AC 2012-4192: SCAFFOLDING AND ASSESSING PROFESSIONAL DESIGN SKILLS USING AN ACTIVE-LEARNING STUDIO-STYLE CLASSROOM

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Scaffolding and Assessing Professional Design Skills using an Active-learning Studio Style Classroom

Abstract

Upon graduation, engineers are expected to have not only technical expertise but also professional skills which will help secure their success as practicing engineers. A studio-style course that complements and supplements a traditional laboratory capstone design experience was designed to teach biomedical engineering professional skills. This course scaffolds student's practice, enables demonstration of professional skills proficiency in this class, and supports the associated senior design laboratory assignments. Herein, we describe the pedagogical approach, course content and design, plus direct and indirect assessment results.

Fifty-four senior biomedical engineering undergraduate students were enrolled in this course which addressed biomedical engineering professional skills including: ethics, technical writing, regulatory issues, human and animal subjects, economic considerations, and entrepreneurship considerations. The class met once a week for 90 minutes with a brief introductory lecture (< 20 minutes) followed by time dedicated for students to work on in-class assignments, both individually and in their design teams with instructor interactions. To ensure students demonstrated proficiency in each topic, students revised their assignments based upon constructive feedback until it was satisfactory. Scaffolding was provided through assignment design, instructor feedback during the studio session, and in written feedback on assignments. The students would subsequently complete related assignments for their associated lab course employing a fading strategy. Student assessment was achieved through graded weekly assignments, while course assessment and effectiveness was determined through Internal Review Board-approved analysis of student grades and student surveys. Student written feedback was analyzed using inductive analysis and the constant comparative method by an expert in qualitative data analysis who was external to the course. Assignments were evaluated according to Bloom's Taxonomy and mapped to Accreditation Board for Engineering and Technology (ABET) criteria.

The course format ensured that students had the opportunity to practice and demonstrate proficiency in the professional skills measured prior to independent application within the associated senior design laboratory assignments. On average, students were required to revise 3-4 assignments out of 14 total assignments to demonstrate skill/concept proficiency. A Bloom's Taxonomy analysis showed that all assignments required students to perform at the level of evaluation and synthesis. Through assignment evaluation, we discovered that our seniors struggled with course topics on design of experiments and statistical analysis; this prompted a revision of a pre-requisite course. Overall, students had a positive response to the course format and valued the skills that were being taught. There was an increase in the percentage of students who believed that they had in-depth knowledge of course topics by the conclusion of the course.

In summary, course objectives were achieved and students demonstrated proficiency of the professional design skills. This pedagogical approach towards teaching these professional skills was found to be engaging and effective; it may be broadly applicable to other biomedical engineering programs and engineering disciplines.

1. Introduction

The career requirements of today's biomedical engineer expand beyond the scope of technological proficiency. Businesses maintain global competitiveness through employment of engineers that are technologically skilled and demonstrate strength in management and business.[18, 20, 21] Newport and Elms reported that technical skills or academic ability alone served as poor predictive indicators of a highly successful engineer.[23] In fact, they found that "soft" engineering skills, including the ability to understand all facets of a project, strong interpersonal abilities, and an entrepreneurial spirit, not technical skills nor prior academic ability, differentiated "effective" from "adequate" engineers.[23] Engineering curriculum reform models, such as the "Three Curricular Pillars," have been established to modernize engineering curricula to better prepare graduates for evolving industry needs.[16, 22] ABET, an agency responsible for accrediting college and university programs in applied science, computing, engineering, and technology, has also recognized the need to broaden engineers' skills by the requirement of programs to demonstrate graduate proficiency in 6 core professional skills,[1] including communication and ethics.

A majority of engineering undergraduate programs satisfy the engineering ABET criteria to produce technically competent and professionally aware engineers through a capstone senior design experience, which utilizes problem-based learning or experiential learning pedagogies.[8, 15, 32] Capstone design literature is replete with resources that address best practices in teaching design courses and methods to scaffold the technical expertise required for students to successfully produce a final prototype or design. However, there are comparatively fewer articles that focus on best approaches to formally teach engineering students professional skills (sometimes referred to as the "soft skills"), rather they focus on assessment.[5, 14, 19, 26] Although assessment of these skills is necessary and required for ABET accreditation, it is equally important to disseminate best practices to effectively teach these professional design skills. Traditionally, these professional skills are passively acquired within the engineering undergraduate curriculum, culminating in the capstone design experience.[5] Despite the acknowledgement that ABET professional design skills can, in fact, be taught[30] there is a deficiency in the supporting literature of methods to teach professional design skills within capstone design courses.

While engineering programs recognize the need to teach professional skills, the pedagogical challenge is to identify methods to effectively embed these skills into the engineering curriculum. Most programs do not have the flexibility to require that students take business, management, and communication courses in their four-year curriculum. Additionally, in order for students to recognize the importance of professional skill development, it may be necessary to link them with technological skill development.[18] In this paper, we describe a novel approach to integrate these skills within the curriculum through a studio-style course that was developed to scaffold the professional design skills as a supplement to the traditional senior design course. We define studio-style as an open classroom format in which students are given minimal guidance (<20 minutes) on class material in a traditional lecture format, and then are provided the majority of in-class time to evolve their understanding of the course topic through instructor and peer interaction that is guided by in-class assignments. The transition to an active-learning studio format was based on research showing that students retain concepts better when allowed to practice the assignments immediately after exposure to the concepts.[2, 11, 13] Furthermore, as summarized by Prince, student participation in active- learning environments improves achievement of learning outcomes, especially when activities are designed for students to reflect on what they are learning.[28] Here, we describe our pedagogical approach, the BME professional skills content, and the student and instructor evaluations of the new active-learning, studio-style course.

