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The Overall Framework of a National Science Foundation-Sponsored Scholarship Program for Enhancing Undergraduate Engineering Education at Utah State University

N. Fang, L. McNeill, R. Spall, and P. Barr
College of Engineering, Utah State University

Abstract

As technology increasingly impacts the nation’s economy and security, high demands have been set for engineering schools to graduate an ever greater number of quality students optimally educated to meet business and industry needs. However, recent statistics compiled by the American Society for Engineering Education reveals that engineering graduation and retention rates at U.S. universities are not keeping up with the nation’s increasing demands for engineering talent. In 2000, less than 5% of all undergraduate degrees were awarded to engineers. Engineering bachelor’s degrees have grown only 1% since 2005.

This presentation describes the overall framework of a project that has been recently funded by the Scholarships in Science, Technology, Engineering, and Mathematics Program (S-STEM) of the National Science Foundation. The goal of the project is to provide S-STEM scholarship support for academically-talented, financially-needy engineering students, and to train these students to become effective scientific and technological contributors when entering the engineering workforce. The first cohort of S-STEM students has been recruited from two departments at Utah State University: Mechanical and Aerospace Engineering (MAE) and Civil and Environment Engineering (CEE).

This presentation describes the project objectives, multi-disciplinary collaboration to promote undergraduate engineering education, and major educational activities that have been particularly designed for this project. Particular emphasis of this presentation is given to the description of a problem-based learning approach that has been implemented in the curriculum since the start of the project. In problem-based learning, students work in teams and learn about an engineering subject in the context of multifaceted and realistic problems. This presentation provides representative examples of how problem-based learning has been implemented in two engineering courses: a sophomore-level Engineering Dynamics course and a junior-level Environmental Management course.
Mechatronics at BYU: A New Course for Undergraduate Mechanical Engineers

Mark B. Colton and Timothy W. McLain
Department of Mechanical Engineering, Brigham Young University

Abstract

In Fall 2015 a required mechatronics course was introduced in the Department of Mechanical Engineering at Brigham Young University as part of a broader curriculum redesign. The course is designed to prepare students to develop smart, microcontroller-enabled products and work in interdisciplinary teams on projects involving mechanical hardware, electronics, and software. Although mechatronics courses often introduce mechanical engineering students to high-level mechatronic design through commercial microcontroller boards, such as the Arduino, our course emphasizes the fundamentals of mechatronics through programming and interfacing single-chip microcontrollers, designing printed circuit boards (PCBs), and low-level system integration. The objective of this approach is to better prepare students to develop real products, which always employ single-chip microcontrollers and custom PCBs. Although this approach requires more intimate knowledge of microcontroller hardware, low-level programming, and electronics than is typically required of mechanical engineering students, our initial results suggest that the level of rigor is appropriate for these students, many of whom excel at mechatronic design by the conclusion of the course. The mechatronics course is part of a required envelope offered in the junior year. The other element of the envelope is a course in system dynamics; the two courses are taken simultaneously and reinforce one another, with system dynamics providing the theoretical background and mechatronics providing extensive hands-on application of those principles through weekly lab assignments and a comprehensive final project that requires student teams to design, build, and program a robot from scratch. In this paper we will describe the development of this course, its structure and relationship to our broader curriculum, and our initial successes and challenges in teaching fundamental mechatronics concepts to mechanical engineering students.
Abstract

The continuous improvement process requires relevant feedback from well-informed participants who share the same goals espoused by the educational institution. A variety of perspectives from students, alumni, industries and faculty are necessary to ensure that educational improvements are effective. The methods for collecting continuous improvement data from students, the industrial advisory board, and the faculty at Utah State University are presented in this paper. Also, the procedures for evaluating the improvements and including all participants in the process were studied. Several issues are discussed as examples, including reducing class size, improving the capstone experience, and correlating basic skills throughout the curriculum. These examples provide evidence of the importance of closing the loop with the participants and articulating the important issues to administrators and students. The success of the improved procedures presented are contrasted to previous methods and demonstrate the importance of continually improving the process.
Abstract

In the past 1.5 years, the Department of Civil & Environmental Engineering at the University of Utah has conducted a pilot study to “modernize” the curriculum. One element of that study has been focused on professional skills, global learning, and cultural intelligence. This paper describes what we have done to integrate and assess cultural intelligence into a course in each year of the program. In particular, learning activities are described along with a cultural intelligence instrument that was selected. The instrument is a product of research from the organizational behavior and cultural intelligence fields of study. It provides both a means to measure a student’s performance level (cultural intelligence quotient, or CQ) and guides students towards specific ways to improve. The courses for implementation were selected specifically to provide a snapshot of the students' abilities at throughout the program, as a trial for where in the program teaching interventions might best occur, and as an exploration in how to teach such skill sets.
Making the Transition from the Physical to Virtual Classroom

Schmucker, D.G.
University of Utah

Abstract

The demand and interest in delivering online instruction for engineering is clearly growing. The different formats vary widely as does the meaning of the terms used to communicate them. This paper presents observations of the author in making the transition from the physical (traditional) classroom to online education. The experiences are based upon 20 years of experience in implementing rigorous models of teaching and learning theory in the undergraduate engineering world and applying them for the past 3 years in the online engineering world. The observations come from fully online experiences as well as partial flipped experiences, synchronous and asynchronous as well as partial hybrid experiences. The paper focuses on implementation in pragmatic terms in connection with sound learning pedagogy. The anticipated audience is those who have any level of experience with traditional educational models and little experience as a member of the team of instructional designers and subject matter experts, i.e., with the creation and delivery of online education.
From Invisible to Responsible Innovators: Engaging and Retaining Low-Income/First-Generation Community College Students in Engineering

Liz Cox and Barbra Sobhani
Red Rocks Community College

Increasing accessibility to engineering pathways and innovating engagement and retention strategies for low-income, first generation (LIFG) college students are important aspects of increasing diversity in STEM. LIFG students are overwhelmingly enrolled at community colleges, yet are underrepresented in the STEM transfer programs and in engineering at four-year universities. Low-income and/or first generation is a category which intersects with other underrepresented categories in STEM such as gender, race, ethnicity and persons with disabilities, yet is often an invisible category in most educational programs. Red Rocks Community College, Lakewood, CO, in partnership with Colorado School of Mines, is piloting a multifaceted approach to make this invisible minority visible through engineering projects that are relevant to the lives of LIFG students.

This paper describes a larger project to go beyond the deficiency model (lens used to define LIFG students by what they lack) in order to create spaces for LIFG students to validate their funds of knowledge (those skills, abilities and experiences developed through manual labor, military, non white-collar jobs, farming, etc.) and thereby move from a state of “belonging uncertainty” in engineering to belonging with certainty. The paper will outline key interrelated activities that support our goal. First, faculty development workshops create faculty as meaningful mentors through pedagogical practices that better engage LIFG students. Second, non-traditional mentoring of LIFG students focuses on opportunities for them to develop social and cultural capital through authentic engineering experiences that are seen as meaningful and impactful to their lives. This occurs in Engineering Club projects, engineering design class (IDEA) and IDEA Lab, and in research experiences at Colorado School of Mines. Through the activities above, the paper will show the piloting of a model of community college and university collaboration to create access and pathways for LIFGs to transfer into engineering.
Teaching Economics Principles to Engineering Students: Lessons and Questions

Scott Houser
Colorado School of Mines

Abstract

The economics education literature is full of research about how to teach economics to specific groups of students, mainly business and liberal arts students. Not much is known about the challenges and opportunities of teaching economics specifically to engineering students. This paper is intended to frame a discussion of those challenges and opportunities.

This paper is informed by experience and assessment data from a required core economics course at the Colorado School of Mines where most students are pursuing degrees in some kind of engineering. The main insights are that teaching economics to engineering students requires explicit communication of relationships between economics and engineering as well as adjustments to both content and pedagogy.

Relative to other students, engineering students are more interested in economic decision-making and innovation. An economics course for engineering students should emphasize tools for cost-benefit analysis and optimization that help students think about personal, social and engineering choices in terms of benefits and costs. Economics instruction for engineers should also focus on the role of innovation. Students who see themselves as innovators are turned off by an introductory economics course that stresses static models where technology is fixed. Innovation should be woven through the course so engineering students can understand incentives for innovation and effects of innovation on markets, workers and economies.

Although the discipline has made some strides in pedagogy, economics instruction is still less engaging than other disciplines. Economics instruction for engineers should incorporate learning tools that have proven to be effective in engineering education. The paper describes how several of these tools can be adapted for an economics course.
A Framework for Developing Effective Concurrent Web-Based Engineering and Technology Curriculum for Rural High Schools

Richard Cozzens  
Department of Engineering and Technology  
Southern Utah University

Abstract

Rural high schools have traditionally lacked access to the most up-to-date engineering and technology curriculum and teaching resources. Recently, the use of communication technology has allowed improved access to learning resources where they would otherwise not be available. With relatively standard technology and limited travel requirements, recent developments have enabled changes to curriculum delivery that should not only provide materials but significantly improve the learning experience. However, a framework that specifically addresses the needs for developing effective concurrent engineering and technology for rural high schools does not exist. Southern Utah University Department of Engineering and Technology developed a framework and tested it in a pilot program. A concurrent engineering and technology curriculum was developed using the framework. The curriculum was then delivered to concurrent high school students using three different curriculum delivery methods. The first delivery method was the traditional face-to-face classroom setting. The second curriculum delivery method was a hybrid format. The third method was purely online.

There were two main objectives to the pilot program. The first was to evaluate the course and verify that it was effective. The instruments used to determine the effectiveness of the course was; Pre Course Survey, Pretest and Posttest, Rubric for Assessing Interactive Qualities (RIAQ) Rubric and Final Grade. RIAQ Rubric was reviewed from five different perspectives; students in the class, students external to the class, instructors, instructional designers and administrators. The second objective was to use the lessons learned from this research to evaluate and improve the framework.

The significance of this research would provide a proven framework for developing not only Quality Matters (QM) approved curriculum but also a framework for applying the curriculum in such a way as to maximize the web-based learning opportunities for students in rural high schools.

**Keywords**: Web-based, curriculum, online, quality, effective, rural, engineering, technology, high school, secondary education
Abstract

Adult learners face several challenges when reintegrating into the classroom setting after working for years. Adult engineering students may experience some of these challenges, especially, with the rigorous academic course load. The current study seeks to build upon the current literature by examining traditional age and adult learners pursuing engineering degrees to understand how these students differ on the factors that impact their academic experience. The results from our study indicated that adult learners differed from traditional age students on important factors. Adult learners reported using more positive appraisal techniques and coping strategies to deal with the pressures of being a student compared to traditional age students, who exhibited higher maladaptive appraisal styles. In contrast, adult learners reported higher levels of personal life stressors and health concerns compared to their traditional age cohort. Exploring engineering student experiences helps to create effective educational practices to offset the challenges that students face in efforts to retain a diverse pool of engineering students.

Keywords

Nontraditional students, Adult learner, Engineering Education

Introduction

Education can be considered the gatekeeper to the American Dream and plays an enormous role within the U.S infrastructure. In today’s society, education leads to job prosperity and increased opportunity. Reports by the Census Bureau have shown direct correlation between education and earnings with the median salary for an individual with a bachelor’s degree ($57,000) being twice that of an individual with just a high school diploma ($27,470). As the job market “gradually shifts from manufacturing blue-collar oriented jobs to white-collar service related professions” education becomes essential in providing career readiness. In consequence, many higher learning institutions have experienced an influx in enrollment rates among a variety of student populations. Adult learners are one of many student groups expected to proliferate within higher education. According to the National Center for Education Statistics (NCES) 2009 report, by the year 2018, it is projected that the number of students 25 to 34 years old will increase by
2016 ASEE Rocky Mountain Section Conference

25%, compared to a 12% increase for those aged 35 and older, and only 9% of those aged 18 to 24 years old.\textsuperscript{3} As diversity continues to increase within the student body, so does the range of needs. Many higher education institutions currently face the challenge of creating inclusive classrooms for diverse student populations including nontraditional and adult learners.

