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Integration of Engineering Theory and Practice in a Junior-Level Machine Design Course

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Abstract

There is currently a trend in engineering education that emphasizes a blending of theory with the application of that theory to engineering practice. Current ABET criteria for accreditation of engineering programs focus on the ability of students to recognize engineering problems in a real system and to correctly apply engineering principles to those problems. In this paper, the authors describe a junior-level course in machine design that integrates a classic, theoretical treatment of the design of machine elements with a semester-long laboratory in which students design and analyze a ski lift to be used on their campus. This is a required course for all Engineering majors in the Mechanical Engineering Concentration at our university. The sequence of presentation of theoretical content in the course is coordinated with the requirements of the ski lift project, so that students are presented with theory on an "as-needed" basis. Preliminary evaluation of student perception of learning based on Student Assessment of Instruction (SAI) data demonstrates that students feel that learning of theoretical content is improved when it is motivated by the need to solve a problem for their ski lift design.

Introduction

A course in the design of machine elements has been a part of most mechanical engineering curricula since the 1950's. The content of this course has its roots in academic research in solid mechanics, mechanisms and machine elements. In most cases this course focuses on the derivation and application of methods used to analyze individual machine elements such as shafts, bearings, and gears. Emphasis is placed on students' ability to correctly apply a particular analytical method to a particular class of machine element. Homework and assessment problems are usually focused on analyses of individual elements in isolation from the surrounding system and required input information is typically provided as part of the problem statement.

In recent years, there has been a trend in engineering education towards "systems level" thinking and the need for engineers to be able to design components and subsystems with an understanding of the effects that their design choices have on the overall system. ABET Student Outcome (c) specifically refers to, "an ability to design a system, component or process to meet desired needs…".

Another recent trend in engineering education has been towards an emphasis on experiential, hands-on learning. It is recognized that the practice of engineering requires a mix of skills, many of which are best learned through experience. In engineering education, this experiential learning most often takes place in capstone projects and industry internships. It is much less common for core engineering courses like Design of Machine Elements to incorporate a project-based, experiential component. There are machine design courses that contain hands-on laboratory modules, however these modules tend to be stand-alone experiences that are not integrated into a larger, system-level design.[1,2]

This paper describes the development of two junior-level courses that are intended to help students learn to do machine design at both a component and a system level and to give students a realistic experience in the practice of machine design. The first course is a traditional, three credit-hour course in design of machine elements. The second course is a one credit-hour laboratory that meets for three hours per week and is a co-requisite for the three-credit course. In this laboratory, students spend the entire semester working in teams of three or four to design a ski lift for use in the mountains around our campus. The lift project gives students the chance to apply their newly-learned analytical skills to the design of a real-world mechanical system.

The courses described in this paper were both taught during Spring Semester, 2016. This was the first time that either of the courses had been taught at Western Carolina University as this was the first Junior class for our new Bachelor of Science in Engineering degree. The lecture and lab courses were taught by the same instructor (Pierce) and there were ten students, all of whom took both the lecture and lab classes. All ten students had completed the required prerequisites of Statics, and Mechanics of Materials.

Wurdinger and Carlson describe five different approaches to project-based learning, ranging from “teacher-controlled” to totally “student-driven”.[3] An example of a teacher-controlled project is a design exercise in which all students analyze a particular machine element under well-defined input conditions. All students perform the same analyses and are graded on the correctness of their result. An example of a student-driven project is a capstone project in which instructors guide the design process but students select analytical methods and design solutions.

In our machine design laboratory, we use an approach in which the project is “set up and orchestrated by the instructor”. The initial problem is defined by the instructor but each student group works on a different version of the problem. Students are given time to frame their own questions, however the nature of the problem pushes them towards particular analytical methods. The sequence in which subsystems are designed is determined by the instructor in order to synchronize topics in the lecture course with tools needed in the design project. Students in the laboratory are evaluated on the correctness of their analyses as well as their ability to manage the design of a complex system.