2. Senior Design at Purdue University

Since its inception in 2006, the capstone senior design course in biomedical engineering at Purdue University has been taught as a 4-credit course that combined a 3-credit design laboratory with a 1-credit lecture. As a whole, the capstone design course has been highly successful; however, assessment revealed a problem in the consistency of addressing professional skills. In an effort to ensure content uniformity and achievement of educational objectives, we proposed replacement of the existing 1-credit senior design lecture course with an interactive studio-style course. The newly formatted senior design experience consisted of three required courses including a 1-credit active-learning studio-style course, a 1-credit preliminary senior design lab, and a 2-credit capstone senior design laboratory. To accommodate a broad range of design projects, the senior design laboratory credits can be taken in one semester or distributed over two semesters with all seniors completing the studio-style course during the fall semester.

3. New Studio-Style Course

3.1 Pedagogical Approach

The goal for the new studio style course was to formally teach students professional design skills or "soft" engineering skills (see first column of Table 1). These are skills that students are expected to know upon graduation, have encountered throughout the engineering curriculum, but have not been covered within the design context until the capstone experience. Our vision was to provide an environment in which students could learn these skills through guided practice, feedback and revision, a pedagogy described by Sheppard as scaffolding.[29] A fading strategy is then used where the students are expected to apply these skills within the capstone design laboratory without the guidance of the instructor.[29] Our scaffolding pedagogy naturally lent itself to a studio style course format because it provides an environment where students learn by actively engaging and practicing professional design skills (as opposed to the passive learning which occurs during a lecture-style course). Course assignments were designed to allow students to focus on, practice, and demonstrate proficiency in fundamental BME professional skills.

3.2 Course Description

The 1-credit, studio-style learning course, *Professional Elements of Design*, was taught once a week for 90 minutes for a single semester to 54 biomedical engineering senior undergraduates. Class periods consisted of a brief introductory lecture lasting less than 20 minutes with the remaining time dedicated for students to work on in-class assignments. All assignments were submitted electronically via Blackboard to instructors by the end of the class period. The in-class activities were designed so that students applied the knowledge and professional design skills discussed in the introductory lecture to their own capstone project. During the in-class activities, four course instructors and one teaching assistant circulated to provide immediate assistance and real time feedback (one instructor to 10 – 15 students). The professional skills covered are listed in Table 1. A slightly different course format was used for ethics and economics, where the course time alternated between mini-lectures and group work. Accommodation of the studio-style course format required the use of a room with a projector and computer access for each student. We accommodated this through a traditional lecture hall for the first 20 minutes and access to computers distributed throughout our computer and teaching laboratories. An example of a single class on the topic of human and animal studies is provided to illustrate the course format and how the material was taught, practiced, and assessed.

Table 1. Topics covered in *Professional Elements of Design* Studio Course mapped to BME professional skills and ABET Criterion.

BME Professional Skills (Course Topics)	ABET Criteria (a-k)	Purdue BME Performance Criteria[a]	Most Common Weaknesses in Student Work
Engineering Specifications	(c), (e)	- Formulate and write an understandable and complete problem statement for a medical or biological application that contains appropriate technical specifications, design criteria, and realistic constraints. - Generate potential design solutions for a medically or biologically relevant problem and evaluate them in terms of the design criteria. - Recognize, identify, and describe the need for an engineering solution to address current challenges in life sciences and medicine.	Technical Specifications
Thorough Due Diligence	(h), (i)	- Collect relevant information, data, and ideas from written publications using multiple sources (both paper and electronic). -Identify and/or describe how biomedical engineering solutions affect society. - Justify selection of a biomedical engineering process in research or product development based on an economic analysis.	Bibliographic format

Table 1. (Continued)

Project Management and Scheduling	(c), (d)	- Create a scheduled plan to implement a design solution for a medical or biological application with subtasks for implementation. - Demonstrate an understanding for the need of a multidisciplinary team to solve a biomedical engineering design problem. - Educate, respect, and compromise with individuals from different perspectives to solve a biomedical problem.	Lack of realistic deadlines, inability to break down project into reasonable goals, linear scheduling
Human and Animal Studies	(b), (j)	- Outline a directed approach to explore concepts or hypotheses related to biological or medical systems using safe and appropriate experimental methodology and validation. - Identify and describe contemporary issues impacting biomedical engineering.	Composing specific and understandable objectives
Hazard Assessment	(e)	- Describe the challenges associated with interactions between living tissues or cells and engineered devices or materials and propose strategies to overcome these challenges.	Focus on defects instead of harm to user as a result of defects
Regulatory Affairs	(j)	-Demonstrate an awareness and understanding of regulatory agencies and specific guidelines which impact biomedical engineering projects in research or product development. - Identify and describe contemporary issues impacting biomedical engineering.	Intended application of product too broad; language inappropriate for FDA (terminology used would raise further questions)
Abstract Writing	(g), (j)	-Present scientific information in a format that is easily understood by technical and non-technical personnel. -Identify and describe contemporary issues impacting biomedical engineering.	Abstracts too technical – not written for general audience
Peer Evaluation	(g)	-Evaluate oral and/or written presentations for clarity and content.	Providing critical feedback