A nontraditional student can be defined as one who has either delayed enrollment into college, attends school part time, works full time while enrolled, is financially independent, or serves in the role of spouse, domestic partner, parent, or caretaker.\textsuperscript{4} These characteristics often create different challenges for nontraditional students, placing them at greater risk for departure from higher education. While nontraditionality is defined by these characteristics, an adult student is defined using an age threshold. For the purpose of this study, we define “adult” as being aged 25 years or over, consistent with the threshold used to track federally-funded adult education in the United States. We recognize that while these groups (nontraditional, adult) are defined by different criteria, there is a strong overlap between the groups. Markle\textsuperscript{5} cited an example from the NCES 2011 report, that 64% of 18-year-old students enrolled in 2003-2004 graduated within 6 years compared to 20% of those aged 24 to 29 years, and 16% of those aged 30 and older. Adult learners exhibit difficulty with immersing themselves within the academic environment which may account for higher attrition rates\textsuperscript{6} in addition, to some campus environments not being hospitable toward nontraditional students.\textsuperscript{7}

In response to these unique barriers, increased scholarly attention has focused on understanding the adult learner experience. Research “provides some important insights into the experiences of adults entering higher education, and identifies factors that interact and may present different challenges for adults than for other groups of students.”\textsuperscript{8} According to Crossan et al,\textsuperscript{9} one barrier that has an impact within the classroom for nontraditional students is their “fragile learning identities”. Within the academic setting, their sense of self may include a history of negative previous educational experiences and “enter with lower self-efficacy beliefs about personal academic skills than the traditional student.”\textsuperscript{10} In addition to this barrier, many nontraditional students experience “feelings of isolation and not fitting in, lack of access to resources, scheduling conflicts, lack of course availability and course times, financial difficulties, and the lack of catering to nontraditional students detracted from the overall college experience.”\textsuperscript{11} Additionally, the challenge of balancing work, school, and life can create pressures for the adult learner. “According to the resource scarcity theory, going back to school creates another role domain that competes for limited resources: the student’s time, energy, and finances.”\textsuperscript{12} These obstacles (amongst many) create difficulty for the adult learner to integrate into the “traditional” university setting.

Literature Review
Research suggests that different internal and external factors influence the learning process for adult learners. With the increasing number of adult students pursuing postsecondary education, it is imperative to understand how these students differ on factors that impact their academic experience and the influence this has on the learning process within the classroom.

**Stress and role conflict**

While “stress is acknowledged as part of the student experience”\(^{13}\), regardless of student status (traditional age vs adult), excessive amounts of stress have been linked to psychological, physical, and emotional outcomes that are harmful. While there are common stressors among college students such as class assignments, homework, and exams, adult learners experience additional stressors that are unique. A major source of stress for the adult learner is balancing work and family while tackling the demands of school. “Unlike traditional, non-traditional students have responsibilities related to their work and personal lives that may lead to demand overload and role conflict when merged with school”\(^{12}\). The manner that adult students perceive the demands of the multiple roles and the extent of the demands has potential consequences on student learning, academic performance, and persistence. Martin\(^{14}\) concluded that perceived stress influenced grade point average (GPA), intent to persist, and goal commitment. Kearns and Gardiner\(^{15}\) found similar results and concluded that the levels of stress that a student encountered influenced academic performance and time management. They found within their study that adult learners that experienced lower levels of academic stress exhibited more satisfaction with their academic experiences and managed their time better. “The commitments and responsibilities adults have outside of university are consistently found to affect their participation in higher education.”\(^{8}\) In efforts to maximize the learning experience for adult learners, exploring stressors that impact the student within the classroom and beyond is essential.

**Appraisal techniques and health concerns**

Appraisal techniques are used to assess a distressing situation or event. The conclusion from the evaluation can be positive or negative depending on the student’s capacity to gauge the situation. If an event is viewed as “harmful or threatening”, the student will utilize negative appraisals and perceive the coursework or life events as overwhelming. In comparison to positive appraisals which views the event as a “challenge to be overcome”. Students that utilize positive appraisal techniques are more likely to view difficult tasks as “manageable” and feel that they are able to accomplish the task. The appraisal techniques that a student uses has an impact on how a student perceives the event, the actions that one takes to resolve the issue, and issues revolving around health. Within this study, questions pertaining to health inquired about psychological well-being such as depression or self-worth. When exploring appraisal techniques, it is plausible that perceived control over a situation influences health outcomes. For example, students that utilize more negative appraisals techniques are likely to experience an inability to overcome difficulties,
lose confidence in themselves, and experience increased unhappiness compared to students that use positive appraisal whom might experience increased feelings of being able to face problems, an ability to enjoy normal day to day activities, and exhibit feelings of overall happiness. For academic success to occur, students must appraise good prospects in the domain and feel that they are able to handle the pressures. Hence, the importance to explore and build upon; especially, within an engineering degree program.\textsuperscript{12}

\textit{Coping strategies and well being}

“Coping style, as most commonly referred to in the literature, is the typical manner in which an individual will confront a stressful situation.”\textsuperscript{16} Within the academic setting, coping strategies can impede or promote learning within the classroom. Differences in coping strategies have been found between traditional age and adult students. Adult students tend to utilize solution driven coping strategies; such as: “task-oriented”\textsuperscript{2}, “Functional”\textsuperscript{17}, or “adaptive.”\textsuperscript{12} These methods are considered healthy because they “engage in direct action to modify the situation and reduce the amount of stress it causes”\textsuperscript{2} and have been linked to positive characteristic traits such as optimism, control, self-esteem, well-being, and hardiness and is negatively associated with anxiety.”\textsuperscript{17} Exploring and understanding differences in coping strategies among different student groups has important ramifications in effectively providing services that help deal with the challenges of being a student.

\textit{Motivation}

Research suggests that academic motivation is related to important educational outcomes, including learning, persistence, and performance. Deci and Ryan\textsuperscript{18} proposed that behavior can be impacted by three different types of motivation: Intrinsic motivation (engaging in an activity for the pleasure and satisfaction of the action itself), extrinsic motivation (engaging in an activity in order to achieve some end or goal), and amotivation (essentially a lack of motivation in which one does not see any connection between engaging in an activity and any outcomes). It appears that nontraditional students tend to display more intrinsic motivation for pursuing higher education compared to traditional students. A report from the “NCES (2002), indicated that 73% of nontraditional students reported that personal enrichment or interest in the subject, gaining skills to advance in their job or obtain a new career, or simply completing a degree or certificate program were important factors in their perseverance.”\textsuperscript{19} The motivations students have for pursuing higher education appears to influence learning style within the classroom. “Nontraditional students are more concerned with what they can do with the knowledge they can get from a class”\textsuperscript{20} compared to traditional students who exhibit more extrinsic motivation. “Traditional students tend to be more focused on getting high grades so they can take the next class and/or be recognized for having earned high grades.”\textsuperscript{20} Understanding the differences in motivational types helps to provide and encourage students to persist in school.
The current study seeks to build upon the current literature by examining traditional and adult students pursuing engineering degrees at a small, private undergraduate institution in the Northeast United States, and to understand how these students differ on the factors that impact their academic experience. Limited literature exists examining adult engineering student experiences within higher education. A few studies explore STEM related fields and suggest that these students encounter similar challenges as other adult students within different degree programs. The adult learners within Shillingford & Karlin’s study self-reported lower levels of math self-efficacy and higher levels of math anxiety than their traditional peers. According to Byars-Whitson et al., external environmental and personal factor were frequently cited for students leaving STEM majors. Based on the work of Giancola et al., undergraduate engineering students were asked to report key stressors, appraisal techniques, perceptions of life satisfaction, role-conflicts, health concerns, coping strategies, and motivations. The original hypothesis were stated such that adult engineering students would exhibit higher levels of 1) Stress, 2) Appraisal Techniques, 3) Satisfaction with Life 4) Role Conflict 5) General Health 6) Coping Strategies 7) intrinsic motivation in comparison to traditional undergraduate engineering students.

Method

Participants

A convenience sampling method was utilized to recruit participants, via posted signs, flyers, and emails. The pool of eligible students consisted of all full-time undergraduate students who at the time were enrolled in an engineering program at University of New Haven. Of the 713 eligible students, 144 responses were collected of which 63 were excluded from analysis as a result of insufficient or missing data. The final sample consisted of 81 (27 adult learners, 54 traditional) undergraduate students pursuing engineering degrees at a small, private institution in the Northeast United States. Within the sample, 60 participants self-reported as male, 20 as female, and one participant identified as transgender. Most of the participants identified as Caucasian (70%). Demographic differences emerged between the two engineering student groups. Traditional engineering students ranged in age from 18 to 24 years (M_age = 20.52) compared to adult engineering students who ranged in age from 25 to 49 years (M_age = 33.78). Nontraditional students within the sample presented similar characteristics as a “typical” adult learner such as: higher occupational engagement, advanced industry experience, and increased commitment to responsibility. Adult students displayed a range of industry experience and came from a variety of socioeconomic backgrounds. 70% (19) of participants reported full time employment, 26 % (7) part-time, 3% (1) unemployed and 58% indicated an annual household income over $40,000. Approximately, 70 % of participants reported being in a committed relationship or partnership. In contrast to the traditional engineering cohort, who exhibited characteristics such as: full-time student status (96.3%), part-time employment (46.3 %), single (92.6%) and less work experience (57.4%).
Instruments

An Engineering Student Experience Questionnaire was developed to allow comparisons between our adult undergraduate student population and traditional age engineering students. Students in the College of Engineering were emailed a description of the purpose of the study and an invitation to participate via Survey Monkey. The survey began with a consent form and then invited students to respond to several categories of questions regarding their experience. For this work, we drew from measures that had previously been applied in the work of Giancola et al., and also included the Academic Motivation Scale\textsuperscript{22}. In this paper, we analyze trends in the Work-Family-School Conflict category form the Giancola et al. study and the Academic Motivation Scale. The following are examples of questions we asked in these categories.

**Stress:** Participants rated their perceptions of their level of work, personal, and school stressors during the past 6 months\textsuperscript{23}, using a 5-point Likert scale from “Never” to” Always” (41 items).

- Unpleasant physical surroundings at work (work stressor)
- Financial difficulties (personal stressor)
- Excessive amount of school work (school stressor)

**Work-Family-School Role Conflict:** Interrole conflict was measured using questions that asked participants rated to what degree they agree with statements that indicate conflict or tensions between four potential areas: family to school, school to family, work to school, and school to work\textsuperscript{24}. They responded using a 5-point Likert scale from “Strongly Disagree” to “Strongly Agree” (14 items).

- My school life makes it difficult to be the kind of worker I would like to be.
- My employer and colleagues are supportive of my educational goals.
- Because my school work is demanding, at times I am irritable at home.

**Appraisal:** Participants rated their positive and negative appraisal styles with eight items from the appraisal scale\textsuperscript{25}. Four items measured positive appraisal and four measured negative appraisal. Participants rated their agreement with statements using a 6-point Likert scale, ranging from “Strongly Disagree” to “Strongly Agree.”

- I tend to focus on the positive aspects of any situation
- I worry that I will say or do the wrong things

**Coping:** The COPE scale was used to measure problem-focused, emotion-focused, and dysfunctional dimensions of coping\textsuperscript{26}. Participants responded to 32 items assessing eight coping strategies: positive reinterpretation and growth, focus on and venting emotions, use of instrumental social support, active coping, denial, behavioral disengagement, substance use, and planning. Participants responded using a 4-point scale from “I usually don’t do this” to “I usually do this a lot.”
Satisfaction With Life: The Satisfaction With Life scale (SWLS) asks participants to respond to five items measuring global life satisfaction, using a 7-point Likert scale from “Strongly Disagree” to “Strongly Agree.”

1. In most ways, my life is close to my ideal.
2. The conditions of my life are excellent.

General Health: The General Health Questionnaire 12 (GHQ-12) was used to measure participants’ overall well-being. Participants reported the extent to which they experienced particular symptoms during the last few weeks, using a 4-point scale from “Not at all” to “Much more than usual.”

1. Felt constantly under strain?
2. Been able to enjoy your normal day to day activities?

Academic Motivation Scale: Participants indicated the level to which they agree with statements about why they go to school, using a 7-point Likert scale ranging from “Totally Disagree” to “Totally Agree” (20 items). Responses are combined for three subscale scores: Intrinsic motivation, extrinsic motivation, and amotivation.