Background

The effective practice of machine design requires a number of different and diverse types of knowledge. The ability to correctly apply analytical methods to the design of individual machine elements is important, however other skills are best gained through the experience of doing machine design. For example, it is common for inexperienced engineers faced with a design task to say, “I don’t know where to start.” This engineer may be very good at applying analytical methods to well-defined problems, however they have little experience working from a clean slate. Starting a new design from scratch requires the machine designer to make estimates and assumptions in order to generate problem inputs. This ability to design without “hard” input data is something that machine design engineers gain through experience.

Another example of experiential knowledge is the ability to understand machines at the system-level. The design of a piece of machinery always starts at the system level and flows down to the component level. Design decisions made at the component level may have ramifications throughout the larger system. Machine design engineers must learn to think at the system level and to look for relationships between design elements.

The primary goals of our course were to combine a strong foundation in the analysis of machine elements with a realistic experience as a machine design engineer. This was done by presenting a conventional 3 credit course that is intertwined with a 1 credit laboratory. The lecture course is very much a traditional class in design of machine elements. Students are introduced to one analytical method at a time and study the application of each method in depth. Evaluation of student learning is done through traditional methods such as homework, quizzes and exams. The selection of topics is similar to that of most design of machine elements courses. The detailed course content is shown in Figure 1; the connection between the lecture and the laboratory is also shown in the figure.

In the lab course, students work in three or four-person ski lift “design firms”. Each design firm is given an initial specification that gives general operating parameters such as speed and number of passengers and defines a unique route for their lift that connects two points in the mountains around our campus. Over the course of the semester, each team designs all the major subsystems of the lift. Students must identify and perform all the appropriate structural/mechanical analyses, construct three dimensional solid models of their designs, perform original design of a new kind of lift “chair,” and perform component selection using online vendor catalogs.

The lift project gives the students an opportunity to apply the analytical methods that they learn in class to a real machine design project. It also gives them experience with working in a design