Table 1. (Continued)

Role of Testing in Design	(b), (e), (g), (k)	- Outline a directed approach to explore concepts or hypotheses related to biological or medical systems using safe and appropriate experimental methodology and validation. -Select the appropriate engineering and science tools and techniques to solve a biomedically relevant problem. -Construct a logical and articulate argument in written format from independent collection of information.	Disconnect between the testing protocol and the goal of the test; statistical testing
Statistical Analysis	(g), (k)	-Construct a logical and articulate argument in written format from independent collection of information. - Select the appropriate engineering and science tools and techniques to solve a biomedically relevant problem.	Choosing correct statistical test
Real World Documents	(j)	-Identify and describe contemporary issues impacting biomedical engineering.	Figures/Tables supporting aim of document
Economics	(h)	- Justify selection of a biomedical engineering process in research or product development based on an economic analysis.	Realistic expenses and income
Ethics	(f)	-Recognize and describe professional and ethical codes of conduct, and ethical dilemmas which pertain to a practicing biomedical engineer. - Explain ethical considerations relevant to experimentation with animal and human subjects.	Strength of argument (lack of facts and references) for ethical decision
Entrepreneurship	(i)		Not Applicable

[a]The performance criteria listed are unique to the BME program at Purdue University; they were specifically developed to evaluate student's ability to meet ABET criterion a-k.

3.3 Student Assessment

Overall, the course was graded as pass/no pass. In-class activities were designed to be thought provoking, applicable to the students' own capstone design project, and adept in assessing competency. Initially, students were encouraged to consult with their groups, but to write up their assignments individually. Over the course of the semester, more team assignments were incorporated (see Discussion). Submitted assignments were assessed and categorized as either pass (P), borderline pass (BP), or no pass (NP). Student work received a "BP" if it demonstrated proficiency, while a "P" required the demonstration of mastery through a complete, logical, in-depth analysis. A “NP” was given when the submitted material failed to demonstrate a sufficient degree of understanding or was incomplete. Due to the preliminary nature of the work, assignment time constraints, and the iterative nature of the senior design experience, student work typically received a “BP”. Written comments were provided to each student indicating the assessment of their submitted work and providing concrete suggestions for improvement to encourage the students to continue to develop these ideas for any related laboratory assignments. To pass the course, students were required to achieve a minimal grade of “BP” on all measured Purdue BME performance criteria (Table 1). Most Purdue BME performance criteria were measured multiple times throughout the course. To ensure that students achieved proficiency of the material, all assignments with an unsatisfactory performance (NP) required revision by the student until either a “BP” or a “P” was awarded.

To maximize student learning, grades and comments were given to students within 48 hours of assignment submission. Within the first 24 hours of submission, a first pass at grading of about 20% of the submissions was performed by the teaching assistant to get an idea of the range of answers received and to generate a template for a variety of written comments, addressing identified weaknesses. After briefly discussing the assignment and what was expected to achieve each grade, the instructors and teaching assistant used the template comments to streamline and standardize the feedback to the students.

3.4. Example Class

To provide a more detailed and concrete understanding of how each topic was taught, practiced by the students, and assessed, an example is described on the topic of human and animal subjects. The learning objectives for this particular topic were: students should be able to (1) describe the certification and training process to conduct human and animal research, (2) recognize, understand, and employ the responsibilities of a researcher to protect and ethically treat a research subject, and (3) justify the necessity of a human and/or research trial and its design. The 20 minute lecture emphasized the ethical and regulatory issues that are associated with working with living subjects. Examples of human and animal subject studies were briefly presented to illustrate the process for getting a study approved through the appropriate regulatory body, possible outcomes of the review process, and the logistics of the typical approval process (submission length, committee review length, approval process for any changes to study, annual updates, etc.). The lecture notes and associated regulatory documentation for the presented examples were made electronically available during in-class activities. After the lecture, the students were asked to work individually on either a human or animal study that could be directly applicable to their senior design project. (The actual assignment text is shown in Table 2).

Table 2. In-class assignment for the human and animal studies topic. Students were expected to choose either a human or animal study and answer the bulleted items individually to demonstrate proficiency.

Option #1: Human Subject Study	Option #2: Animal Subject Study
▪ Brief description of study objective and rationale ▪ Potential risks to subject ▪ Benefits to be gained by the individual and/or society ▪ Identify a human study that is applicable to your project (i.e., to the condition which you are studying). Support through relevant references; use IEEE citation style.	▪ Brief description of study objective and rationale ▪ Will the animal experience any unnecessary stress, pain, or injury. Explain your answer. ▪ Benefits to be gained by the individual and/or society ▪ Justify your choice of animal species. Support through relevant references; use IEEE citation style.