1. For the pleasure I experience when I discover new things never seen before.
2. Because I want to have “the good life” later on.
3. Honestly, I don’t know; I really feel that I am wasting my time in school.

The survey concluded with a demographics questionnaire. Required questions asked for: gender, class load (full- or part-time), class level (freshman, sophomore, etc), and age. Optional questions requested ethnicity/race, employment status, marital status, length of employment in current job, level in the organization, whether the student was first in the family to attend college, number of children, yearly income, and GPA. The survey concluded with a debriefing page that included contact information for questions on the results of the study.

Procedure

A list of names and e-mail addresses of all qualifying students were obtained from the Office of Institutional Research. A total of 713 students were emailed and invited to participate in the online study. Participants reviewed and signed the informed consent document before moving on to complete all the questionnaire items. The study was approved by the university’s institutional review board.

Data Analysis
All statistical analyses were conducted using Statistical Package for the Social Sciences (SPSS) version 21.0. Independent-sample t-tests were conducted for the following variables: stressors, work-family-school role conflict, appraisal, coping, satisfaction with life, general health, and academic motivation to examine if differences emerged between adult learners and traditional students. Statistical significance was set at .05.

**Results**

**Stress**

**Table 1. Student Status and Differences in Stress Response Patterns**

<table>
<thead>
<tr>
<th></th>
<th>Adult Mean (SD)</th>
<th>Traditional Age Mean (SD)</th>
<th>t</th>
<th>df</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work Life Stressors</td>
<td>42.07 (10.66)</td>
<td>38.98 (12.85)</td>
<td>-1.08</td>
<td>79</td>
<td>.284</td>
</tr>
<tr>
<td>Personal Life Stressors</td>
<td>26.33 (5.82)</td>
<td>22.20 (6.24)</td>
<td>-2.87**</td>
<td>79</td>
<td>.005</td>
</tr>
<tr>
<td>School Life Stressors</td>
<td>28.89 (8.94)</td>
<td>32.94 (9.97)</td>
<td>-5.66</td>
<td>79</td>
<td>.078</td>
</tr>
</tbody>
</table>

Note. *p < .05, **p < .01. t = t-test value; df = degrees of freedom

Stressors in work, school, and life were examined among traditional age and adult students. For work stressors and school stressors, there was no significant difference between traditional age and adult students. There was a significant difference in personal life stress, with adult students reporting higher levels of personal life stressors compared to their traditional counterparts.

**Appraisal Techniques**

**Table 2. Student Status and Differences in Appraisal Techniques**

<table>
<thead>
<tr>
<th></th>
<th>Adult Mean (SD)</th>
<th>Traditional Age Mean (SD)</th>
<th>t</th>
<th>df</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive Appraisal</td>
<td>20.70 (2.55)</td>
<td>18.56 (3.39)</td>
<td>-2.91**</td>
<td>79</td>
<td>.005</td>
</tr>
<tr>
<td>Negative Appraisal</td>
<td>9.63 (4.19)</td>
<td>12.67 (4.44)</td>
<td>2.96**</td>
<td>79</td>
<td>.004</td>
</tr>
</tbody>
</table>

Note. *p < .05, **p < .01. t = t-test value; df = degrees of freedom
The use of positive and negative appraisal techniques was investigated to explore if differences emerged between the two student groups. A significant difference was found for positive appraisal styles between traditional age and adult students. Adult students utilized more positive appraisal techniques to deal with the pressures of being a student compared to traditional age students. Traditional age students appeared to use more maladaptive appraisal styles, as indicated by a significant difference for negative appraisal styles between traditional age and adult students.

**Satisfaction with Life**

<table>
<thead>
<tr>
<th></th>
<th>Adult Mean (SD)</th>
<th>Traditional Age Mean (SD)</th>
<th>t</th>
<th>df</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Satisfaction</td>
<td>25.22 (6.61)</td>
<td>24.52 (7.41)</td>
<td>-.417</td>
<td>79</td>
<td>.678</td>
</tr>
</tbody>
</table>

Note. *p < .05, **p < .01. t = t-test value; df = degrees of freedom

No significant difference was found between traditional age and adult students on general life satisfaction.

**Interrole Conflict**

<table>
<thead>
<tr>
<th></th>
<th>Adult Mean (SD)</th>
<th>Traditional Age Mean (SD)</th>
<th>t</th>
<th>df</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Family to School</td>
<td>5.30 (2.23)</td>
<td>5.57 (2.45)</td>
<td>.494</td>
<td>79</td>
<td>.622</td>
</tr>
<tr>
<td>School to Family</td>
<td>13.67 (4.53)</td>
<td>12.06 (3.99)</td>
<td>-1.64</td>
<td>79</td>
<td>.106</td>
</tr>
<tr>
<td>Work to School</td>
<td>5.56 (1.93 )</td>
<td>6.65 (2.76)</td>
<td>1.844</td>
<td>79</td>
<td>.069</td>
</tr>
<tr>
<td>School to Work</td>
<td>11.44 (4.50)</td>
<td>12.31 (3.85)</td>
<td>.906</td>
<td>79</td>
<td>.368</td>
</tr>
</tbody>
</table>

Note. *p < .05, **p < .01. t = t-test value; df = degrees of freedom
For work to school role conflict, the difference between traditional age and adult students approached significance. No significant differences were found between traditional age and adult students on any of the other role conflict subscales (family to school, school to family, school to work).

**General Health**

**Table 5. Student Status and Differences in General Health**

<table>
<thead>
<tr>
<th></th>
<th>Adult Mean (SD)</th>
<th>Traditional Age Mean (SD)</th>
<th>t</th>
<th>df</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health</td>
<td>35.85 (6.65)</td>
<td>32.70 (5.71)</td>
<td>-2.213*</td>
<td>79</td>
<td>.030</td>
</tr>
</tbody>
</table>

Note. *p < .05, **p < .01. t = t-test value; df = degrees of freedom

There was a significant difference general health scores with adult students reporting more health concerns than traditional age students.

**Coping Strategies**

**Table 6. Student Status and Differences in Coping Strategies**

<table>
<thead>
<tr>
<th></th>
<th>Adult Mean (SD)</th>
<th>Traditional Age Mean (SD)</th>
<th>t</th>
<th>df</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptive</td>
<td>51.59 (8.42)</td>
<td>43.81 (9.54)</td>
<td>-3.592**</td>
<td>79</td>
<td>.001</td>
</tr>
<tr>
<td>Maladaptive</td>
<td>21.48 (3.47)</td>
<td>23.19 (5.01)</td>
<td>1.59</td>
<td>79</td>
<td>.117</td>
</tr>
</tbody>
</table>

Note. *p < .05, **p < .01. t = t-test value; df = degrees of freedom

There was a significant difference in scores for adaptive coping strategies between traditional age and adult students, with adult students using more adaptive coping strategies. There was no difference between traditional age and adult students on maladaptive coping strategies.
Motivation

Table 7. Student Status and Differences in Motivation

<table>
<thead>
<tr>
<th></th>
<th>Adult</th>
<th>Traditional Age</th>
<th>t</th>
<th>df</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrinsic Motivation</td>
<td>23.93 (4.31)</td>
<td>21.93 (5.68)</td>
<td>-1.610</td>
<td>79</td>
<td>.111</td>
</tr>
<tr>
<td>Extrinsic Motivation</td>
<td>66.07 (12.25)</td>
<td>67.11 (12.32)</td>
<td>.358</td>
<td>79</td>
<td>.721</td>
</tr>
<tr>
<td>Amotivation</td>
<td>6.37 (3.13)</td>
<td>7.94 (5.43)</td>
<td>1.393</td>
<td>79</td>
<td>.167</td>
</tr>
</tbody>
</table>

Note. *p < .05, **p < .01. t = t-test value; df = degrees of freedom

There were no significant differences between traditional age and adult students on any of the motivation measures, including intrinsic motivation, extrinsic motivation, and amotivation.

Discussion and Conclusion

Higher education institutions face the challenge of providing services and programming to meet the needs of traditional age and adult learners. In efforts to enhance the understanding of the student experience, this study explored factors that influenced the learning process for adult and traditional age students. One variable that has displayed mixed results were stressors pertaining to school, work and personal life. Within the literature, researchers 12, 23 found conflict between family and student roles more prevalent in comparison to other researchers which found conflict between work and student roles as a greater stressor in student’s lives.23 Adult learners within our sample reported higher levels of personal life stressors than traditional age students; while interestingly, not reporting higher levels of interrole conflict within any area of their lives. The interrole conflict result can be attributed to role perceptions between genders. “Women experience high levels of conflict due to their internalization of the intensive mothering and ideal student roles while men do not experience this.”5 According to Stone and O-Shea29, men may not experience this sense of conflict because prioritizing school is “privileged, allocated special significance within the family” and is the expectation of being a “good provider.”30 The majority of our sample were males and may hold similar “good provider” ideologies. This result may serve to support that men experience interrole conflict in a different manner than women. Within the educational setting, this ideology may have an impact and have potential consequences on student learning, academic performance, and persistence; especially, for women.

Numerous studies have indicated that adult learners utilize more positive coping strategies to deal with the pressures of being a student. The results from our study add to the current body of
knowledge by including engineering adult learners. Coping strategies that are solution driven help adult learners to deal with the demands of multiple roles of student, employee, or spouse or caretaker. The possibility of having multiple roles increases task-oriented strategy out of necessity in supporting the focus on learning for its own sake. Engineering adult learners would rely more on task-oriented coping strategies; especially, with the rigorous academic course load, Major, Holland & Oborn found that students who disengage or use maladaptive coping strategies will not adequately cope with obstacles they encounter in their major. Thus, they will have a more difficult experience and will be more likely to experience negative outcomes, feeling less committed to the major as a result.

Although previous research has associated adult students with increased intrinsic reasons for pursuing higher education, this study did not find similar results and can be linked to the high degree of motivation required for pursuing an engineering degree. One explanation for this result is student status of participants. According to Seymour & Hewitt, the greatest attrition among STEM majors occurs in the freshmen and sophomore years. Within our sample 20 of 27 participants were junior standing or higher, which may suggest that our study respondents internalize high levels of motivation required to persist through engineering degree completion.

Government and industry continue express high demand for STEM-trained workers and much effort has been put in place by government agencies and academia to increase the pool of trained candidates. Yet, the output of qualified candidates remains low. In 2012, “only about 40% of students who enter a STEM major graduated”. With the increasing number of adult learners students pursuing higher education, federal, and institutional initiatives call for increased retention and degree completion rates; especially within the engineering degree program. From this work, different factors emerged that may influence the adult engineering students within higher education. This contributes to the knowledge base and assists in development of programs that increase retention rates and diversity within engineering programs. Further research should focus more closely on support programs or services that may address various coping strategies for this population.

Limitations

The results of the present study need to be considered with some caution due to a number of potential limitations. First, the results are limited in generalizability because this was a small sample from one university. Second, the study utilized a quasi-experimental design in order to compare adult and traditional age students, but therefore did not allow for random assignment. Similarly, “adult” students were defined by an age cutoff only, but operationalizing adult and traditional in different ways could yield different results. Another limitation is that the dependent variables were all obtained through a self-report questionnaire. The inclusion of multiple sources of information or more objective sources would have provided more comprehensive data. Finally,
the cross-sectional nature of the study does not allow for us to examine if these constructs change over time. Perhaps an analysis of these variables over time would reveal new patterns; this is an important consideration for future research.

References


**Biographical Information**

1. **Audrianna Rodriguez** received her M.S. in Clinical & Community Psychology from the University of New Haven, 2016.

2. **Maria-Isabel Carnasciali** is an Associate Professor of Mechanical Engineering at the University of New Haven, CT. She obtained her Ph.D. in Mechanical Engineering from Georgia Tech in 2008. She received her Bachelors of Engineering from MIT in 2000. Her research focuses on the nontraditional engineering student – understanding their motivations, identity development, and impact of prior engineering-related experiences.