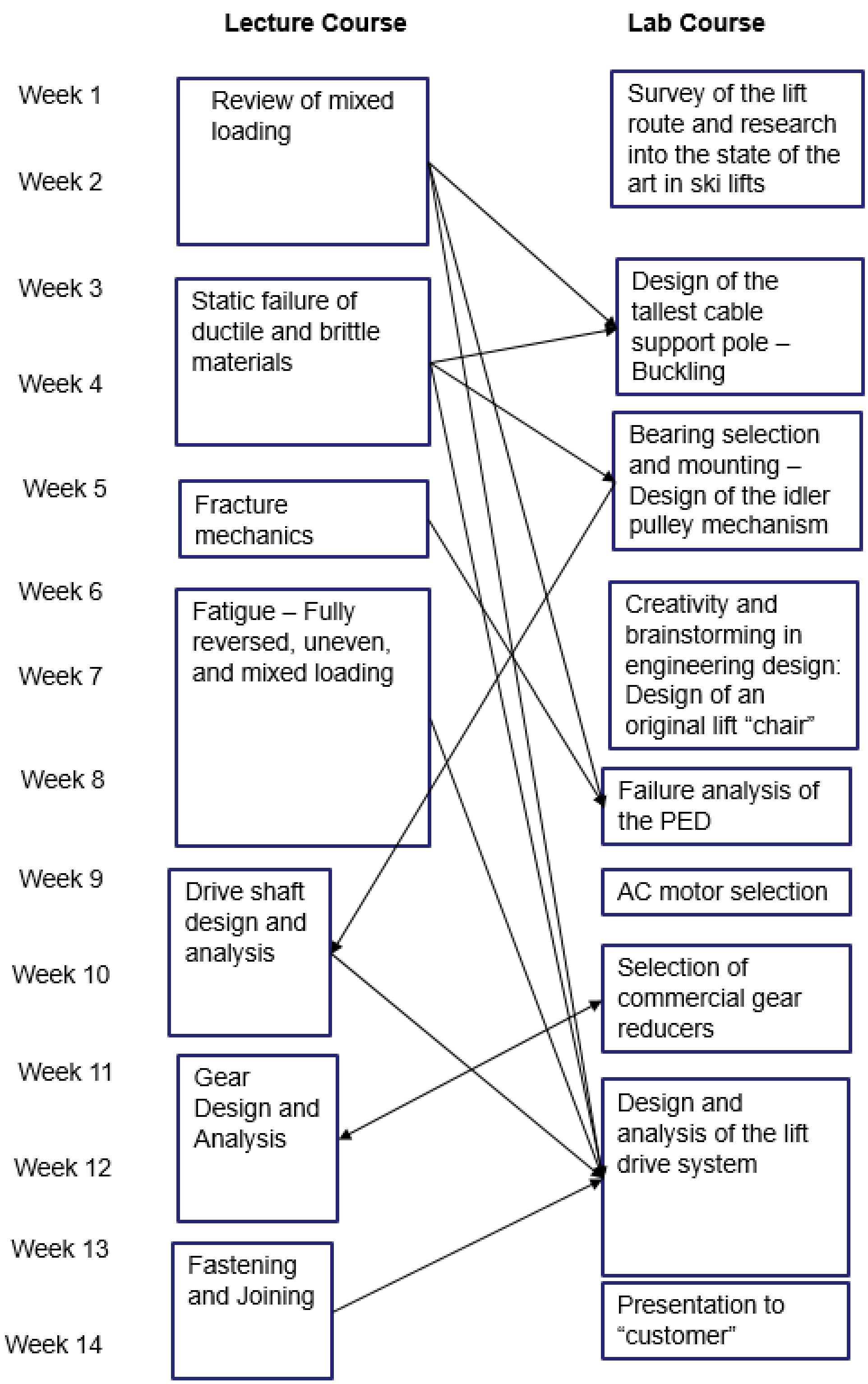

Figure 1: Content of the lecture and lab courses. Arrows indicate the flow of topics between courses.

environment where much of the input information is soft. This requires students to make reasonable assumptions in order for their designs to proceed. Finally, the lift project gives students the opportunity to engage in systems-level thinking since the design of each of the major lift subsystems has a profound effect on the design of other subsystems.

Assessment

Both the lecture course and the laboratory are used for the assessment of our engineering program. The outcomes that are assessed are as follows:[4]

Outcome (a): an ability to apply knowledge of mathematics, basic science and engineering science

Outcome (c): an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability

Outcome (e): an ability to identify, formulate, and solve engineering problems

Outcome (g): an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

Outcome (k): an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

In the lecture course, the primary instrument used for ABET assessment is the final exam. In the lab course, assessment instruments include most of the reports, analyses, and CAD models developed in the design of the ski lift during the semester.

It is worth noting that students in the lab course are asked to write several engineering reports and to give technical presentations on their design work to external "customers." Development of these technical communication skills is an important part of the laboratory course, however formal assessment of the ABET outcomes related to these skills is done in other courses in our curriculum.

Course Design

The content and timing of the lab and lecture courses were selected so that the two courses complement one another (Figure 1). The first few weeks of the lecture course are concerned with a review of stress analysis under mixed loading conditions and column buckling. This is followed by the development of static failure criteria. In the lab, students apply techniques for predicting failure to the design and analysis of the cable support poles and the chair or gondola. The lecture course then launches into a multi-week study of high-cycle fatigue. This study of fatigue is concluded just as students are moving to the design of the lift drive system in the lab. This requires them to perform fatigue analysis of drive components. Students also study the principles of operation of AC motors and learn to select commercially-produced gear reducers as part of the drive system design. This study of commercial drives complements the classroom lectures during this period, which cover the design and stress analysis of individual gears.

As previously stated, a primary goal of the lab course is to give students a real-world experience working as a machine design engineer. The lab follows each of the major steps in the design of a large, custom-designed mechanical system. The individual assignments for the laboratory are listed in this section.