To address the assignment, students were expected to design a human or animal study applicable to their own senior design project. Students were not expected to perform the study, but rather demonstrate they had the skills to think through an appropriate study that would test an aspect of their senior design project, including identifying the benefits and risks to test subjects. The final aspect of the assignment was to identify an appropriate human or animal study within peer-reviewed literature online to help justify their experimental design. During class, students have access to computer labs or allowed to bring in their own laptops. A previous class (thorough due diligence) addressed methods on how to find appropriate literature through databases accessed within the Purdue library system.

Assessment of student work from the class on human and animal studies revealed that the most common weakness was lack of specificity in communicating the study objective. The scope of the project was often vague, and the rationale did not provide appropriate level of detail. In some cases, students were very technical and brief in their description, suggesting that they need to be more aware of their audience and understand that reviewers for human and animal studies will not necessarily be familiar with the technology being explored. These problems were brought to student’s attention through feedback and were appropriately addressed during the second submission.

4. Evaluating Course Structure

Course assessment was performed by critically evaluating and comparing student performance and instructor expectations. Student attitudes and the perceived value of the course were collected through surveys and evaluations (see section on course effectiveness –student surveys for details). All data collection was in accordance with Institutional Review Board (IRB) approval.

4.1 Course Effectiveness: Student Performance (Grades)

4.1.1 Methodology

Student grades were used to extract data on the success of the course. Multiple BME performance criteria were individually assessed within each assignment. Therefore, a single assignment could contain multiple assessment component grades, depending on the degree of proficiency of the concept as related to each component. When quantifying the overall grade of individual assignments, the lowest grade received across all components of the assignment was used. The number of students who received NPs on the first attempt of an assignment was determined by summing the total number of students who received "NP" on any part of the assignment on the first attempt. To present the data as the number of students who achieved proficiency on the first attempt of the assignment, the number of students receiving "NP" was subtracted from the total number of students in the course. The number of repeated assignments by a student was determined by summing the number of repeated assignments required for a student to demonstrate proficiency (receive a passing grade ("BP" or "P")) across all assignments. All data were converted to percentages.

4.1.2 Results

Student performance on each in-class topic for the first attempt at the assignment is shown in Figure 1 with the most commonly identified weaknesses summarized in Table 1. For about half of the assignments (6/14), 60% or more of the students met the expected level of proficiency of the professional skill (as quantified by the associated performance criteria). For other topics, like economics, more than 95% of students met the expected level of proficiency on the first attempt. However, some topics were more challenging for students to demonstrate proficiency on the initial attempt of the assignment (human and animal studies, regulatory, abstract writing, role of testing in design). There did not appear to be a change in performance based on team versus individual assignments. Towards the end of the course, there were some students who chose to not submit assignments since they had previously passed the particular BME performance criteria being assessed and therefore would pass the course. (This grading policy has been changed for the most recent offering, see the discussion).