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4. **Melissa Whitson** is an Associate Professor of Psychology at the University of New Haven. Her current research interests include examining risk factors, protective factors, and services that affect mental health outcomes for low-income students and families and the implications for prevention and intervention. She received her PhD in Counseling Psychology from Columbia University and carried out postdoctoral work in Community Psychology at Yale University.

5. **Viktoria Zelenak Berendt** received her M.S. in Industrial & Organizational Psychology from the University of New Haven, 2014.
Inexpensive Metal 3D Printers in Engineering Education: 
The Revolution Continues

Nebojsa Jaksic, Nikolas D’Angelo, and Gabriele Vigano
Department of Engineering, Colorado State University - Pueblo

Abstract

This work describes an implementation of inexpensive, safe, open source, metal clay 3D printers in engineering education labs. The 3D printing process and an existing, commercially available design were improved to reliably create small load-bearing metal parts like gears and other bronze objects. Mechanical properties of 3D printed plastic and metal specimens were compared. The results of tensile tests were used as an illustrative pedagogical tool. An instrument was developed to measure students’ perspectives on inexpensive metal parts created by metal clay 3D printers. Preliminary results show that students believe that 3D printed metal parts are useful. By creating and testing their own specimens students reinforced their knowledge of materials. Also, they learned how to use a novel engineering design/production tool.

Keywords

3D printing, additive manufacturing, Mini Metal Maker, metal clay

Introduction

Laboratory-based experiential learning occurring during engineering design exercises is one of the fundamental modes of learning in engineering education. As a part of the engineering design process, the use of modern engineering tools like 3D printers is highly desirable, especially since 3D printers can speed up the process considerably. Justification for adoption of 3D printers in engineering education is well documented in engineering education literature.

In the past few years, inexpensive 3D printers that can produce plastic parts became ubiquitous devices in education due to the expiration of many 3D printing technology-related patents. Many K-16 educational institutions have at least one 3D printer, predominantly of the fused deposition modeling (FDM) design. While acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), or nylon can create functional objects, for some applications plastic parts are just not strong enough. Until now, 3D printing in metal was for a privileged few because of the high prices of 3D metal printers (sometimes over $1,000,000) which are often 100 times more expensive than the inexpensive FDM 3D printers that print plastic. In addition, the prices of metal powders used in these 3D printers are prohibitive. While one kilogram of ABS filament used in plastic 3D printers may cost $50, one kilogram of metal powder (which is much denser than plastic) used in metal 3D printers may cost over $1000. Finally, due to the explosive nature of some metal powders (e.g. Ti, Al, etc.) strict safety procedures must be followed.

This work addresses the authors’ experiences with a novel, inexpensive, safe, experimental, open source 3D printer that prints objects using specially formulated bronze clay that after post-processing results in pure bronze objects. In the next section, the adoption of general 3D printing
technologies into two engineering curricula is described. Then, a short overview of the state-of-the-art metal 3D printing devices and processes is provided. Next, the first inexpensive, commercially available metal clay 3D printer with the associated process for creating metal parts is introduced. The improvements made to the printer and the process are disclosed. Tensile test results of samples created by the metal clay 3D printer are compared to the samples created by 3D printers using ABS plastic. Finally, an instrument measuring students’ perspectives on inexpensive 3D printing technologies is presented. A few examples of metal parts are provided. The addressed student learning outcomes are: increased practical knowledge of material properties and testing procedures through testing of student-created specimens, and increased proficiency with a new design/manufacturing 3D printing technology as a tool of the engineering profession.

Curricular Context

Two undergraduate BS (industrial engineering and mechatronics) and two graduate MS (industrial and systems engineering and mechatronics) engineering programs are directly impacted by the engineering department’s 3D printing lab. The 3D printing lab availability (the lab is open every workday for six to eight hours and it employs two half-time student technicians) is an important factor in developing students’ expertise with this technology. The FDM 3D printers are used to create parts in many undergraduate engineering courses. A formal introduction to the lab’s 3D printers is presented as a part of Computer-Aided Design (CAD) topics in the first year course, Engineering Graphics. Then, in the Engineering of Manufacturing Processes course, various 3D printing (additive manufacturing) technologies are introduced. Finally, a lecture and a hands-on lab comparing traditional Computer Numerical Control (CNC) machining with additive manufacturing technologies are included as a part of Computer-Aided Manufacturing (CAM) topics in the Computer-Integrated Manufacturing (CIM) course. The above three courses are mandatory for both undergraduate programs. Graduate students often take Engineering of Manufacturing Processes and CIM courses at the graduate level. While undergraduate students experiences with 3D printers culminate in their senior design projects, for graduate students, the two graduate level courses coupled with available 3D printers often result in inspiration for further studies and research in these areas.

Current Metal 3D Printing Technologies

Metal parts produced by 3D printers are used in the aero-space industry, medical industry, automotive industry, and jewelry industry. In general, production of metal objects using 3D printing technologies can be categorized into three groups of processes:

1. Pattern-based: where 3D-printed (plastic, starch, or wax) parts are used as patterns for casting. Direct 3D printing of molds can be included in this group.
2. Indirect: where an initial metal powder-based part is 3D printed, and then such part is heat-treated (or sintered) in a furnace
3. Direct: where parts are produced by either a) heat-joining of metal powder (powder bed fusion) or b) direct deposition of metal (wire or powder) with the aid of an external energy source (directed energy deposition).

While the first group of processes can be easily implemented using inexpensive 3D printers based on inexpensive materials, the other two groups previously could not. For example, an indirect process called binder jetting uses liquid binder to selectively join powder material layer by layer.
(the printer draws in glue on powder). There is no need for a support structure since the powder that is not fused acts as support. However, both the printer and the metal powder are expensive and the post-processing to produce functional parts is long since it often includes heat treatment to vaporize the binder, sintering, and infusion with another metal (most often bronze) to increase the strength of the parts. However, due to the use of metal powders safety protocols must be followed.

The direct group of processes usually requires expensive heat sources such as high-power (100 – 1000W) fiber-optic lasers, electron beams (50 – 3000W)\textsuperscript{9}, etc. to fuse the metal powder together. The powder bed fusion sub-group includes: selective laser sintering (SLS); direct metal laser sintering (DMLS) that is similar to SLS except it sinters metal alloys; selective laser melting (SLM) that fully melts the metal powder; and electron beam melting (EBM) that requires vacuum. The directed energy deposition sub-group uses either metal wire or metal powder that is extruded from a nozzle and is deposited according to the layer specifications. As the material is deposited it is melted by a laser, electron beam, or arc discharge. This is similar to material build up by an automated gas metal arc welding (GMAW) process. Directed energy deposition processes are often used in part repairs.

**Inexpensive Metal 3D Printing: Mini Metal Maker**

As shown in Table 1, the only commercially available metal clay printer on the market, Mini Metal Maker, is price-compatible with inexpensive plastic 3D printers based on technologies like FDM or stereolithography digital light projector (SLA DLP\textsuperscript{10}). The metal clay 3D printing belongs to the indirect group of processes where the final part is produced from the 3D printed part using an additional post-process. Mini Metal Maker system (including the kiln) is much less expensive than any of the metal printers currently on the market ($100,000 to $500,000)\textsuperscript{11}.

<table>
<thead>
<tr>
<th>Name</th>
<th>Technology</th>
<th>Price</th>
<th>Material</th>
<th>Price/Mat</th>
<th>Resolution</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>MakerBot Replicator 2X</td>
<td>FDM</td>
<td>$2500</td>
<td>ABS, PLA</td>
<td>$50/kg</td>
<td>100 µm</td>
<td>varies</td>
</tr>
<tr>
<td>Pegasus Touch</td>
<td>SLA DLP</td>
<td>$3000</td>
<td>FSL3D resin</td>
<td>$138/kg</td>
<td>50 µm</td>
<td>1s/layer</td>
</tr>
<tr>
<td>Mini Metal Maker</td>
<td>FDM</td>
<td>$2300</td>
<td>Metal Clay</td>
<td>$200/kg</td>
<td>100 µm</td>
<td>varies</td>
</tr>
</tbody>
</table>

Table 1. Comparison of three inexpensive 3D printing technologies\textsuperscript{10}

While the Mini Metal Maker was introduced to the maker community in 2015, there hasn’t been much buy in from engineering faculty and students. Currently, only three clay formulations are available: bronze-based (available directly and through Mini Metal Maker), stainless steel-based and Sterling silver-based clay. The silver-based clay requires a kiln that can reach 1700 °F and can be fired in air. The company that created these clay materials, Metal Adventures, Inc., is planning to introduce copper-based clay shortly thus increasing the selection of materials.

A Mini Metal Maker system consisting of a 3D printer and a small digital kiln is shown in Figure 1. A cartridge (syringe) with 50g of bronze metal clay and a disposable plastic nozzle are depicted in Figure 2. The metal clay uses water-soluble binder. Basically, Mini Metal Maker is a small CNC machine (automated x-y-z table) having a syringe pump driver as a tool. Figure 3.a shows printing of an object using metal clay. Since the metal clay is still somewhat expensive ($200/kg), in the
department’s 3D printing lab, trial 3D printing is often performed with reusable modeling clay, as pictured in Figure 3.b.

After printing, bronze clay parts are dried and then fired in a small digital kiln. The firing process is specific to the bronze clay used and the part geometry. The process produces bronze parts by sintering, thus an appropriate temperature curve is programmed into the kiln’s controller to
minimize residual stresses. In addition, one of the design recommendations to the students was to avoid sharp angles whenever possible, again to minimize residual stresses. Figure 4 shows a gear before and after firing. In the example shown in Figure 4.a, the as-printed clay part is about 12% larger by volume than the finished metal part shown in Figure 4.b. The average shrinkage in our tests is about 8%.

The Mini Metal Maker hardware and all the software packages used to operate Mini Metal Maker are open source. The recommended software stack (tool chain) includes 3D modeling software (Tinkercad) that produces .stl or .obj files, slicing software (Slic3r) that creates layer by layer G-code as .gcode files, printer controller software (Printrun or Pronterface) that connects a computer to the 3D printer via USB cable and controls the printer, and printer firmware (Marlin). In addition, the printer-specific configuration files are provided by the manufacturer\textsuperscript{12}. Since the department has a number of SolidWorks licenses, this software package is used for 3D modeling.

**Metal Clay 3D Printing Device and Process Improvements**

*Hardware Improvements*

After a few basic test prints a small gear was printed. However, the obtained bronze gear shown in Figure 5.a had irregular teeth. The gear’s horizontal layers where offset from each other. Upon careful observation of the process it was determined that the z-axis linear guide had too much play causing somewhat erratic behavior of the printer. As a solution, this original guide was replaced with a higher-quality guide, a 260 mm Hiwin MGN15H Compact Linear Guideway. Figure 5.b shows the gear obtained after the change. The two white circles in Figure 5 highlight the difference in gear teeth.
Objects with overhangs could not be printed. The maximum printing overhang angle was in the order of a couple degrees. This was regarded as a serious disadvantage of the metal clay 3D printing process. Then, after studying clay and ceramic designs, it was discovered that applying heat (using a hair dryer) to layers during printing increases the maximum printing overhang angle considerably, to over 50° depending on the layer height/width ratio. After the manufacturer was informed of this result, the manufacturer disclosed a heater/dryer device design that was in the developmental stage. Figure 6 and Figure 7 depict objects 3D printed using a hair dryer to dry the layers during printing. In Figure 7, even the use of a heater didn’t result in a successful print due to large overhang angles involved in the object geometry.

Figure 5. 3D printed gears: a) before and b) after installing a high-quality z-axis linear guide

Figure 6. Successful bronze parts illustrating overhang angle improvements

Figure 7. Unsuccessful 3D Printed part showing layer separation due to large overhang angles
**Process Improvements**

There is an extrusion speed adjustment knob on the back of the 3D printer. It should be set and adjusted during printing to obtain good printing results. However, it was discovered that the speed of extrusion for the remaining layers (setting 3) should be lower than the extrusion speed for the first layer (setting 5 or 6 as suggested in the owner’s manual\textsuperscript{12}). This manual adjustment of the speed control knob during printing was necessary to achieve good adhesion between the object and the building platform; otherwise objects would not stick to the platform thus resulting in failed prints. To avoid manual adjustments of the Extrusion Speed Control Knob an option in the slicing program has been exploited to allow programmatic changes of the extrusion speed for each layer.