> Assignment 1: Survey of the lift site and research into the state of the art in ski lifts – Students are given the location of their lifts. They must use GPS to survey the site, plan the lift elevation, and identify the tallest cable support pole, as shown in Figure 2. They must also perform research into the design and operation of ski lifts. Deliverables – An oral presentation to the class in which students present the results of their surveys and their lift research and a document that is Revision 0 of the lift specification document. This specification must include lift operating parameters such as power consumption and lift capacity.

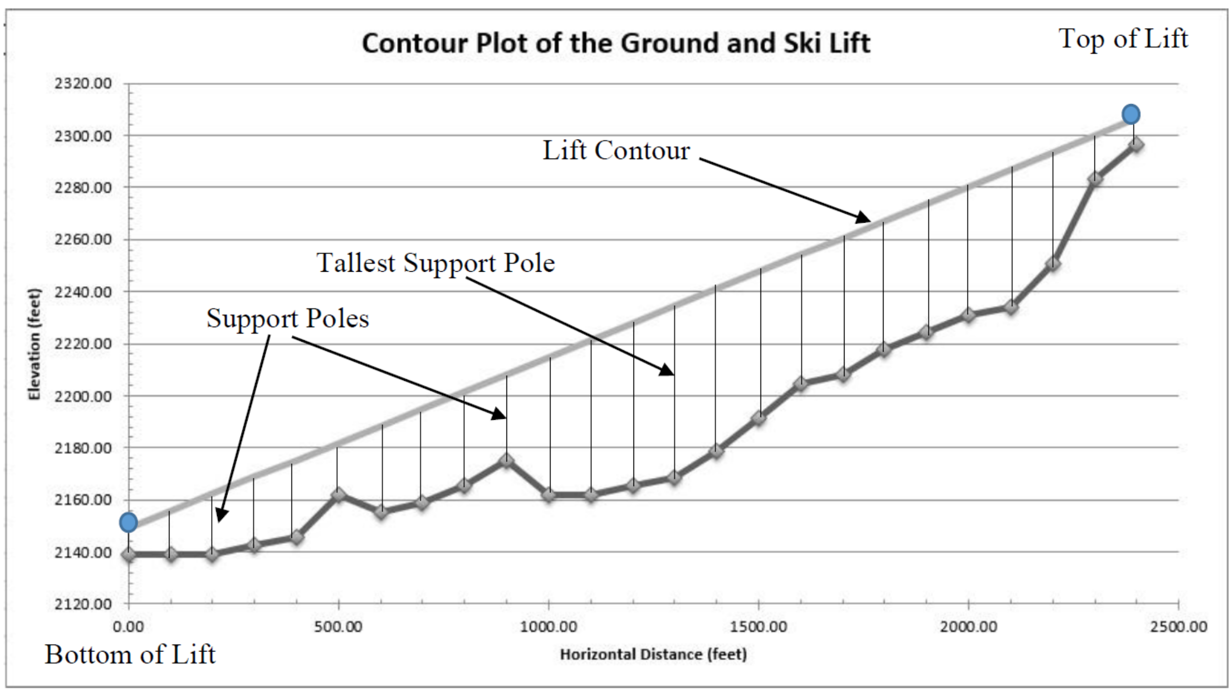

Figure 2: A sample site plan for Assignment 1.

Assignment 2: Design and analysis of the tallest support pole - Students must estimate loads on the cable support poles, then use these estimates to design the tallest support pole. This requires the design and analysis of an eccentrically-loaded column and structural members such as beams and struts. Deliverables – A brief design report that presents reasoning behind the design and all analyses. Also, a CAD model of the support pole must be prepared.

Assignment 3: Design, component selection, and analysis of the cable support wheels, bearings, and pivots – Students study mounting and selection of rolling element bearings and learn to perform L_{10} life calculations. Using this knowledge and the online Timken Bearing Engineering Guide they select bearings from the Timken catalog that can be used for the cable idler sheaves. They then design the sheaves, mounts, and pivot arms for the cable support poles. Deliverables – A brief engineering report that presents bearing selection and analysis, analysis of structural mounting components. Also, a CAD model of the entire support pole assembly with the idler mechanism is prepared as part of this deliverable.