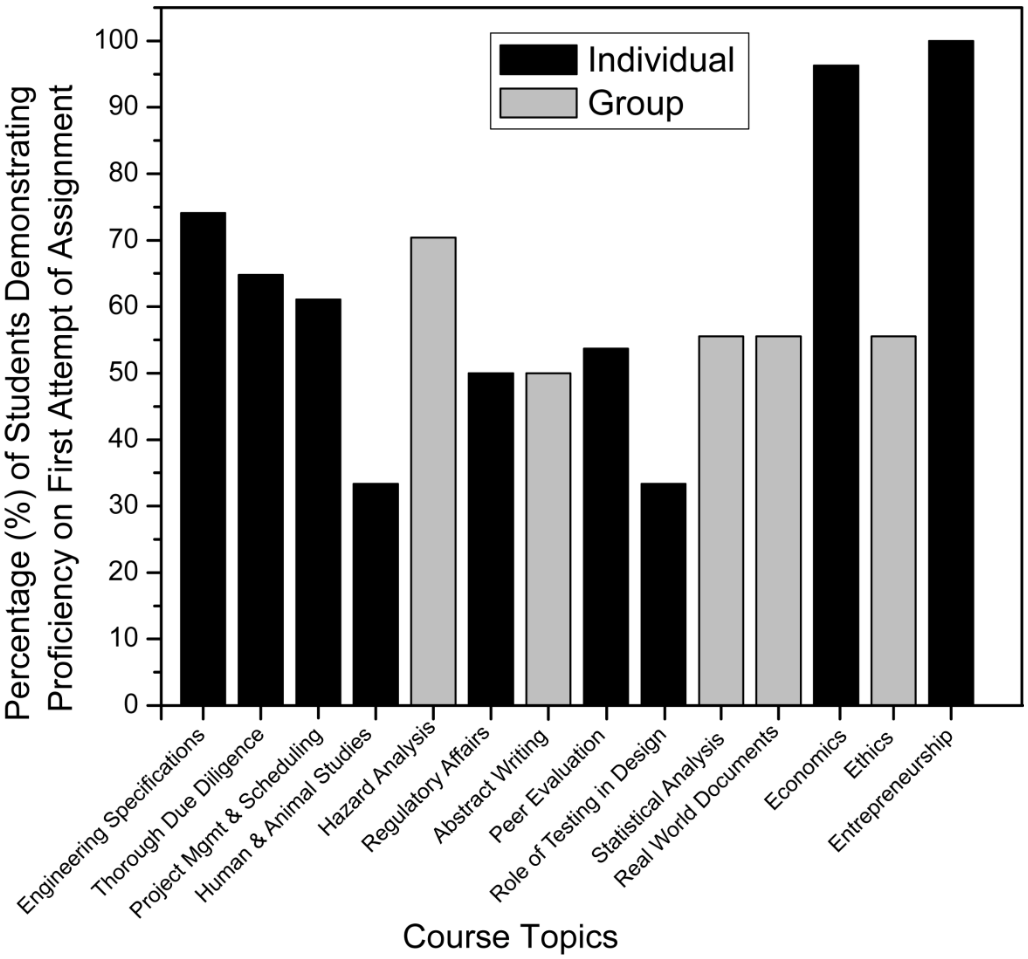

Figure 1. Percentage of class demonstrating proficiency on first attempt of assignment. For each topic, students were graded on whether they demonstrated proficiency of the BME performance criteria measured in each assignment. Students earning a borderline pass (BP) or pass (P) demonstrated understanding of the material.

Because this course was based upon the pedagogy of scaffolding to teach the BME professional skills within the context of design, students were allowed to revise assignments if the work did not meet expectations. Figure 2 shows the number of repeated assignments required per student for the duration of the course. On average, students had to repeat a total of three to four assignments over the entire semester. A few students (3/54 or 5.5% of the class) showed skill proficiency on all assignments in the first attempt, and a few (4/54 or 7.4% of the class) students struggled to meet skill proficiency on seven to eight of the assignments. We also examined the number of times necessary for a revision attempt per assignment (data not shown) and found that most students were able to resolve inadequate performance on the second submission. There were a few individual cases (< 10) where more than two iterations were required to achieve satisfactory performance.

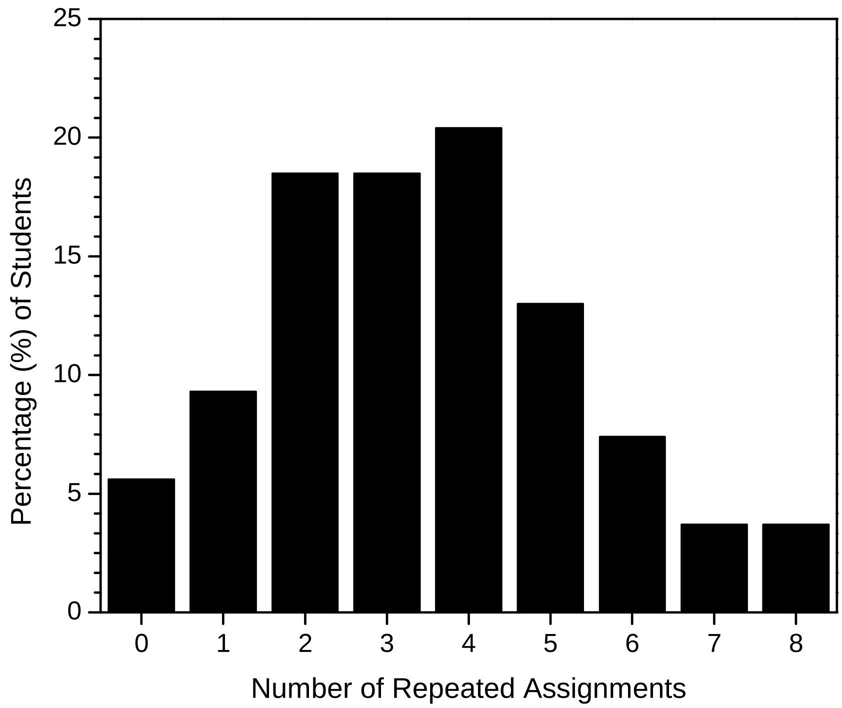

Figure 2. Summative percentage of students having to repeat assignments throughout the course. Because students were required to demonstrate proficiency of the material, an "NP" required assignment revision. For example, 9% of students had to repeat 1 assignment out of 14. The number of revisions ranged from 0 to 8 per student, with an average of 3-4 revisions per student.

4.2 Course Effectiveness: Student Survey

4.2.1 Methodology

To evaluate student response to the course structure, pre-, mid-, and end-of-course surveys were administered. Class participation in the pre-course survey was 100% (54/54), 91% (49/54) of the class participated in the mid-course survey, and 96% (52/54) participated in the end-of-course survey. Two-way contingency tables separating the student perceptions between level of knowledge (in-depth or superficial) and time of survey administration (pre- or post-) were developed for selected BME professional skills. A χ^2 test was performed (α= 0.05) to test the association between the row and column variables.

On both the mid- and end-of-course survey, students were asked to provide comments on how to improve the course and what they liked about the course. Class participation in providing written feedback was 69% (34/49) for mid-course survey and 71% (37/52) for the end-of-course survey. Student written feedback was analyzed using inductive analysis and the constant comparative method[7, 25] by an expert in qualitative data analysis who was external to the course. Inductive analysis refers to a process in which themes are allowed to emerge from the data as opposed to attempting to fit the data to a predetermined coding scheme. Using constant comparison, emergent themes are continuously adjusted and refined throughout the inductive data analysis process to produce a set of themes that best describes the essence of the data.

