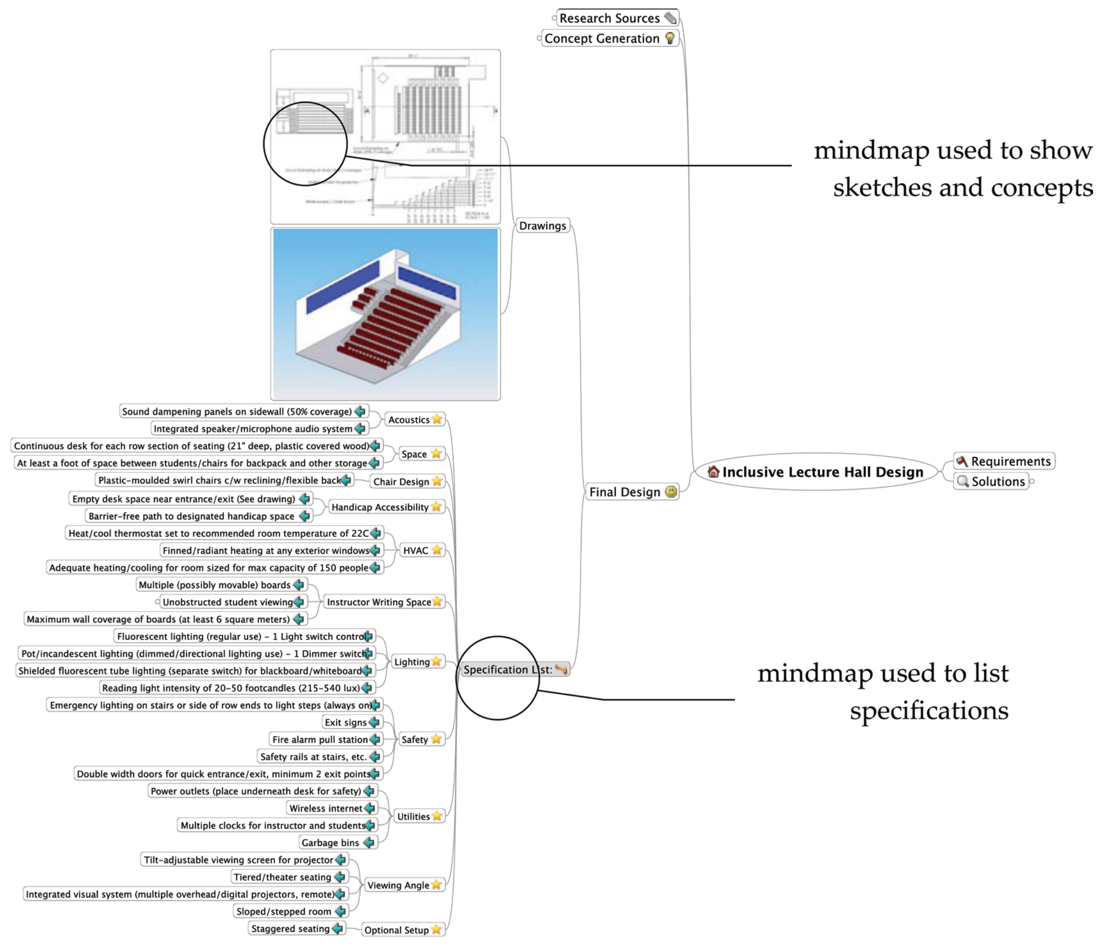

Figure 4c: Student mindmap.

range of cortical skills—word, image, number, logic, rhythm, color and spatial awareness". The pilot project is intended to gain insight into if students using mindmaps in a design project would:

1. See the forest for the trees.
2. Create a simulation of a "team" logbook.
3. Make easy connections between design stages.

In addition, the pilot project is intended to test if mindmaps will allow instructors to see when a design project may have gone off-track.

In the winter term of 2005/06, all 550 first year engineering design students were introduced to FreeMind. They were given a 'how-to-use' FreeMind map made with FreeMind and a brief in-class demonstration. This software is easy and intuitive to use and requires minimal instruction. Most students were able to use it effectively after about half an hour. The software tool was used for a three-week redesign project that was part of a year long project with Engineers Without Borders (EWB). Students were asked to redesign the existing, somewhat mature technology of a treadle pump. Students were given some requirements up front, one of which was that women and children should be able to operate the treadle pump. The project was largely focused on design management, part of which was to create a Gantt chart.

Students had to create three mindmaps using FreeMind, capturing the status of their redesign at the end of each week. The software allowed, as previously mentioned, the easy creation of an outline, which some groups used to structure their final reports [Fig. 5a–d].

We observed that by using the non-linear mindmap format students were able to see how some design ideas did not meet the customer requirements, and that some concepts had to be revisited after the detailing and verification stages of the design process [Fig. 8]. When used, this revisiting/linking software function was one of the approaches that resulted in good mindmaps. Figure 8 shows a partial map in which students showed that a final design decision was made based on a comparative analysis of three design concepts.

FreeMind was given to the students as a tool to explore. Other than having to show the process of redesign over a three week period, no specific deliverables for content were required for each week. But, in the final analysis of 150 maps created in our pilot study, it was determined that some initial requirements would have been useful to set the students on the right track.