Some failed prints were traced to imprecise leveling of the building platform. Even the leveling procedure as specified in the manual\textsuperscript{12} often wouldn’t solve the problem. Therefore, as shown in Figure 8, an analog dial indicator was mounted in place of the cartridge to level the building platform more precisely.

![Figure 8. Leveling the building platform by using a dial indicator](image)

**Tensile Testing of 3D-printed Specimens**

Figure 9 shows a student-developed graphical user interface for a material testing machine created in LabVIEW software package. In this tensile test, the grips separation rate was 0.2 in/min. The black circle shows the last value of the stress measurement (3D-printed bronze specimen).

An illustration of material strengths of 3D printed materials is presented next (plastic is compared to metal). A plastic (ABS) specimen (ASTM D638 standard) was 3D printed and tested using an upgraded Instron Model 1123 material testing machine. The grips separation rate was 0.2 in/min. The results are obtained by measuring crosshead movement. Also, a 3D printed bronze specimen (a standard for powder metals is used) depicted in Figure 10 was 3D printed and tested using the same testing machine and testing conditions.
Figure 9. A Stress-Strain curve for a bronze specimen showing a student-developed LabVIEW interface

Figure 10. Bronze tensile test specimens

The stress-strain curves for a 3D-printed ABS specimen and a bronze specimen are shown in Figures 11 and 12. The ultimate tensile strength (UTS) from the curve for 3D printed ABS is about 4640 psi (32 MPa) which is close to the published average UTS of 28.5 MPa\cite{13}. Also, the recorded UTS for the 3D-printed bronze specimen was 28,353 psi (195.5 MPa). For solid bronze (Cu Sn12) UTS is about 40,000 psi (280 MPa) but less than that for sintered powder bronze. Still, this test shows that bronze parts are about six times stronger than ABS parts. The results increased students’ practical knowledge of materials.
Students’ Perspectives

A short questionnaire, shown in Table 2, is developed to measure students’ opinions on inexpensive 3D printing technologies. The questions are rated on the five point Likert scale where 1 is the lowest and 5 is the highest rate. The questionnaire was administered to two groups: the engineering students involved in 3D printing (2) and the members of the Maker movement that visited the engineering lab during an open house event (6). The aggregate results are shown in Table 2. As expected, the students and the Makers are more familiar with printing plastic than metal clay. They all see value in 3D printed plastic objects. This shows their acceptance of 3D printing in plastic as something ordinary. However, they also see value in metal objects that they can create. Comparing the results of questions 4 and 5, one may infer that participants are somewhat reluctant to send out their designs for 3D printed metal objects.
Table 2. Student Questionnaire on Inexpensive 3D Printing Technologies

<table>
<thead>
<tr>
<th>Question</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. How familiar are you with 3D printing in plastic?</td>
<td>3.75</td>
</tr>
<tr>
<td>2. How familiar are you with 3D printing in metal (metal clay)?</td>
<td>2.62</td>
</tr>
<tr>
<td>3. How useful are the 3D printed plastic objects to you?</td>
<td>4.88</td>
</tr>
<tr>
<td>4. How useful are the 3D printed metal objects to you (general, Shapeways)?</td>
<td>3.62</td>
</tr>
<tr>
<td>5. How useful are the 3D printed metal objects to you (bronze, in-house)?</td>
<td>4.43</td>
</tr>
<tr>
<td>6. What metal/alloy would you like to see next for metal clay 3D printing (in our lab)?</td>
<td>steel (3), Cu (3), Al (2), Ag (2), Au (2), Ti (2), other: Co (1)</td>
</tr>
</tbody>
</table>

Later, another question (Why are metal parts more valuable (useful)?) was asked of the engineering students who were available in the 3D printing lab. Most of the answers cited metal characteristics such as strength, hardness, conductivity, and luster. Some answers included density, thermal conductivity, and machinability. In Question 6, steel and copper choices are somewhat biased because of students’ previous experiences. Namely, they often build robots and they want them to be strong, so steel seemed a good choice, especially since it is used predominantly in our machine shop. Also, they were introduced to graphene-based conductive filament in our lab (not a great conductor), thus they wanted copper as a good conductor of electricity. The results suggest that most of the participants are fully aware of the benefits that 3D printed metal parts provide.

The instrument will be improved and distributed to a larger number of students in the Fall Semester. Question 6 will also ask why students would prefer certain metals. Also, the question on usefulness of metal parts will be added to the questionnaire.

Summary and Conclusions

This work describes a commercially available, inexpensive, safe, experimental, open source, metal clay 3D printer (Mini Metal Maker) and its use in an engineering education lab to create bronze objects. First, inexpensive 3D printers are placed in the curricular context of multiple engineering programs. Then, a classification and an overview of state-of-the-art metal 3D printing technologies are presented. A description of a particular inexpensive metal clay 3D printing system (including its operation) is provided. A number of improvements to this system are documented: installation of a higher-quality z-axis linear guide; addition of a forced drying heat/fan sub-system; mounting of a dial indicator for more precise leveling of the build plate; adjustments of extrusion speed during printing, etc. The results are supported by examples. Also, sample stress-strain curves for 3D printed specimens in ABS and bronze are included illustrating the difference in strength between metals and plastics.
In conclusion, it is possible to create metal objects safely with inexpensive metal clay 3D printing systems in engineering labs without resorting to casting. The comparison of tensile test results of the plastic and metal 3D printed students-created test samples has value as a pedagogical tool. Through experimentation, students gained experience in using an important and novel engineering design tool. A questionnaire developed and administered to measure students’ perspective on inexpensive 3D printing technologies shows positive preliminary results but it should be further improved/changed (to measure student learning outcomes directly) and administered to a larger number of students (to allow statistical analysis). Finally, this paper is envisioned to serve as a valuable resource in implementing a metal clay 3D printer for creating small metal parts.

Bibliography


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Dr. Jakšić holds the Dipl. Ing. degree in electrical engineering from Belgrade University, the M.S. in electrical engineering, the M.S. in industrial engineering, and the Ph.D. in industrial engineering
from the Ohio State University. He is currently a Professor and a Program Director in the Engineering Department at Colorado State University-Pueblo. Dr. Jaksic has been a faculty in higher-education institutions for 25 years. He has published over 50 papers in engineering education, and holds two patents. Dr. Jaksic served in a number of functions at the American Society for Engineering Education (ASEE) and has received numerous awards. His interests include robotics, automation, and nanotechnology engineering education and research.

Nikolas D’Angelo
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A System Engineering Approach for Implementing An Electrical or Computer Engineering Master’s Capstone Course

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Abstract

The paper presents how an electrical or computer engineering Master’s capstone course incorporates system engineering concepts. The project in the capstone course attempts to provide a balance among technical merit, system-level thinking, and improved communication skills. The student has an opportunity to integrate specialized technical skills but also appreciate a system-level thinking and mindset. The engineering faculty would like students to focus first on ‘what’ functions must the system perform to meet customer requirements or market needs that is a solution to a particular problem. Usually, students are fixated on the ‘how’, applying their particular and interesting technology without consideration to a particular market or customer needs. To continue and stress the importance of technical depth, several factors about technical merit are provided for further assessment of student outcomes. Examples of selected deliverables by students from several projects and assessment tools are given to illustrate the system-level thinking.

Keywords

capstone course, system engineering, system thinking, system mindset, master’s programs

Introduction

The paper describes the implementation of system engineering concepts for an electrical or computer engineering capstone course for CTU’s Master’s programs. Course deliverables help track student progress during the 11-week course and assess the degree of meeting course objectives. A student must frame a vague engineering problem and define requirements for their proposed solution to an identified need. Following a systematic engineering process, students must design and model a system, and then develop a test plan and protocol to verify their design that meets their system requirements. The student must communicate regularly with the faculty mentor and present their project through the Preliminary Design Review (PDR), Critical Design Review (CDR), and a final technical report. Since the system engineering approach requires written documents that a professional engineer will likely encounter in a large government project, student deliverables are described and used to encourage system thinking as depicted by the system engineering process based on the Vee Model offering two perspectives. To help assess system-level thinking and technical merit, a detailed rubric is developed for the CDR. Student deliverables from selected projects are provided to illustrate the system-level thinking.
and mindset. The next section briefly describes the two master’s programs followed by a section describing the objectives of the capstone course.

Description of MSEE and MSCE Programs

Colorado Technical University’s Master of Science in Electrical Engineering program allows a student to build on their engineering expertise. The program provides an in-depth understanding of modern systems design for emerging and evolving electrical engineering technologies. In the program, students have an opportunity to be deeply involved in advanced design projects including digital, spread-spectrum and space communications, CMOS circuitry and computer architectures. Students can develop essential project management and leadership skills designed to give them a competitive edge and be helpful in senior-level engineering responsibilities. The Master of Science in Electrical Engineering degree is focused on providing an overview of industry-relevant technologies for those who aspire to work in electrical engineering.

Similarly, the Master of Science in Computer Engineering program emphasizes effective optimization of computer systems within organizations strengthening their competitive advantage, as well as motivating and leading workers responsible for the technological advances. The program attempts to maintain and give students a competitive edge in industry and commerce making creative scientific and engineering advances as well as producing high quality products.

<table>
<thead>
<tr>
<th>Electrical Engineering</th>
<th>Computer Engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modern Computer Architecture</td>
<td>Modern Computer Architecture</td>
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<tr>
<td>Modern Computer Design</td>
<td>Modern Computer Design</td>
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<td>Modern Solid State Devices</td>
<td>Modern Solid State Devices</td>
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<tr>
<td>Digital Signal Processing</td>
<td>Computer Systems Security Foundations</td>
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<td>Spread-Spectrum Systems</td>
<td>Software Systems Engineering Process</td>
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<td>Modern Electronic Design</td>
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<td>Space Communications</td>
<td>Leadership and Ethical Decision-Making</td>
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<tr>
<td>Modern Electronic Design</td>
<td>Project Management Processes in Organizations</td>
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<tr>
<td>Leadership and Ethical Decision-Making</td>
<td>Project Planning, Execution and Closure</td>
</tr>
<tr>
<td>Project Management Processes in Organizations</td>
<td>Select one CS 600-level course</td>
</tr>
<tr>
<td>Project Planning, Execution and Closure</td>
<td>Select one EE 600-level course</td>
</tr>
<tr>
<td><strong>Electrical Engineering Capstone</strong></td>
<td><strong>Computer Engineering Capstone</strong></td>
</tr>
</tbody>
</table>

Table 1. Core Courses in the Master Programs

Twelve core courses each for the Electrical Engineering and Computer Engineering programs are shown in Table 1, where each program requires the successful completion of an 11-week capstone course. With this short overview of the master’s programs, more details about capstone course and its objectives are described next.

Capstone Course Description and Objectives

The capstone course provides the student an opportunity to integrate skills developed throughout the Master’s program by completing a project or study that focuses on a technical problem or current issue in engineering. The students must: define the problem or opportunity, identify constraints, complete an analysis, prepare and deliver a professional report, and prepare and deliver a professional presentation.
Specifically, by the end of the course, each student will demonstrate the ability to:

- Frame an ill-defined engineering problem and define appropriate requirements that the solution must satisfy.
- Design and implement a test protocol to verify that the designed system meets the defined requirements.
- Design and/or model a system to meet the defined requirements.
- Integrate skills, concepts, and/or tools acquired in prerequisite coursework and apply the same to successfully complete the project.
- Independently acquire any additional skills, concepts, and/or tools necessary for successful project completion.
- Communicate regularly with the faculty mentor and keep a journal of all work completed in the project.
- Communicate the results of the project to peers and mentors through an oral presentation and a technical report.

Table 2 lists the key activities and deliverables for the 11-week capstone course and student deliverables required for successful completion of the course. A weekly description of the system engineering and technical activities are given later in this paper. The table also shows typical percentage weights for the Project Plan and Journal (22.5%), Systems-Level Thinking and Communications (47.5%) and Technical Merit (30%). Students must take an ill-defined problem and follow a system engineering approach to bring their system solution into being.