4.2.2 Results

Figure 3 shows the change in student opinion of having in-depth knowledge on course topics at the start of the semester (pre-) and the conclusion (post-). There was a statistically significant difference in the percentage of students that felt they had in-depth knowledge of the course topics by the conclusion of the course for five of the eight professional skills ($p < 0.05$, Chi-square test).

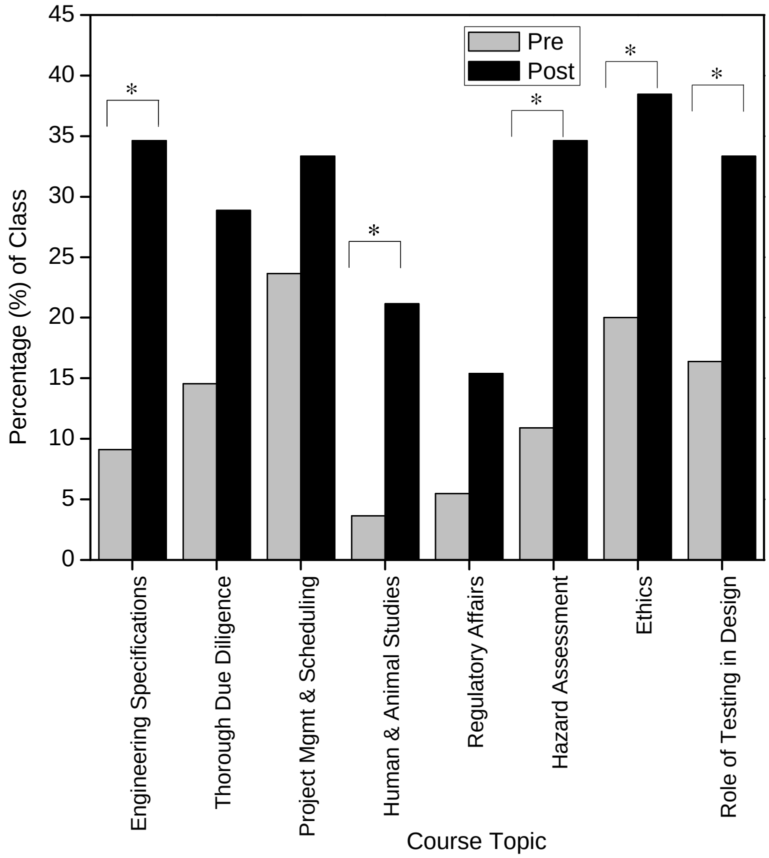

Figure 3. Change in student opinion of having in-depth knowledge on course topics at the start of the course (pre) and the conclusion (post). There was a shift in the percentage of students that felt they had in-depth knowledge of the course topics by the conclusion of the course. Percent was determined from n=54 for the pre-course survey and n=52 for the post-course survey. Statistical significance ($p<0.05$) as determined from a Chi-square test between pre- and post-surveys is indicated by the asterisk.

As part of the mid- and end-of-course surveys, students had the opportunity to provide written feedback, which have been categorized into themes (shown in Figure 4). Review of students' comments showed the greatest concern was the misalignment of the pace of the studio-style lecture activities with the 1-semester senior design laboratory requirements, as 23 comments addressed this theme. Due to academic holidays, the delivery of some of the course topics occurred after the students in the 1-semester senior design experience addressed the material in the laboratory component of the course. Since this course offering, the lecture component of the course has been re-structured to minimize the misalignment. Additional concerns raised by students at the mid- and end-of-course survey included the time (Monday at 8am) at which the course was offered, problems with assignments (especially that there was not enough time to complete the assignments), and the value of material presented. Student comments also focused on positive aspects of the course, with students specifically noting class organization and the relevance of the course themes. We interpret these comments as the students valuing timely feedback/mentor interaction and career preparation.