Several areas of interest appeared during our analysis of the maps [Fig. 7]:

- The shape of the map was directly correlated to the quality of the map.
- Vertical-oriented or round maps (≈75%) tended to be thorough and well-planned.
- Horizontal-oriented maps tended to be of poor quality and not thorough.

Within the vertical maps two common characteristics emerged:

- Repetition as an organizational tool was used by about 50% of the class.
- The repetition of node- and branch-structure caused a more complete analysis of each engineering theory category.

The first year class is introduced to a design process we call: familiarization, functionality and testing. Students go through an iterative process and check decisions at each stage. In the testing phase students should be checking ‘back' to see whether the tests fulfil and answer the requirements found in the familiarization phase. By repeating questions asked within each testing node, students were able to check whether they had considered every aspect of the design familiarization and requirements and whether each aspect had been addressed in the following stages [Fig. 8]. Other characteristics that emerged:

1. Groups that added a separate branch focusing on project management (≈50%) also tended to show a thorough discussion of their redesign project. This project management branch forced

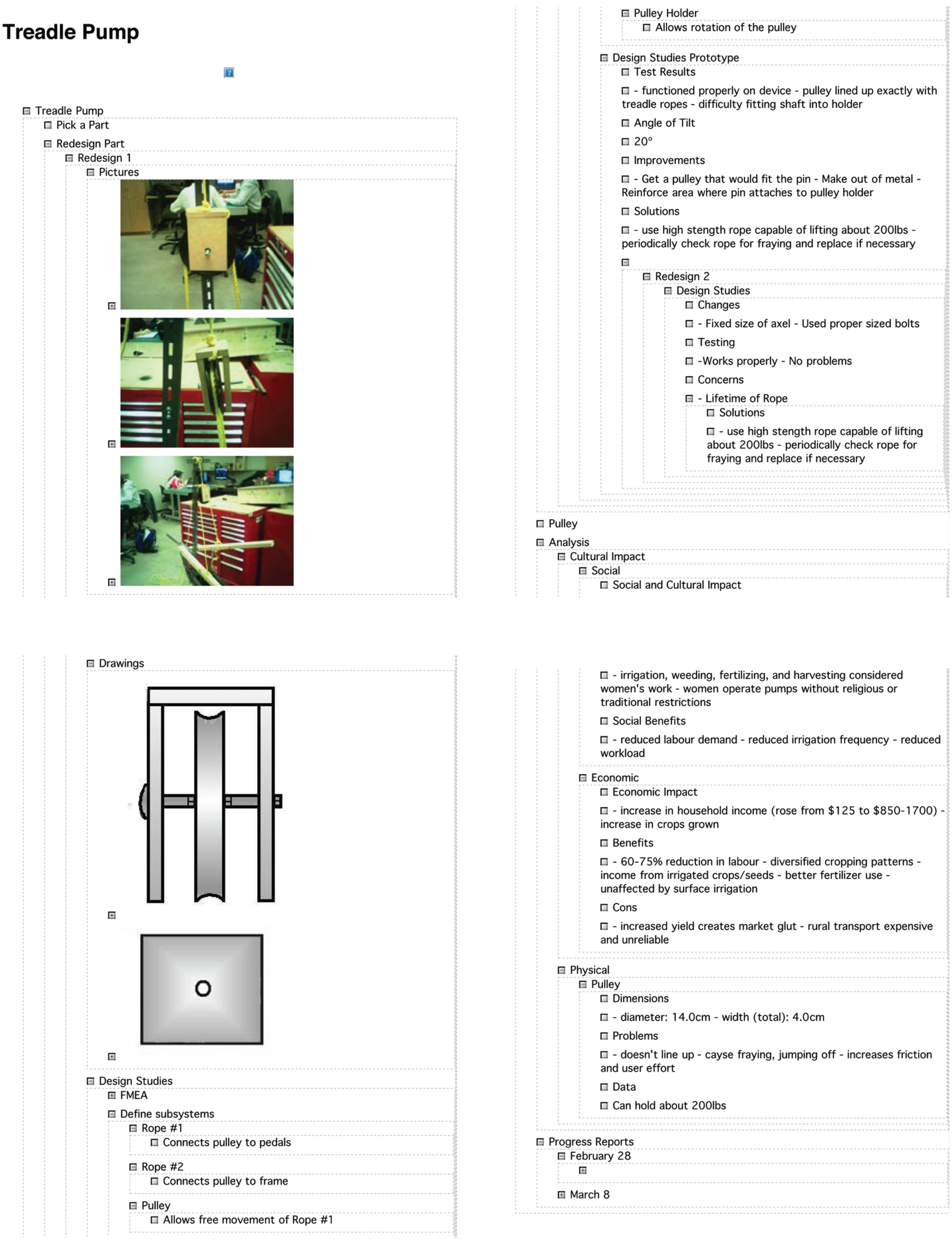

Figure 5(a–d): Mindmap as XHTML linear outline.