Before getting into details of the weekly description of student deliverables or activities summarized in Table 2, the next section provides several motives for using system engineering concepts in the capstone course.

Why Apply System Engineering Concepts?

The authors have taught several graduate several courses in electrical, computer and system engineering. Consequently, one key reason why the engineering faculty wanted to adopt a system engineering approach is to have students developed a systems thinking or holistic perspective. Also, since the local area of the Colorado Springs campus has a heavy military presence, the course deliverables incorporating system engineering concepts are ones that the student will likely encounter in a defense- or government-oriented company while emphasizing the need and importance on improving written and oral communications skills.

When advising students, some students, prefer to take system engineering over project management based on their past experience. Consequently, project management courses found in the graduate programs are often substituted with system engineering courses. The rationale
for this substitution is because program management handles the day-to-day activities of a technical project or program like balancing the schedule, cost and technical system performance. On the other hand, system engineering takes a longer view and broader perspective such as system life cycle and looking at the system from various perspectives, such as: affordability, usability, reliability, maintainability, supportability, manufacturability, and disposability\textsuperscript{1}.

As a result, system engineering also requires spending more time on the initial or front-end of the project/program planning near the beginning of a project/program where there is less focus on day-to-day activities balancing technical performance, schedule and cost. Within this context, project/program management activities can be viewed as a subset of the system engineering process. Program/project management becomes more important as the program matures near operational use and maintenance after development of the system is complete. Project or program management is integrated within the system engineering courses using appropriate textbooks\textsuperscript{1-3}.

However, when it comes to starting a project, many times students are absorbed on the solution or technology. The students are focused on the ‘how’ preferring to apply a particular and interesting technology without consideration to a particular market or customer need. This initial approach by the student may be viewed as bottom-up thinking as shown in Figure 1.

When starting a project, the department would like the students to focus first on the ‘what’: that is, what functions must the system perform to meet customer requirements or market needs that is a solution to a particular problem. This view of market or demand push is known as top-down thinking. These two competing views are commonly known to industry as: technology push versus requirements pull (or market/demand pull). Figure 1 depicts these two point of views. In summary, a system engineering approach expands the student learning experience to have a holistic thinking perspective while building upon their specialized electrical or computer engineering skills. The method attempts to help student change their emphasis from a technology-focused solution to one that meets customer needs. However, the engineering department values both bottom-up and top-down approaches used in combination when bringing a system solution into the marketplace.

The next section, describes a system engineering process using the Vee Model\textsuperscript{1,2,3} to help form the systematic approach and timeline of weekly deliverables. It’s an attempt to provide a step-by-step and iterative method to help students expand their system engineering perspective in order to deliver a well thought out and comprehensive technical solution to the marketplace.

**The System Engineering Process and the Vee Model**

Figure 2 depicts one system engineering process known as the Vee-Model. One perspective of the Vee Model comes from a test and evaluation perspective\textsuperscript{1} shown in Figure 2a and the other one provides an architecture perspective\textsuperscript{2} shown in Figure 2b.
In Figure 2a, the Vee-Model looks at the system, subsystem and component level of testing. The model starts with an identification of user needs and requirements on the upper left and ends in the upper right with a fully system-level acceptance test and evaluation.

The left side of the Vee Model shows the decomposition of the system broken down to subsystems and then down to the component level of design. The technical activities involves defining and resolving the system architecture in order to mature the design (or definition) of the system with increased fidelity.

Figure 2a shows that the right ride of the Vee-model involves the integration of the system while testing upward to verify the design at the component, the subsystem and finally the system level. The testing process flows up and to the right as higher levels of subsystems are verified, ending at the system level that is eventually validated through user acceptance testing and evaluation.

The test plan needs to insure that overall specifications are met while testing is performed at all-levels (component, subsystem and system). The test plan verifies and validates the entire the system in preparation for user acceptance.

From a ‘Grand Design’ and architecture perspective shown in Figure 2b, the definition of the system design begins by first deciding ‘what’ functions do the system solution need to perform which helps define an initial functional architecture. The functions are then collected and allocated to an appropriate subsystem which further defines the functional architecture. The process of defining the functional architecture increases the system fidelity and definition during the design stage. The design of the subsystem functions is further decomposed down to identify (or design) physical components (hardware/software) which defines the physical architecture. At this point, the physical architecture describes the ‘how’ the system solution is implemented. Moving up to the upper right side of the Vee Model, the components are tested and then integrated and tested up to the subsystem and then system level. The result is an enterprise architecture that is deployed for the intended customers or stakeholders for final user acceptance.

Using this system engineering process model, the following section describes the activities or deliverables involving system engineering activities for each week. Students are encouraged
and advised several weeks before the start of the capstone quarter to begin thinking about their project so they are well-prepared to start quickly. The student must design a new product that meets a market need, and either demonstrate how it behaves or model its performance. Several self-motivated and talented students followed this advice and successfully completed technically challenging projects described later in the paper while following the system engineering process.

**Description of Student Deliverables and Activities**

Table 3 lists the schedule of activities portraying samples of the system engineering process. This approach is structured having weekly deliverables but flexible enough to accommodate both disciplines as well as other technical specialties.

<table>
<thead>
<tr>
<th>Week</th>
<th>Assignment</th>
<th>Points</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction and product ideas (Journal)</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>Project Plan and Resources (Journal)</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>Product Definitions, Requirements/Specifications, Formal Proposal Submitted for Approval</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>Product Acceptance, Acceptance Test Protocol (Journal)</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>System Block Diagram/ Specifications, Interfaces and Testing, Formal Requirements and Acceptance Test Plan (Journal)</td>
<td>17</td>
</tr>
<tr>
<td>6</td>
<td>Preliminary Design, Midterm Presentation - PDR</td>
<td>100</td>
</tr>
<tr>
<td>7</td>
<td>Block Details, Details of Interface Block (Journal)</td>
<td>17</td>
</tr>
<tr>
<td>8</td>
<td>Critical Design Review Outline and Status Report</td>
<td>17</td>
</tr>
<tr>
<td>9</td>
<td>Technical Details Final: Details of Control and Cumulative Design Details (Journal)</td>
<td>17</td>
</tr>
<tr>
<td>10</td>
<td>Outline of Presentation for Critical Design Review</td>
<td>75</td>
</tr>
<tr>
<td>11</td>
<td>Final Oral Presentation and Demonstration (CDR)</td>
<td>200</td>
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<tr>
<td></td>
<td>Final Technical Report (must include above journal items)</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Technical Merit</td>
<td>300</td>
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<td></td>
<td><strong>TOTAL</strong></td>
<td>1000</td>
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Table 3. 11-Week Course Schedule of Capstone Course

Electrical and computer engineering students, especially those who are international students, may be unfamiliar with the system engineering process. To take this into account, the weighting scheme and weekly deliverables, allows the student to learn about the system engineering process iteratively during the 11-week course without heavily penalizing the students during the first-half of the course.

The rest of this section briefly describes the weekly and reported activities by the student that is intended to develop a system engineering mindset throughout the capstone course.

**Week 1: Product Ideas and Resources.** The first assignment identifies in an informal report, a product or an improvement to a product that should be invented. The student must determine what product will be created, who will use it, what benefit it will provide, and how will success be demonstrated...in other words, the student must perform some market research. The student will be required in the next assignment to demonstrate that there is a need for this product. The student must provide a list of resources which will be used, to help define and describe this new product, and the people or companies who will be affected by it directly or indirectly. The student needs to include what the user would request from the system performance. These considerations will help identify system "Requirements" or specifications.
The student must meet with the customer or instructor to discuss the expectations, course requirements as well as being prepared to discuss the ideas more fully. By the end of this week, a proposed product should be chosen by the student.

**Week 2: Justification of Need Plus Project Plan and Resource.** The student should have discussed their proposed project with the professor by this week. What is now needed is a review of the following:

- Problem that needs to be solved.
- People who will be impacted
- Proposed product description, and
- Acceptable system or product performance and behavior

Specifically, the student needs to include in a research of proposed solutions and how it will impact the people and companies. The questions the student needs to answer are: Who is affected? What are their needs? What additional information does this provide about constraints? After answering those questions, students need to think about what proposed system solution is needed to "pass" the user acceptance test. These additional considerations will help further identify system "requirements" or specifications in the course assignments during the upcoming weeks.

Also, the student needs to provide a description of a problem that is supported by documented information showing that the problem exists as well as considering the level-of-effort in terms of costs, time, money, resources, or human work hours needed to solve a problem. The deliverable also needs to include what the user would expect from a “good” system.

**Week 3: Formal Proposal and Project Plan.** By this time, the student should have a good understanding of the problem and proposed solution. During the past few weeks, the student should have: (1) reviewed and framed the problem statement, (2) investigated the anticipated users of the proposed product or service with an identified need (3) performed background research on market demand or needs and (4) anticipated resources and constraints to implement the solution.

For this assignment, the student submits a formal proposal, including: the problem statement, product or system description that solved the problem and an initial list of requirements/specifications. The proposal should be submitted at least one day before meeting with the instructor to discuss it.

**Week 4: Acceptance Test Plan and Protocol.** This test plan and protocol needs to demonstrate that the product does what is required and must relate back to the system requirements and specifications. The acceptance test plan and protocol must include the: test set-up, the inputs to the system, and the correct response of the system. It should include any information about the actual "workings" or implementation of the system and should not prejudice that actual design by
specifying any particular hardware or implementation. At this point, the student should focus on ‘what’ the system must do and not on ‘how’ to implement the system solution.

**Week 5: Block Requirements, Interface and Review.** Students must identify major blocks, or subsystems which will help build the product solution. Students need to answer questions about each of the major areas (or subsystem) of implementation. They must review the guidelines for good requirements and allocate the system functions to the various subsystems. The student must consider: system and subsystem level of requirements/specifications, a system and subsystem level tests, and interface specifications.

**Week 6: Preliminary Design Review (PDR).** The PDR should include all of the information to date, as well as identifying critical issues necessary to finish the project:

- Definition of the product, requirements/specifications, and the acceptance demonstration that the student intends to provide
- Fundamental subsystem blocks of the system, and details of signal inputs and outputs between the subsystem blocks
- Alternate product implementations which were rejected
- Proposed solutions to individual subsystem block performance requirements

**Week 7: Block Details, Details of Interface Block.** The student’s activity report should include further details of their interface blocks down to the component level. The student must discuss how the different components of the subsystem relate to each other, and how they work internally. The student needs to update revised acceptance tests and any other revisions based on the PDR.

**Week 8: Assess Preparation for Critical Design Review and Design Options.** The student must review items completed during the previous weeks before their demonstration in Week 11. In addition, the student must identify and provide further research into the technical choices in the system design and then provide theory and data to support the choice of the best system.

**Week 9: Justified Options and Details of Control.** The student must support their selected design among the options that were researched. The student should include any details of control Details of control means to describe the student’s proposed functional and system architecture in their system final configuration down to the component level of implementation.

**Week 10: Preparation for Critical Design Review and Outline of Oral Presentation to Engineering Faculty.** The student meets with instructor to discuss preparation for CDR presentation and demonstration. The discussion must include:

- The product description and must identify users, environment, benefits and performance
- Specifications that will include the items to be measured to demonstrate the product does what was promised, and the test plan protocol which defines "pass" for each requirement.
- Review of the acceptance test protocol
- Demonstration of the product, in hardware or modeling to show performance and quality of propose product for the final oral presentation
Input from the "customer" will then be used to provide corrections in the final report detailing 1) the product, 2) specifications 3) system diagram including blocks, and interfaces 4) interface specifications, 5) detailed subsystems and 6) design tradeoffs.

For design tradeoffs, the instructor is looking for what choices did the student make and why. The student must include the rationale of hardware/software selection as well as the design choices that the student eliminated.

**Week 11: Final Report and Oral Presentation, Technical Merit.** The final technical report is a polished version and compilation of previous work and deliverables that was revised and fine-tuned to produce a professional document. In addition to items for Week 10, the student must include:

- A presentation due on Week 6 defining the product and outline their progress to date (Preliminary Design Review)
- A demonstration of the product or providing sufficient modeling to demonstrate performance and quality of the proposed product (Critical Design Review)
- Other items identified in weekly progress and activity reports
- A final report detailing: (1) the product, (2) specifications, (3) system diagram including blocks, and interfaces, (4) interface specifications, (5) detailed subsystems and (6) design tradeoffs, that is: what choices did the student make and why including the components, or elimination of design choices and why?