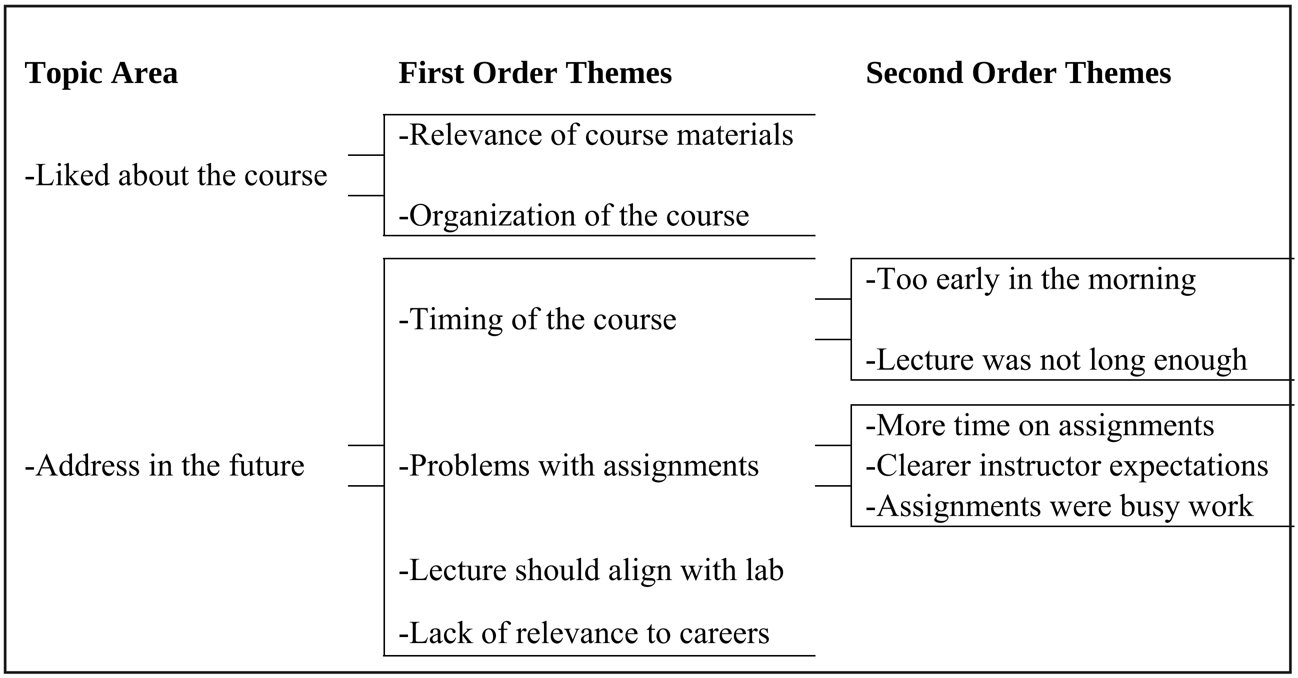

Figure 4. Graphical representation of themes derived from the qualitative data analysis of student written comments from mid- and end-of-course surveys. The questions explored student perceptions relating to the aspects of the course that they liked and that should be addressed in the future. First order themes indicate the main ideas that students took away from the course related to each of the main topic areas. In certain instances, first order themes are further broken down into second order themes to better communicate the students' experiences.

4.3 Reflections on Assignment Design with Respect to Bloom's Taxonomy

To determine if the assigned activities required the students to engage in and practice higher order thinking skills, the assignments were assessed based upon the Bloom's taxonomy scale. We created a rubric with keywords[6] that described each level of Bloom's taxonomy. Three reviewers (chosen from the instructors of the course, the teaching assistant, and a consultant from the center of instructional excellence) independently assessed each of the assignments for evidence of the keywords. Although most assignments spanned the range of Bloom's Taxonomy, almost all assignments required students to perform at the level of evaluation and synthesis. Of note, the entrepreneurship assignment had many parts that were not at the level of evaluation and synthesis, but rather at the level of comprehension, which resulted from the assignment being a report and reflection on an entrepreneurial seminar.

5. Discussion

5.1 Student Performance

Overall, we found the material was more challenging for students than anticipated. This is supported by the high percentage of students who did not meet the expected level of proficiency for a given assignment on the first attempt. After critically looking at the course and the BME curriculum, we identified several reasons why students might not have performed as expected: challenging structure and content of the course, grading scale (pass/no pass) for the class, and new material for students.

Retrospectively, the course itself is challenging, both in structure and content. This is the first time that students have been exposed to a studio-style format in an upper level engineering course, and thus, we expected to have some resistance to the course, which often occurs when students accustomed to lecture formats are immersed in the active-learning pedagogy.[10] In addition, with all assignments expecting students to perform at the evaluation and synthesis level of Bloom's taxonomy, students must show maturation and proficiency when considering the topic in terms of their own design project. Similarly, the course topics differ from those taught in traditional courses. In an effort to enhance student learning, each topic was motivated by its importance and the role it played in engineering design. However, the importance of the course topics may not be readily apparent to all students, especially those who have not held industrial internships. Although there has been little research on student perception of the importance of learning "soft engineering design skills", survey results have shown that engineering students, when compared to industrial representatives, place much less importance on professional skills like communication.[24] Additionally, the open-ended questions asked in the mid- and end-of-course surveys were specifically designed to acquire critical assessment of the course; therefore, it was not surprising that many student comments were negative in nature.

Since the course was graded as pass/no pass, students may have perceived the course to be easy and, as a result, may have taken the course less seriously. The decision to grade the course as pass/no pass was based on the course goal for students to demonstrate proficiency of the material; assessing student work for proficiency naturally lends itself to the pass/no pass grading scale compared to the traditional A-F grading scale. However, pass/no pass courses have been cited by students as demotivating to student learning,[12] most likely because students are extrinsically motivated to learn by achievement of high letter grades. To help motivate student learning, future course offerings will be graded based on a demonstration of skill proficiency, attendance, and class participation.

Some of the topics covered (hazard assessment, regulatory affairs, role of testing in design, economics, and entrepreneurship) had not been formally taught elsewhere within the required courses in the BME curriculum. Thus, students were getting their first exposure to these topics and were then required to show proficiency of the material within the same course period. Other topics had been introduced to students within the required core courses, and students were expected to show increased levels of understanding and demonstration of proficiency. Our goal was to challenge and force students to engage with material with which they may have not been familiar or comfortable to ensure they were exposed to the topics before having to handle them in a non-academic setting.