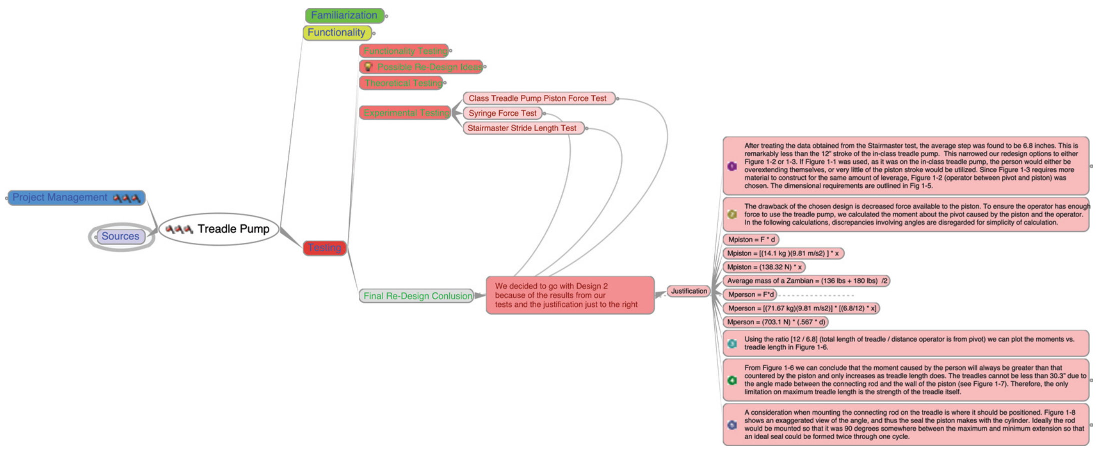

Figure 6: Linking function.

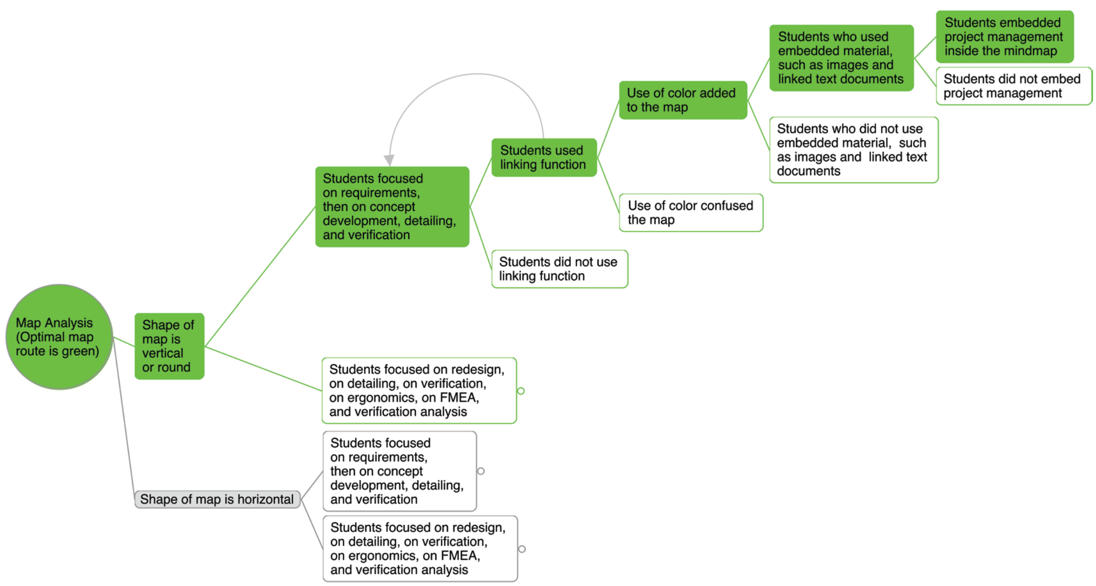

Figure 7: Optimal mindmap route.

all group members to look at and use the map frequently—very little was forgotten. One of the requirements for future mindmap projects should be a project management component, embedded within the map.

2. A function that no logbook or case study has, is the linking function. Students can visually show in the map where they have gone back to do more research or where they came to

certain conclusions that were crucial to their final design [Fig. 6]. About 45% of groups used this linking function, all of these groups had maps that had a vertical or round shape, perhaps because of the linking arrows, but this linking showed a thoroughness and in general a more rigorously developed map.

3. Another aspect that was looked at was the size of sections branching out from the central "problem statement" node. A significant number of groups (≈38%) did a very good customer requirements/familiarization branch. These groups did well in terms of redesign and concept generation because they had a thorough understanding of the problem and were able to link back to potential customer utility. Well developed requirements/familiarization branches resulted in larger subsequent branches and a generally better design outcome. An additional 4% of groups focused largely on ergonomics, a requirement specifically mentioned by EWB. The pump had to be able to be used by women and children.

   In contrast, 38% of groups focused on the redesign aspect of the project, and on detailing and functionality. Even though these groups made maps, they still got lost in the forest because they jumped to one design idea and never let it go. This group would have been helped by a set of requirements before beginning the mindmap.