Assignment 4: Design of an original means of engaging and supporting lift patrons as they ride the lift (referred to as the "Patron Engagement Device" (PED)) – Students study tools for creative brainstorming and product design. These methods are applied to generate an original design for the PED. Students are asked to generate PED designs that address problems that are inherent in having both skiers and snowboarders riding together. Deliverables – A report that describes the ideas generated during the structured brainstorming process and the reasoning behind the selected design. Also a CAD model of the PED design is required; an example of one such design is shown in Figure 3.

Assignment 5: Structural analysis of the PED design – Students must identify potential failure modes for their PED designs and analyze against these failures. Deliverables – A brief report that describes the reasoning behind failure mode selection and presents the analyses and derivation of factors of safety against the most likely failures of the PED.

Mid-Term Deliverable: Oral presentation of all design and analysis work performed up to this point.

Assignment 6: Selection and operation of AC motors and commercial gear reducers – Students study the operation of AC motors and perform research into commercially-available motors. Students also study different types of commercially-available gear reducers in order to find a motor/reducer combination that can be used to drive their ski lift. Deliverables – An oral presentation presenting the results of their research.

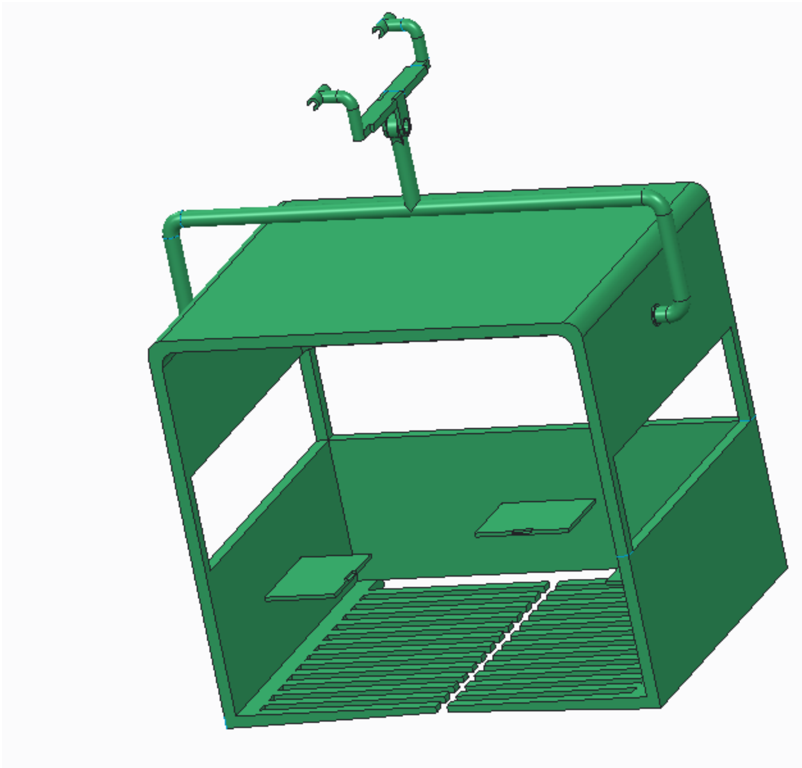

Figure 3: A CAD model of the PED design.

Assignment 7: Design and analysis of the ski lift drive system – Students perform all design, modeling, and analysis work for the drive assembly. All mounting and power transmission elements must be designed and analyzed. Drive components must be selected from vendor catalogs. Drive elements must be analyzed against fatigue where appropriate. Deliverables – A brief report describing the design of the drive system and analyses. Also CAD models of the drive assembly such as the example in Figure 4.

End of Semester Deliverables: Oral presentation to a panel of "customers" in which students describe all aspects of their lift design. A final report that is a compilation of all earlier design reports. Final versions of all lift CAD models and all analyses. Also CAD models of the drive assembly such as the example in Figure 4 must be submitted.

By the end of the semester, students develop all the major subsystems of an original ski lift design. Students perform structural analyses of the major components and select many of the bearings and drive components from vendor web sites. Students also apply nearly every topic that is covered in the lecture course to the design of their lifts, thereby getting experience in applying theory toward the design of machine elements.