5.2 Course Improvement

5.2.1 Real-time Course Changes

The course was designed to enhance student learning through both student-teacher and student-student interaction. To provide immediate feedback, we had four instructors and one teaching assistant walking the room, available to answer questions during the course. We initially designed assignments to be completed individually, while encouraging group interaction and discussion. This way, students would benefit from working in groups while ensuring that each student was individually assessed. A meta-analysis performed by Springer, Stanne, and Donovan summarizes the benefit of working in small groups: students demonstrate greater achievement, higher persistence, and better attitudes compared to peers that work alone.[31] However, we found that students did not interact with each other on individual assignments, despite our encouragement to discuss the assignment with peers. Further, few students utilized the instructors if questions about the assignment arose. To encourage students to interact with instructors and other students, we modified the assignments midway through the semester to include instructor approval checkpoints and at least one exercise per assignment that was to be completed as a team. We discovered that requiring instructor approval before a student or team was able to complete the next portion of the assignment kept the students engaged and provided students a more concrete understanding of the assignment resulting in fewer re-grades on assignments. Additionally, including required team exercises increased collaboration on assignments, enhanced the caliber of the submitted assignments, and had the additional benefit of decreasing the amount of time required for grading.

5.2.2 Curricular Changes

Interestingly, we found that students had the most difficulty with *Human and Animal Studies* and the *Role of Testing in Design*, both which dealt with design of experiments and had elements of statistical analysis. Experimental design is a critical skill for engineers. To help students attain proficiency of these critical engineering design skills, we changed the course mid-semester to include a session on experimental design and statistical analysis. The identification and level of concern raised by this curriculum (or programmatic) weakness led to the redevelopment of a junior prerequisite course to include substantial focus on experimental design and statistical analysis.[27] We anticipate students will perform better in these areas because of this curricular change. Integrating professional skills development prior to the capstone course is championed by other investigators who emphasize the need to integrate professional skill development throughout the curriculum.[3, 9, 17]

5.2.3 Future Changes

Initially, in-class assignments were too ambitious and required modification to ensure that students could feasibly complete them within the allotted class time. One of the top complaints with the course reflected this – students felt they did not have enough time to complete assignments. However, we suspect that these comments resulted from students being uncomfortable with the new course pedagogy, especially since there was a decline in this concern over the course of the semester as students accumulated more practiced in engaging in this course format. To help make students more comfortable with the course format, future offerings of this course will implement a 30-minute time extension, for a total class time of two hours. This additional time will be dedicated strictly for allowing students more time to work on in-class assignments.

From the instructor perspective, the course was grading intensive. Grading for the course was variable from week to week and ranged from no grading (when students had a career consultation day and no formal assignment) to more than 15 hours of grading. This was in part due to the highly detailed feedback that was given to the students, the maintenance of a grading schedule in which students received graded assignments within 48 hours of submission, and the required regrading of assignments. Revising assignments forced students to reflect on instructor comments while correcting misconceptions or misinterpretations. The grading schedule was maintained to provide rapid feedback, which has been shown to increase student achievement and learning.[4] Although this course design is most beneficial for student learning, the instructors acknowledge that this time commitment might not be feasible for course propagation or for programs/departments with limited resources. The balance between student learning and instructor resources is difficult to achieve. The assignments could easily be modified to be entirely team-based, however, this leads to problems with individual accountability in ensuring that all students have demonstrated proficiency of the professional skills taught.

5.3 Course Perceptions

After an initial review, the course seems to have been effective in achieving its goal of teaching students professional skills. This is supported by the student-demonstrated proficiency of the professional skills and the increase in student perception of knowledge (pre-/post-surveys in Figure 3) as a result of the course, which partially validated the course revision to a studio-style learning course. End-of-course surveys demonstrated that the course improved student perceived ability to integrate and apply knowledge of design skills, implement the engineering design process, and enhance communication skills. We acknowledge the potential weaknesses of using student perception of knowledge as support, but find that this data provides valuable insight into student attitude towards the course, which can ultimately help or hinder student learning. Student comments also demonstrated an appreciation for course topics:

> *This course has really allowed me to better understand how to be an engineer and the roles and ways of thinking engineers have.*
> *Very broad and gives good understanding of what we need to know in our careers.*

Student comments also positively acknowledged professor interaction and timely feedback on assignments, which made grading for the course worthwhile. Future assessment and analysis will evaluate written assignments in the laboratory design course for evidence of unprompted adoption and practice of these professional skills.

6. Conclusions

This educational design strategy supports consistent delivery of content within a course that is taught by a variety of instructors. The modules and associated presentations for each topic have been developed and can be implemented by any instructor to (1) teach engineering professional skills, (2) better prepare students for engineering roles, and (3) to serve as an ABET assessment point in the curriculum. In addition, these modules could be modified to be suitable for other engineering disciplines (or training programs in industry) by removing the BME examples and inserting other examples. Therefore, these modules are useful to the science and engineering profession, not only to the BME subset.

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