4. Little use was made of embedded images and linked text or spreadsheet documents: only about 20% of groups made use of these functions [Fig. 8]. The mindmap is first and foremost a visual document, meant to give an instant overview of the design process. Images direct the eyes much faster than text and are therefore a good map design element. The embedded text files make for a very thorough map and a generally better supported document. The inclusion

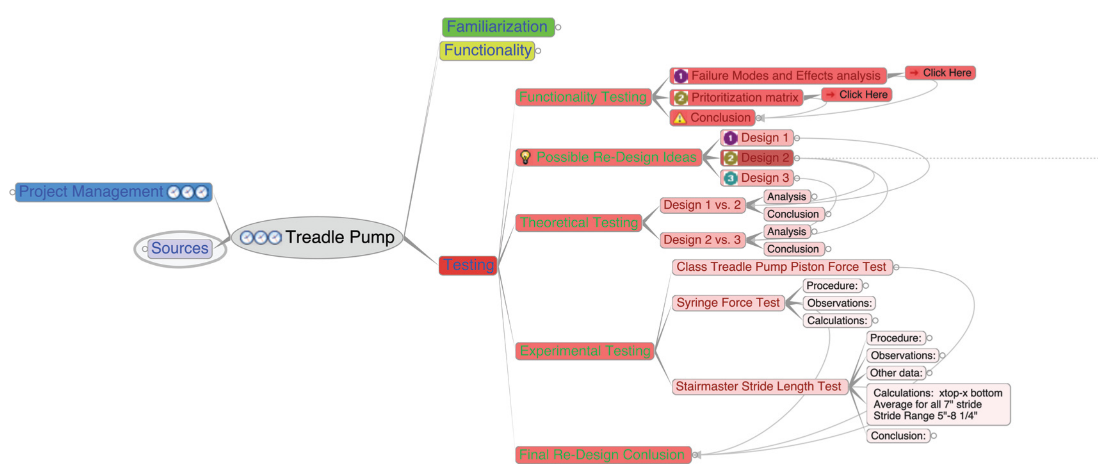

Figure 8: Embedded files and repetition.

of images and text files also resulted in a very rich XHTML document for possible website use. This area will be stressed in the requirements for the mini-project.

5. A final observation was the depth of the maps. Groups that used four or more sub-categories in each branch ended up with a very detailed design [Fig. 8].

The mindmaps in this pilot project provided the students with a new group work/group management tool. In addition, the maps were useful in generating project status reports and final report outlines. The maps organized research material easily and quickly [6]. With some additional direction from the instructors, the mindmapping software proved to be a good additional "bridging" tool for the mini-project.

Fourth Year

From the pilot project, we were able to answer the four questions set at the beginning of Section 5. Students began this project with minimal instruction. Our analysis of their work indicates that a significant number of students were able to see the "forest for the trees", with 38% having detailed maps. Approximately 45% of teams included a project management branch in their map, showing that many teams were also using the map as a team logbook. Also, mindmaps were partially successful in providing better connectivity between design stages—approximately 38% of the teams made use of the linking function. Finally, the mindmaps clearly demonstrated that 38% of teams went off track by only exploring one design solution. Overall, our pilot study successfully demonstrated mindmapping capabilities.

In September of 2006 we ran the first official mini-project in the fourth year capstone design course. FreeMind was introduced in lecture at the start of the mini-project. By the end of the 15 minute presentation, most groups had already downloaded, installed and started a mindmap. In piloting this exercise, students proposed mini-projects that focus on campus improvement as part of a campus-wide competition. It was felt that after four years on campus, students have many improvement ideas. The goals of this exercise were to:

- provide teams the opportunity to work together before embarking on the full year project
- introduce teams to the full PDP (product development process) in a short period of time
- gain an appreciation of the relationships between each phase and the importance of following a process for product design.

The mini-project was to give students the opportunity to see the overall challenges and opportunities of the PDP over a short period of time, setting the context for the lectures to follow. Although the mini-project was much smaller in scope and shorter in duration than the full project, the basic process was the same.

The mini-project exercise was structured to move teams through each of the phases of the PDP in a short period of time. Students were required to use their experience to date to tackle each of

Mini Project Questionnaire Summary Results: Sept. 2006

sufficiently completed questionnaires for consideration: 52
discarded questionnaires (lack of meaningful comments): 6
completed questionnaires = 52 + 6 = 58

What was the best aspect of the mini project?

- Number of questionnaires with meaningful answers (47)
- Team building and/or ice breaking within team and introduction to group dynamics in advance of the main project (31) 66%
- Walking through a project start to finish / overview of the PDP (8) 17%
- Learning new software (7)
- Good topic (4)
- Miscellaneous comments:
  - Question and answer during presentations
  - Learn difference between requirements and solutions
  - Intro to course

What was the most frustrating aspect of the mini project?

- Number of questionnaires with meaningful answers (48)
- Took time away from the main project (18) 38%
- Little time between intro to concepts and deliverables (18) 38%
- Vague goals/requirements/deliverables (11)
- Too rushed (10)
- Lack of feedback for all groups (5)
- Learning new software (2)
- Miscellaneous comments:
  - Group presentations (including audience criticism)
  - Lack of structure for the project
  - Cannot implement the concepts

What recommendations would you make to improve the mini project?