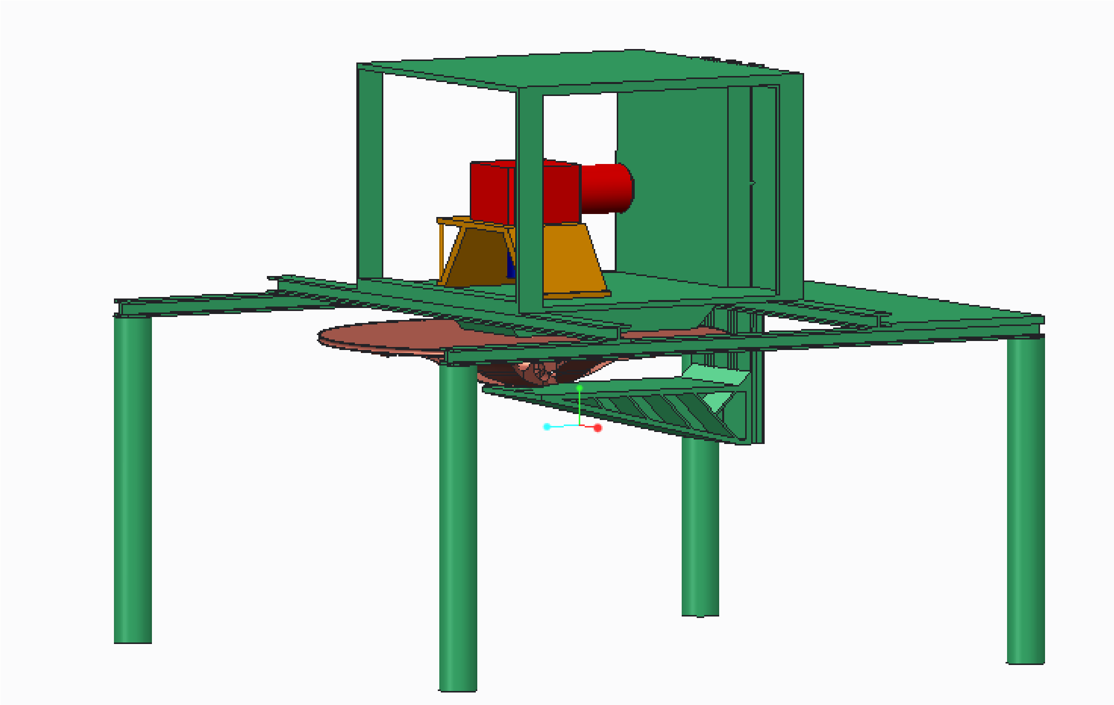

Figure 4: An example of the ski lift drive assembly.

Student Perception of Learning

This section discusses the results from an evaluation of student perception of learning for the lecture and laboratory based courses. These results are from the Spring of 2016, which was the first time either of the courses was offered at our university. Student perception of learning was measured through an end-of-semester survey that was completed by ten out of the twelve students enrolled. Since the survey was part of the end-of-semester Student Assessment of Instruction (SAI), an Institutional Review Board request for human subjects research was not necessary. The survey was conducted in the electronic format only and students had access to the survey during the last four weeks of the semester. All of the students surveyed were in both the lecture and the laboratory course.

In the survey, students were asked to respond to a statement such as, “My instructor advances my knowledge of course content.” Students respond to the survey questions using a four point Likert scale (4=Strongly Agree, 3=Agree, 2=Disagree, 1=Strongly Disagree). Responses to statements from the surveys that relate to students’ perception of their engagement and learning are included in Table 1.