In addition to the above a systems engineering deliverables, the completed project must consider sufficient scope and technical merit to demonstrate proficiency and expertise in this capstone project. The next section lists several factors and considerations to help stress the importance of technical merit during the execution of the capstone project.

**Technical Merit**

The engineering department anticipated that a student can satisfy meet the weekly deliverables from the system engineering process but the project may lack technical depth at the Masters level. To take this into account, a percentage weight of 30% for technical merit is considered. Several factors are considered to evaluate and assess the technical depth and merit of a project including:

- Degree of technical difficulty in solving a problem and finding a solution
- Evidence and technical depth of analysis on the solution
- Considerations and technical depth of alternative solutions
- Substantiate proposed solutions with data and facts including technical and economic feasibility
- Evidence and technical depth of synthesis and evaluation tasks from engineering courses in the Master’s program
- Evidence and technical depth of newly acquired technical skills not emphasized or taught in the program (also measures degree of independent learning by the student)
- Evidence of integrating information from many sources to gain insight to the problem
Evidence and technical depth of multiple perspectives for a given problem (economic feasibility, reliability, maintainability, sustainability, safety, etc.)

During the last several years, providing a right mix for a capstone course with technical merit, system engineering thinking, and improving communication skills continues to be an evolving learning experience and challenge for both faculty and students.

Throughout the progress of incorporating system engineering concepts in the capstone course and to provide further assessment of the system engineering process and technical merit, a rubric for the Critical Design Review was developed and provided in the next section.

**Rubric for Critical Design Review (CDR)**

Table 4 depicts the rubric for the CDR. The rubric has several criteria to assess and evaluate the student’s understanding of system-level thinking when providing a solution that meets a customer need and having technical merit.

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>Sophisticated</th>
<th>Competent</th>
<th>Unsatisfactory</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PROJECT INTRO/NEEDS IDENTIFICATION (20pts) Score:</strong></td>
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</tr>
<tr>
<td>All system requirements and associated subsystem requirements are included. Requirements do not use ambiguous terminology. Each requirement has a realistic and complete test plan with valid pass and fail conditions using numbers. (16-20pts)</td>
<td>Some design requirements do not have engineering satisfactory requirements associated. Some ambiguous terminology is used in requirements. Most requirements have a realistic and complete test plan with valid pass and fail conditions using numbers. (7-12 pts)</td>
<td>Design requirements are not explained. Design requirements are not formatted as a list. Requirements are mostly vague or incomplete. Requirement does not have realistic and complete tests with valid pass and fail conditions. (0-6pts)</td>
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</tr>
<tr>
<td><strong>SYSTEM REQUIREMENTS AND TESTING (20pts) Score:</strong></td>
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<tr>
<td>Alternative possible solutions are described fully and completely. Several of the designs are feasible and could potentially solve the design problem. A final detailed solution is present. (16-20pts)</td>
<td>Alternative possible solutions are described, but the reasoning behind selecting or deselecting them is not clear. (7-12 pts)</td>
<td>No final design solution is suggested, or reason behind decisions is not presented. No other possible solutions are discussed. (0-6pts)</td>
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<tr>
<td><strong>DESIGN SOLUTIONS (20pts) Score:</strong></td>
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<tr>
<td>System and subsystem block diagrams logically describe the product. Adequate number of blocks exist, all signals (internal and external) and connections are defined. The inputs to each subsystem, the outputs from the subsystem and a detailed description of the functionality of the subsystem are provided. (10-15pts)</td>
<td>System and subsystem block diagrams includes an adequate number of blocks, all external connections are defined, blocks cover adequate scope for beginning design. (5-10pts)</td>
<td>System or subsystem block diagram is missing or is insufficient for beginning design. (0-5pts)</td>
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<tr>
<td><strong>BLOCK DIAGRAM (15pts) Score:</strong></td>
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<td></td>
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<tr>
<td>Authors’ purpose is clear. Information is logical. Introduction is clearly presented. Conclusion is presented and defended. (8-10pts)</td>
<td>Author’s purpose is partially clear. Most information is logically provided. Conclusions is presented, but is not defended. (3-7pts)</td>
<td>Information is not logical. An introduction and/or conclusion have not been provided. (0-4pts)</td>
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<tr>
<td><strong>ORGANIZATION (10pts) Score:</strong></td>
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<tr>
<td>Consider Ethics, Economics, Reliability and Safety well and thoroughly in the design. (5-10)</td>
<td>Consider Ethics, Economics, Reliability and Safety issues. (5-7)</td>
<td>Miss or does not consider Ethics, Economics, Reliability and Safety issues. (0-4)</td>
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<tr>
<td><strong>DESIGN CONSIDERATIONS (10pts) Score:</strong></td>
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<tr>
<td>All borrowed material has been cited in correct format in the documentation. Contains a reference list that lists all sources cited. References and citation adhere to IEEE or APA style guidelines. (5pts)</td>
<td>Contains a reference list that lists sources. Not all borrowed material has been cited in all the documents. (1-4 pts)</td>
<td>No references list and citation provided. (0pts)</td>
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</tbody>
</table>

Table 4. Rubric for Critical Design Review

Each criteria provides three levels of evaluation: Sophisticated, Competent and Unsatisfactory. The list of criteria are: (1) identification of needs, (2) system requirements and testing of system towards meeting the requirements, (3) proposed design solutions and criteria for selection of solution, (4) block diagrams that describe the solution (includes system, subsystem, and component design and (5) design considerations when looking at the system from many perspectives including thoughts about ethics, economics, reliability and safety.

The rubric has proved useful to assess student outcomes and account for both system-level thinking and technical merit such as the capstone projects briefly described in the next section.
Examples of Student Deliverables to Assess System-Level Thinking

The deliverables associated with the course emphasize the typical processes and similar documents that a student will likely encounter in a large engineering project found in government or in the defense industry. These documents are: mission need statement, system-level requirements and specifications, technical proposal, cost proposal, test and evaluation plan, preliminary design review (PDR), critical design review (CDR) and final technical report. The weekly deliverables attempt to increase the awareness of documentation needed in a typical government contract.

Table 5 lists examples of capstone projects that followed the system engineering approach. Snapshots of student deliverables from these projects serve as samples of the system engineering and thinking process. The following deliverables are some of the many examples to illustrate students’ attempts to develop a system engineering mindset to find an opportunity and to fill a need or market demand.

**Bulk SMS software for Kenyan Schools.** To demonstrate and meet a need, one MSCE student developed a Short Message Service (SMS) software for Kenyan school systems. In Kenya, there is a lack of effective communication between the school and parents, such as an awareness of student progress in a course. The graduate student proposed to design and implement a SMS-based communication system for the schools, with the overall goal of enhancing communication from the school to parents, staff, governing boards and students. The functional and non-functional requirements for the application are listed in Table 6 and acceptance test plan listed in Table 7. The system intends to ease processing of examination results, track student fees and provide important SMS alerts to parents or any selected group, concerning student progress and well-being, or any other school related issues.
Caber Adventure GoPro Gimbal Project. The goal of this MSCE project is to design a system to allow active sports and motorsport adventurers to make more professional video recordings of their experiences. Table 8 provides a list of student’s functional requirements and as submitted in their final report. Each requirement has a test. The student also defined interface requirements where the student configured a motorcycle helmet to hold a gimbal-stabilized GoPro Camera.

### Table 7. System Level Acceptance Test Plan from Bulk SMS software for Kenyan Schools Project

<table>
<thead>
<tr>
<th>Req #</th>
<th>Requirement</th>
<th>Pass / Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The system shall support mounting a GoPro Hero 3+ in a secure manner</td>
<td>Pass / Fail</td>
</tr>
<tr>
<td>2</td>
<td>The system shall maintain the GoPro Hero 3+ in a horizontal position when the system chassis is held in a fixed position.</td>
<td>Pass / Fail</td>
</tr>
<tr>
<td>3</td>
<td>The system shall maintain the GoPro Hero 3+ in a horizontal position during pitch movements.</td>
<td>Pass / Fail</td>
</tr>
<tr>
<td>4</td>
<td>The system shall maintain the GoPro Hero 3+ in a horizontal position during roll movements.</td>
<td>Pass / Fail</td>
</tr>
<tr>
<td>5</td>
<td>The system shall mount to other devices with quick release mount.</td>
<td>Pass / Fail</td>
</tr>
<tr>
<td>6</td>
<td>The system shall operate on standard vehicle or equivalent portable power.</td>
<td>Pass / Fail</td>
</tr>
<tr>
<td>7</td>
<td>Camera shall stay securely fixed to system unless removed by operator.</td>
<td>Pass / Fail</td>
</tr>
<tr>
<td>8</td>
<td>Recorded video shall not present pitch changes when the system chassis changes pitch from 0° ± 45°.</td>
<td>Pass / Fail</td>
</tr>
<tr>
<td>9</td>
<td>Recorded video shall not present roll changes when the system chassis changes roll from 0° ± 45°.</td>
<td>Pass / Fail</td>
</tr>
<tr>
<td>10</td>
<td>The system shall remain fixed in relation to mounted platform.</td>
<td>Pass / Fail</td>
</tr>
<tr>
<td>11</td>
<td>The system shall operate properly with applied voltage between DC 7.4V ~ 14.8V</td>
<td>Pass / Fail</td>
</tr>
<tr>
<td>12</td>
<td>The system shall be user friendly</td>
<td>Pass / Fail</td>
</tr>
</tbody>
</table>

### Table 8. System Acceptance Test Plan from Caber Adventure GoPro Gimbal Project

Auto-Fetch System. One MSEE student owns a dog who can tireless play with the student all day. The student wanted to figure out how to keep the dog entertained with his vision of an Auto-Fetch System. The student did some research and found that the American Society for the Prevention of Cruelty to Animals (ASPCA) there are approximately 70-80 million dogs in the
U.S., and between 37 and 47 percent of households have a dog. The following is a narrative portion from the student’s formal report:

“All of the most common reasons people give away their dogs is that their place of residence does not allow pets, they don’t have time to take care of the dogs, or there are behavioral issues. Behavioral issues and a lack of time for the dogs can be linked together, as behavioral issues often arise from a dog being left alone for extended periods of time. One particularly frustrating behavioral issue is destructive chewing. Chewing is a normal thing which dogs do to help relieve anxiety, frustration, and boredom, but this can be very frustrating to owners when dogs decide to chew up the furniture or one’s favorite shoes. One of the issues which can lead to destructive chewing is when a dog does not get enough physical and mental stimulation. A bored dog may decide to chew up something which he should not, so a non-destructive alternative needs to be available for the dog. There are many chew toys which are available for this purpose, but dogs will often lose interest in such toys quickly, and revert to chewing on things they ought not. A better solution is needed.”

Figure 3 shows a subsystem block diagram of the Auto-Fetch System and student depiction of the project. He self-taught himself on the use of CAD software for this project. Table 9 shows the student’s proposed test plan and protocol that matches the stated requirements for this system. The student performed Matlab/Simulink models and learned about curve fitting techniques to gauge the performance of the launch mechanism.

3-D Printed Quadcopter. During 2014, Professor Santiago wanted to encourage students to start thinking about their project early before enrolling in the capstone course. In late 2014 and in one of Professor Santiago’s graduate classes, he described some of the IEEE projects from the CTU student branch, including showing videos how a team of quadcopters working together to perform athletic feats from University of Pennsylvania and a Swiss Federal Institute of
Technology (ETH Zürich). After the presentation, Professor Santiago had one exceptional and self-motivated MSEE student who built a 3D Printed Quadcopter that took three quarters to complete. The student did some market research showing the cost savings on the use of quadcopters to monitor the hot-spots following the devastating fires in Colorado currently done with helicopters and boots-on-the-ground firefighters. Other drone applications he found were law enforcement and search and rescue. From a technical merit and systematic testing perspective, the 3-D Printed Quadcopter Project illustrates this nicely. In this project, the student learned how to build a 3-D printed quadcopter and taught himself about control theory not taught in the Master’s Program, and then implemented it using an Arduino microcontroller (not taught in the graduate courses). During the course of this project, the student developed a temperature control system to uniformly build 3-D printed parts for the quadcopter. After building the 3D-printed parts and integrating the motors and Arduino controller, he tested his control algorithm to orient and stabilize the quadcopter at fixed and various angles based on user selected inputs. One phase involved tethering the controller to test for one dimension so that the quadcopter can fly stably at various user-selected angles. Figure 4 shows the quadcopter testing the controller for a fixed angle. Then, the student tested his control algorithm in two-dimensions and then successfully flight-tested the untethered quadcopter in three-dimensions.