- Number of questionnaires with meaningful answers (30)
- Improved feedback for the groups (8)
- Give more time for / reschedule deliverables (7) 23%
- Make it shorter (6)
- Improve clarity of requirements for deliverables (5)
- Incorporate into main project (4)
- Get rid of the mini project (4)
- Make it longer (3)
- Miscellaneous comments:
  - Narrow the scope
  - Topic needs more creativity
  - Choose a topic of merit
  - Hands on project
  - Focus on the process rather than the project
  - Mindmap software on MEB PC's
  - Mindmap tutorial

Figure 9: Student survey questionnaire.

the phases. Groups were expected to work effectively as a team to achieve the overall goal of the project, breaking the problem down into manageable pieces using a "divide and conquer" approach. Given the short time frame for the mini-project, teams had to work to:

- manage each phase of the project and the available resources
- communicate effectively within the team and with "customers".

This was an opportunity to see what works and what does not work for teams before proceeding on the full year project. The mini-project experience was to avoid making the same mistakes in the larger project, and more effectively manage team activities during the full year project.

A survey [Fig. 9] was conducted at the end of the mini-project to get feedback from the students. 66% of students thought the project was good for team building and/or ice breaking within the team and an introduction to group dynamics in advance of the main project. Seventeen percent felt that it was good to walk through a project start to finish and get an overview of the PDP.

Students also experienced some frustrations with the project. Thirty-eight percent felt it took too much time away from their full year project. Another 38% felt that the time between the introduction to concepts and the next deliverable was too short.

We also asked students to identify areas of improvement. Twenty-five percent would have liked more feedback to individual groups. After each phase of a deliverable four teams were chosen at random to present their next findings, these findings were then discussed in class with a group of 80 students. It is understandable that each group would have benefited from a critique situation each time, but given the allotted time for the project this would have been impossible logistically. Another 25% would have liked to have had more time for the project, however 15% felt the mini-project should have been incorporated in the full term project.

At the end of the mini-project groups had come up with very good ideas for the campus improvement competition (Fig. 10). They will have a chance to submit these ideas to the competition this semester.

One of the biggest differences between the first and the fourth year maps was visually. First year students did a thorough job of color coding branches and including lots of images. Perhaps a leftover from high school, but important for the clarity of mindmaps. The fourth year class, perhaps more jaded at this stage in the game, seemed reluctant to include color and images and perhaps felt this was too juvenile. Luckily the capstone group made up for lack of color and graphics with more engineering content (as one would hope after 4 years) and a clearer concept of problem goals and solution criteria.

The first and fourth year mindmaps provided a lot of useful information that has led to some restructuring of design assignments and approaches. In the first year program mindmapping has become a permanent feature of the curriculum. In the fourth year course the second iteration of the mini-project was held in September 2007. A comparison between the first and second iteration is

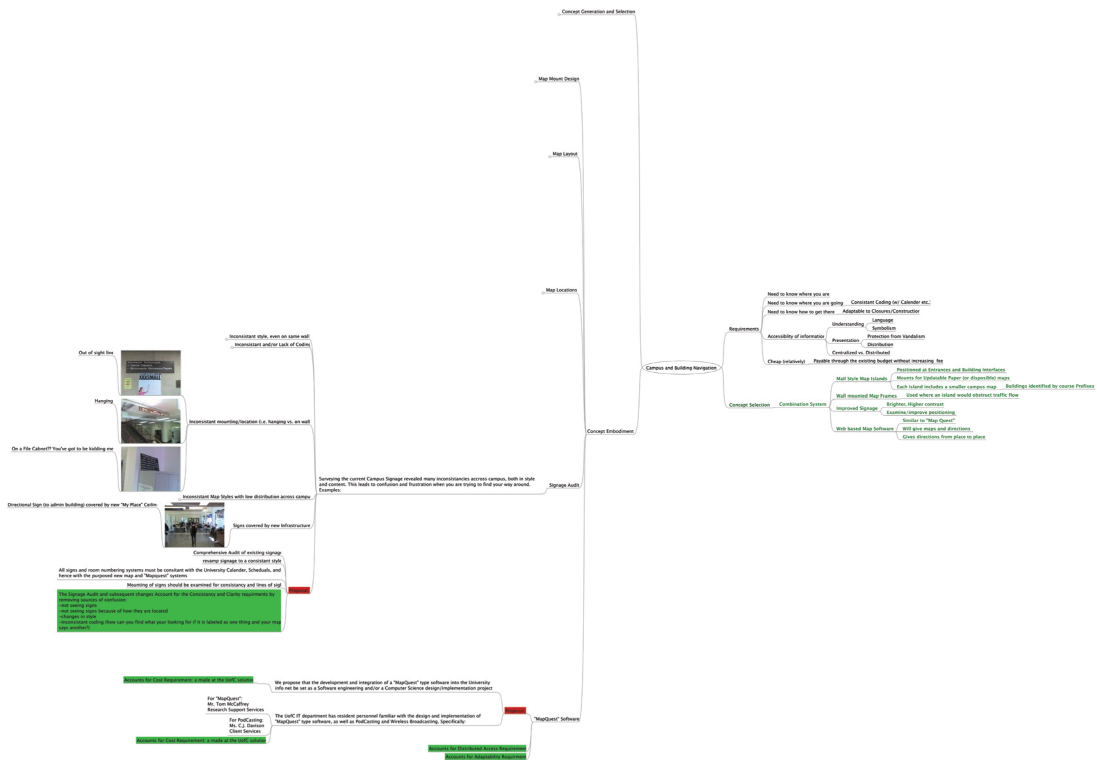

Figure 10: Improving Campus Navigation.

also under way. To make our material available to other programs, we are turning the mini-project into a design module on a website called the CDEN e-Design portal. In the following two sections CDEN and the e-Design portal are described.