Survey Statement	4 = Strongly Agree	3 = Agree	2 = Disagree	1 = Strongly Disagree	Mean Result	Standard Deviation
Survey Results from the Lecture Course						
My instructor advances my knowledge of course content.	9	1	0	0	3.9	0.30
My instructor promotes my understanding of important conceptual themes.	8	2	0	0	3.8	0.40
My instructor enhances my capacity to communicate effectively about the course subject matter.	9	1	0	0	3.9	0.30
Survey Results from the Laboratory Course						
My lab instructor advances my knowledge in this lab section.	8	2	0	0	3.8	0.40
My lab instructor makes me more curious about the subject matter.	9	1	0	0	3.9	0.30
My instructor helps me learn important techniques in this course.	8	2	0	0	3.8	0.40

Table 1: Results of the SAI survey of students' perceptions of learning.

Results of the surveys were overwhelmingly positive in both the lecture and the lab course. In the lecture course, all 10 students "strongly agreed" or "agreed" that the course, "advances my knowledge of course content," "promotes my understanding of important conceptual themes," and "enhances my capacity to communicate effectively about the course subject matter." In the comments section of the feedback students noted that the course was, "…applicable to life. We don't just learn from the book."

Feedback in the lab class followed similar themes. All 10 students "strongly agreed" or "agreed" that the course, "…advances my knowledge…" and "…makes me more curious about the subject matter." Students commented that the best aspects of the course were, "Using what we did in the class for the ski lift," and that they "…learned a lot of different things about one big system."

It is clear from the surveys that students perceive that they are learning valuable skills from the courses. In the future, we plan to implement more direct methods to measure the effects of the ski lift project on student learning. It is acknowledged that the small class size may have been beneficial. However, this will be tested in the future semesters with class size of 25 or more.

Discussion and Future Work

This paper has described the development of a pair of courses in machine design. A traditional course in the design of machine elements is coordinated with a semester-long laboratory course in which students work in teams to design all the major subsystems of a ski lift. The primary goal of this approach is to give students a genuine experience in working as a machine design engineer so that they can develop experience-based skills. Skills such as working with soft input information and systems-level thinking are best learned through practice.

Surveys of student perceptions of learning indicate that students find both the lecture and the lab course to be engaging. They report that the courses stimulated their interest in machine design and they feel that the ski lift project helped them to develop important skills. In the future, we will take a more formal approach to measure student achievement. In particular, we would like to measure attainment of soft skills such as systems-level thinking in students who have been through the ski lift project versus those who may not have gone through a laboratory course to apply the theoretical content learned in the lecture.

The pair of courses discussed in this paper were offered for the first time in Spring 2016. The course material and student feedback presented were from that first iteration. In the future, we plan to change the sequence of topics in order to improve the synchronization of the lecture topics with the lift design. In particular, we plan to move topics in fastening and joining to the fifth week of the course. This will allow students to apply the content learned in these topics to the design of their cable support poles during the first third of the semester.

Another change that we intend to make to the lab is the addition of a two-week introduction to finite element analysis (FEA). FEA is an indispensable tool for machine design and we feel that it is important to discuss the correct application of this tool during the lift design project. While two weeks is not enough time for students to become proficient at FEA it is enough time to introduce the method and provide guidance as to its proper application to machine design.

In summary, we have completed the first iteration of a pair of courses designed to teach students both hard, analytical skills and soft, experience-based skills. Course topics are synchronized between the lecture course and a laboratory-based project in which they apply the methods that they have just learned. Student perceptions of learning indicate that this approach is engaging and effective. We will repeat the course sequence with a few modifications during the next academic year and formally measure outcomes and student learning.

References

1. Le, X.L., Duva, A.W., Jackson, M., 2014, "The Balance of Theory, Simulation and Projects for Mechanical Component Design Course," Proceedings of the 121st ASEE Annual Conference and Exposition, June, 2014.

2. Monterrubio, L.E., Sirinterlikci, A., 2015, "A Hands-on Approach in Teaching Machine Design," Proceedings of the 122nd ASEE Annual Conference and Exposition, June, 2015.

3. Wurdinger, S., Carlson, J., 2010, *Teaching for Experiential Learning, Five Approaches that Work,* Rowman and Littlefield Education.

4. Engineering Accreditation Commission, 2014, *2015-2016 Criteria for Accrediting Engineering Programs,* ABET.