6. CDEN DESIGN MODULES

In order to make this work accessible, we are currently in the process of developing an on-line courseware module that will allow both engineering design educators and students to the opportunity to share their experiences in this area. The basic idea is to use the inquiry-based blended learning project described in the previous section as a template for short design projects at other universities and to combine this with a repository of projects.

In recent years there has been considerable interest in on-line courseware for engineering education. Most notably, the MIT OpenCourseWare (OCW) project [7] has attracted considerable interest from engineering educators and has spawned a number of similar OCW projects from universities in China, Japan, Vietnam, and the United States. Already this work is approaching MIT's original vision of a global Web of knowledge to improve education around the world; however, as the amount of on-line material grows, it is becoming more and more diffcult for engineering educators to keep abreast of their individual fields of interest.

In the area of engineering design education, the Canadian Design Engineering Network [8] is currently promoting a similar on-line initiative focused on promoting the development and the sharing of educational engineering design tools. Central to this is the notion that the internet will be used to deliver design-directed learning modules to improve engineering design competency in future engineering graduates [9].

CDEN was established in 2000 to promote the development and the sharing of educational engineering design tools among all Engineering Schools within Canadian Universities. The general goals of the CDEN/RCCI network are to "enable the communication of best design practices between schools, promote the production and sharing of courseware, help inject more real design experiences into the university, and allow all schools to access the best available expertise in areas of detailed interest" [10].

A central aspect of the CDEN project is the joint development of web-based design courseware modules that can be shared by members of the CDEN community. These courseware modules were at first considered to include lectures, case studies and open-ended design projects. The basic idea was to support existing faculty with design materials and encourage schools to collectively build the critical mass within a team environment needed to promote the importance of design and effect significant improvement in existing programs.

In order to make these engineering design courseware modules accessible to students and educators, the authors, in conjunction with the University of Calgary's Learning Commons [11], have developed the CDEN e-Design Portal [12] as shown in Figure 11. This portal is used to manage the submission, searching, and retrieval of CDEN modules.

To organize CDEN design courseware modules submitted to the website, "topics" and CDEN Tiers are being used to provide the website with a sense of structure and context. The portal's front page features a given topic or tier, as well as highlight various modules of interest, whether they are the newest resources to be added, or the most popular resources at that time. This general structure is shown in Figure 12.

From this front page, users are able to view pages for each tier and topic. These pages feature editorial content that further contextualizes the materials in a magazine-like format. There is also a way for users to contribute to discussions on that topic or tier, providing a means for them to build their own context.

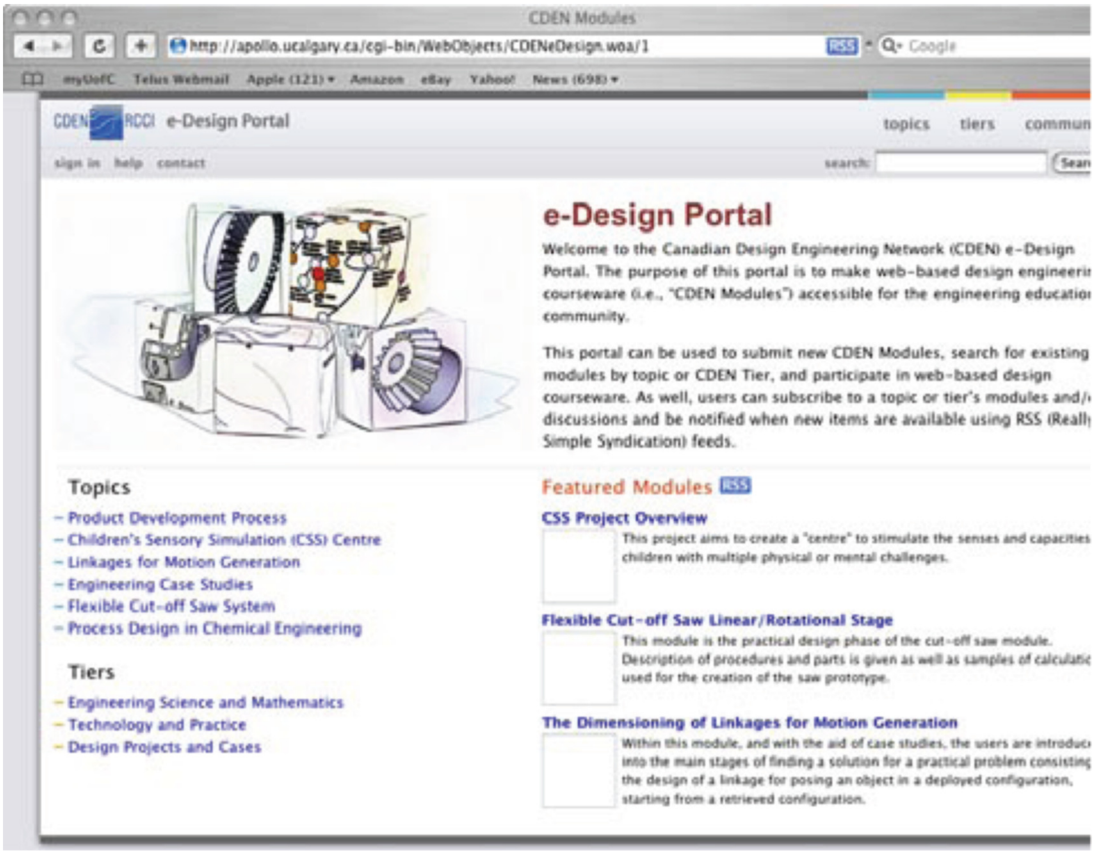

Figure 11: The CDEN e-Design portal.

The modules used throughout the tiers and topics have various relationships to each other. For example, a topic might have several modules at various levels of abstraction (i.e., "tiers") that can be inferred to be related by topic. These relationships are used to help guide instructors and students to various modules that can be used to support their teaching and learning, without forcing them to perform additional searches to find these resources. A user would be able to select a module to view more information about it and be provided with a list of other modules that are used in the same tier and/or topic as the selected one.

Although metadata is important to enable efficient indexing and retrieval of modules, the focus is shifted from metadata to the modules themselves for users. For example, users are provided with a guided interface for metadata entry which asks the user questions about the module being added and combine that with an analysis of the module itself (both the file and its contents) when building the metadata description of the module. Since the teaching of engineering design competency is

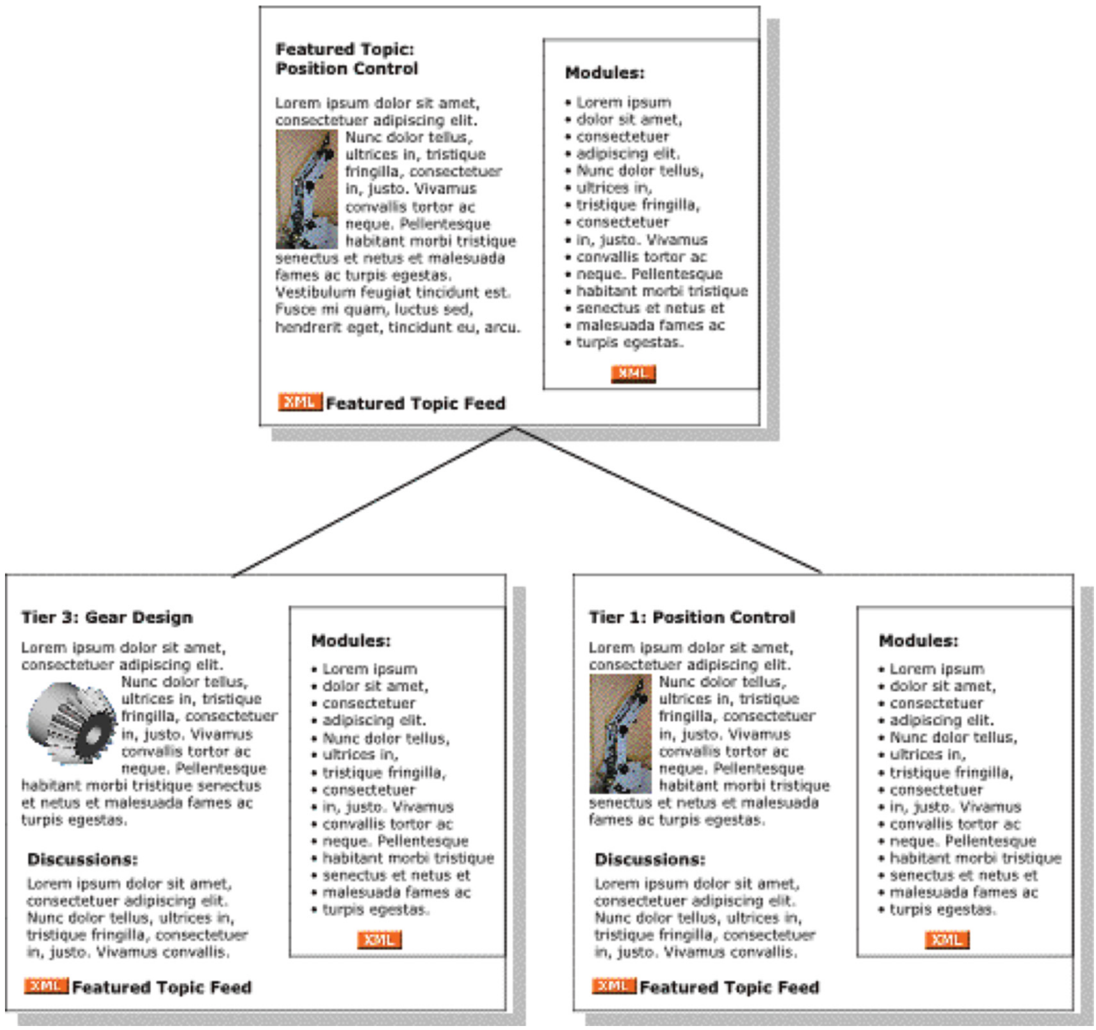

Figure 12: The general structure of the e-Design portal.

a key issue, it was felt that the metadata should be organized around the notion of design competencies [13] to allow users to search and retrieve modules on this basis. More specifically, users are required to select the competencies from seven categories before uploading their module: *general knowledge, specific knowledge, knowledge of procedures, operational skills, experiential skills, cognitive skills,* and *social/personal skills*. This metadata is then used to index and ultimately enable search and retrieval of modules referenced in the e-Design Portal.

In order to illustrate this approach to module delivery, we can look at an example of a flexible cut-off saw. In this case, the flexible cut-off saw can be thought of as a mechatronic system that integrates various subsystems: i.e., basic drive systems, position and velocity measurement, simple logic, state machines and programmable logic controllers (PLC's), basic manufacturing issues, and safety issues in machinery design. The cut-off saw system is intended to be flexible and modular in nature. For example, it should be possible to vary the size and complexity of the problem as well as the level and type of automation used (e.g., from zero to full 5-axis CNC). One might for instance consider just a straight cut to length arrangement, with or without automated sensing of stock, or one might wish to cope with compound angles on each end of the stock (and the 4- or 5-axis of control required). As well, the cut-off saw system should include some form of automated loading.

A case study of the linear/rotational stage embodiment design provides an example of a module that uses a guided discovery approach to instruction. In this case, the student can explore the various sub-systems that make up the linear/rotational stage design. As in Clark and Mayer's *e-Learning and the Science of Instruction*, this module falls into the perform-principle goals category given its reliance on job-realistic problems and supporting resources. They note, with this type of instruction, it is "the instructor's job to serve as the cognitive guide and the learner's job to make sense of the presented material in the context of solving a job-related problem" [14].

In the next section, we describe our current work on developing a CDEN design module for the mindmapping project described previously.

The Capstone Design Mini-Project Module

As noted, the next step in our inquiry-based, blended learning design project is to move our material to an on-line format. The basic objectives are to provide easy access to the teaching module so that it can be shared with other capstone design courses, and to provide a repository of projects

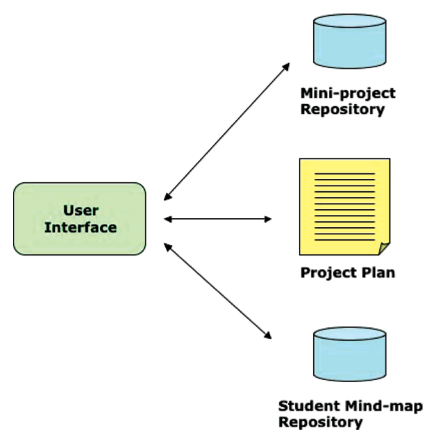

Figure 14: The capstone design mini-project module.

that can be used by educators and students. With these objectives in mind, we have developed a simple architecture for the module as illustrated in Figure 14.

The *Project Plan* is the heart of the module: it encapsulates the planning work that was done by the authors on the pilot project and the mini-project, and is effectively a combination of “instructor manual” and “student materials”. Capstone design course instructors will use this part of the module to develop their course plan for the mini-project by accessing written material on the mini-project, suggested mini-project schedules, scoring rubrics, and tutorials on the Product Development Process. Student resources will include a FreeMind tutorial and links as well as student-oriented versions of the instructor materials.

The secondary objective of providing a repository of projects that can be used by educators and students is intended to be addressed by the two data repositories shown in Figure 14. The *Mini-project Repository* will be used to store and retrieve mini-project descriptions developed by users as well as links and references to external short projects [15]. The intention is to allow the user to search the database, add new projects, and retrieve past projects.

The *Student Mindmap Repository* will be used to store completed projects that can be used as project examples for students as well as a source for instructors. For example, instructors may choose to use these student projects to illustrate points during design methodology lectures. This may include examples of where good design practice was used, or alternatively, examples of how problems could have been avoided.

Since this module will be accessed over the internet, it is our intention to use the MySQL/PHP [16] as the main programming approach. The open-source PHP scripting language allows sophisticated code to be developed to manage the various components of the on-line design module. MySQL is a web-based relational database management system that is well suited for the needs of the modules two repositories. Like other CDEN design modules developed by the authors XHTML and CSS will be used to simplify the “usability” aspect of module interface [17].

7. CONCLUSIONS AND FUTURE WORK

Mindmaps or concept maps have proven to be valuable learning tools. In a recent study the following advantages were found when using mindmap/concept-map strategies [18]:

- focuses the learning task,
- links learning and new learning,
- visual map of the connections the learner makes between concepts,
- identifies valid and invalid connections made by the student,

- provides a schematic summary of learning,
- leads to deep learning,
- organizes information,
- learning becomes transparent,
- students can self-assess,
- concept maps are individualized and hard to plagiarize,
- assessment becomes part of learning,
- can be assessed within the existing assessment system.

In the fall of 2006, concurrent with the capstone mini-project, a second iteration of the first year design class mindmapping project was conducted. The quality of these mindmaps was significantly better, partially because they were shown examples of good maps from the previous year. As mentioned previously, we recently finished a second iteration in the capstone design course and will be analysing this year's maps over the next few months.

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