Remote Control Unmanned Vehicle (RCUV). Another MSEE student during the Winter Quarter of 2015 tackled a technically complex project that uses a cellular network for controlling an RCUV, where a system block diagram is depicted in Figure 5. The student provided further details down to the component level for
each subsystem in Figure 5. After establishing a market need in this growing field, the student performed simulations using Matlab/Simulink software and detailed hardware components. The student investigated the system from a variety of perspectives, including: affordability, reliability and technical feasibility. In addition, the student provided a thorough presentation of his investigation, including: hardware analysis and selection criteria, data-path analysis, and detailed circuit schematics. Using both Matlab/Simulink simulations and inexpensive hardware, the student highlighted the degradation of performance under certain scenarios with noisy environments resulting in a loss of communication link or synchronization.

Conclusion

The engineering department successfully incorporated system engineering concepts into a graduate capstone course in both electrical engineering and computer engineering. The approach expands the student experience by providing them with a more holistic view of engineering. Based on the student deliverables from the course, this was accomplished by having the student think more at the system level and from a variety of perspectives before coming up with a technical solution. The system-level thinking builds upon the specialized technical skills from other courses found in CTU’s graduate engineering programs. The capstone course attempts to provide a right mix of technical merit, system engineering thinking, and improved communication skills.

References


Biographical Information

Professor John Santiago teaches courses in electrical, computer and system engineering after retiring from the USAF with 26 years of service in 2003. He began teaching at CTU the following year. His interests include: interactive multimedia for e-books, interactive video learning, and 3D/2D animation. Professor Santiago recently published a book entitled, “Circuit Analysis for Dummies” in 2013 after being discovered on YouTube. Professor Santiago received several teaching awards from the United States Air Force Academy and CTU. In 2015, he was awarded CTU’s Faculty of the Year for Teaching Innovations. Professor Santiago has been a 12-time invited speaker in celebration of Asian-Pacific American Heritage Month.

Dr. Jing Guo is a Professor in Engineering College at Colorado Technical University. She is the course director in circuits and electronics area. She taught variety of underrated and graduate courses including capstone design in Electrical and Computer Engineering area. She worked as Subject Matter Expert (SME) of “EE110 Introduction to Engineering” Online Course Development.
The Challenges of Teaching Engineering Labs Online
Dr. Jing Guo, Dr. Kathy Kasley, and Dr. John Santiago
College of Engineering, Colorado Technical University

Abstract
The paper presents the Engineering Department’s development and the pilot delivery of an online laboratory experience to support the electrical and computer engineering online delivery of a previously on campus course, “EE110: Introduction to Engineering”. The most significant challenges in support of students in the construction, debug, and measurement of circuit parameters include the following: (1) replacing face-to-face interaction with both the instructor and other students in a group setting for debugging or troubleshooting circuits and (2) effective ways to promote student cooperation in helping one another. The paper describes the design of online labs for this course and selection of equipment. A pilot class has been delivered on campus with the materials generated as a simulation of an online course. Learning outcomes between the pilot class and the face-to-face class are compared. This paper discusses challenges and successes of teaching online labs, based on the recent experience and feedback from student surveys of the course. In conclusion, online laboratory activities need to be carefully structured to provide an effective learning experiences with a benefit similar to the classroom.

Keywords
engineering lab, online flipped lab, online laboratory experiments, flipped classroom, introduction to engineering

Introduction
Faculty members in the Colorado Technical University College of Engineering started to develop online courses since April of 2015. Because the undergraduate degrees in electrical engineering and computer engineering at CTU are ABET-accredited, the online courses that need to be developed have to meet ABET standards as well. In addition, the courses must meet the same learning outcomes whether delivered online or traditional face-to-face instruction. This paper presents faculty experiences in developing and conducting engineering laboratory experiences to be completed remotely for an online course. The project attempts to convert a face-to-face course entitled, “Introduction to Engineering” for online delivery by using existing technology tools from e-learning education, or from internet marketing. The most challenging part of the project concerns the replacement of the interactive demonstration, dialog, and immediate feedback for the student working with the equipment on campus with online support for the interaction with the equipment. In traditional labs taught on campus in laboratory setting, the instructor has the opportunity to observe students performing experiments. In this setting, the instructor can easily help students understand the process of debugging or troubleshooting circuits. Also, students usually work in teams helping each other fix circuit issues during lab sessions. Consequently, there is a significant amount of immediate feedback from the instructor and other students when troubleshooting circuits. Further special effort needs to be invested in
fostering student cooperation in an online environment. It is important to ensure that the learning outcomes in online lab collaboration are comparable to campus based-laboratory experiences.

“Introduction to Engineering” is a first engineering course for electrical and computer engineering students. The campus-based course includes both lecture and lab sessions. The course introduced basic analog and digital circuits. All four full-time engineering faculty were involved in developing this course because it includes labs with different topics, such as analog circuits, digital circuits, simulation, and hands-on soldering and kits assembly as well as very basic communications theory. In addition, all faculty members wanted to gain experience in the creation of content for online delivery. As the challenges related to teaching online labs are addressed for this first course, then future development of additional electrical and computer engineering courses will become much smoother for online delivery.

EE110 is a four credits course having a length of 11 weeks (or one quarter). A required course for both electrical and computer engineering students, it is a prerequisite course for EE221, Circuit Analysis I. The development of EE110 online content was divided by four full-time engineering professors, each professor created specific sections of the course. In this way, professors can help each other learn about software tools to build engaging content. At one time, the engineering faculty became familiar with the process of online course development and its delivery of instruction. This paper concentrates on the laboratory content with the schedule shown in Table 1. The introductory course has nine Labs. The initial lab assignment manual provided step-by-step procedure of the experiments with screenshots of the circuits set-ups and the measurements results. Short videos for some labs were developed for explanation and demonstration the lab procedure. Subsequent laboratory assignments had supporting videos, screenshots, and pictures, as appropriate. This paper describes some of the key lab experiments during the design and development of ‘Introduction to Engineering’ labs for online delivery. The lab materials include manuals with images, photos and short introductory videos.

To ensure the quality of the course, the transition to an online course involved the following six stages as shown in Table 2. The paper also describes the selection of equipment and software for online equipment and lab kits. National Instruments’ (NI) myDAQ was selected to be the basis for the lab equipment for the course since the myDAQ package includes several software-based instruments, such as a signal generator, an oscilloscope and a multi-meter. The advantages and limitations of myDAQ are discussed along with additional affordable equipment for the student as recommended. The importance of one-hour synchronous chat session dedicated to lab work is also described. A pilot class was delivered as a simulation of an online course before being fully operational as an online course. The pilot class used all of the developed online course material and methods to simulate the online teaching. This paper compares the learning outcomes resulting from instruction for online labs and face-to-face labs. The challenges of teaching online labs, along with the feedback from student surveys of the course are also
presented. Based on the results, effectively teaching engineering labs online is possible but with challenges that needs to be carefully considered. Suggestions for overcoming these challenges of online teaching of labs are discussed at the end of this paper.

<table>
<thead>
<tr>
<th>Pre Design Stage (April-June, 2015)</th>
<th>Set up schedule and assign design work to the four full time professors; make decision on development tools and lab equipment.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Stage (July-September, 2015)</td>
<td>Four professors corporate to development the online EE110 based on the schedule.</td>
</tr>
<tr>
<td>Pre-Pilot Course Delivery(October-December, 2015)</td>
<td>Testing the online course material by using the material in the delivery of EE110 face-to-face course. Trying to catch the errors and typos in the material, and improve the quality of the material.</td>
</tr>
<tr>
<td>Pilot Delivery (January-March, 2016)</td>
<td>Simulate the online environment for face-to-face students; receive feedback and evaluation of the course for continuous improvement of the course.</td>
</tr>
<tr>
<td>Hybrid Delivery (July-September, 2015)</td>
<td>Continue simulate the online environment. Students come to class three hours each week instead of five hours for the pilot class</td>
</tr>
<tr>
<td>Online Delivery (October-December, 2016)</td>
<td>Fully online delivery of EE110.</td>
</tr>
</tbody>
</table>

Table 2. EE110 Design and Delivery Stages

**Summary of Approaches to Online Lab Teaching**

In general, there are three ways to teach online Engineering Labs. They are the “virtual lab”, the “remote lab”, and “lab with portable kits”. In the “virtual lab”, the experiment is mimicked by using simulation software, such as LabVIEW, MATLAB, and Multisim. This method provides a simulation of a real circuit. But students still need to assemble and work an actual circuit. The teaching of the “remote lab” emulates a traditional lab, allowing students to set up and control an experiment in a remote client mode. In that way, students can gain experience similarly done at a traditional lab. But usually the equipment setup and maintenance cost and manpower needed to invest in a remote system is relatively high. “Lab with portable kits” means each student has a small, inexpensive lab kits which provides functions such as a digital multi-meter, oscilloscope, function generator, and power supply.

Berry presented a paper comparing the online and on-campus version of teaching a sophomore-level introductory course in DC and AC circuits. The course included active hands-on lab components. National Instruments’ myDAQ was used as the lab equipment for this course. Online students were required to submit lab memos that included the purpose, procedure, the results, and screenshots from the myDAQ and Multisim of the lab experiment. To assess student outcomes, ‘Lab Practical Exams’ were used in the course as well. Astatke mentioned that Mobile Studio IOBoard developed by Rensselaer Polytechnic Institute is used in their Electrical and Computer Engineering (ECE) labs for their online sophomore level electrical engineering courses. Zhai compared three distance experiment forms: virtual experiment, remote control experiment, and video demonstration experiment. Since the cost of remote control form is too
high, they combined virtual experiment (simulation) and video demo in their Electrical Online Lab.

By comparing the three ways of online lab teaching, the cost of implementation, and reviewing the experiences from other universities, the engineering department chose “lab with portable lab kits” for the online course development. The next two sections describe the myDAQ hardware and additional equipment needed to conduct the lab experiments.

Selection of National Instrument’s myDAQ Hardware

Normally, a traditional circuit analysis lab needs equipment such as DC variable power supplies, function generators, multi-meters, and oscilloscopes. The faculty explored kits having these functions. The department compared the main specifications of equipment NI Elvis II and NI myDAQ. The comparison between these pieces of hardware from National Instruments is listed in Table 3.

ELVIS II has much better performance, but is more expensive than myDAQ, the price of ELVIS II is more than 10 times of myDAQ. The ELVIS II has a variable power supply, and can provide maximum output current up to 500mA, but myDAQ has a maximum output current limited to 2mA. Both ELVIS II and myDAQ hardware have virtual instruments for ‘+/-15V’ power supply, digital multi-meter, function generator and oscilloscope. The Elvis II system has a few more virtual instruments than myDAQ. It was decided that these ELVIS instruments are ‘nice-to-have’ features but are not necessary for the purposes of our engineering curriculum”. On the other hand, myDAQ has a Level Output, which could be used as a variable power supply. The physical size of ELVIS II is much bigger and much heavier. After the purchase of a few ELVIS systems it was decided that the faculty can use the ELVIS virtual instruments for demonstration purposes in more advanced courses. However, the NI myDAQ is found to be an affordable and acceptable choice based on the cost and functional comparison found in Table 3.

<table>
<thead>
<tr>
<th>Main Laboratory Specifications Instrument</th>
<th>NI ELVIS II</th>
<th>NI MyDAQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Input</td>
<td>8 differential or 16 single ended channels</td>
<td>2 differential or 1 stereo audio input channels</td>
</tr>
<tr>
<td>Analog Output</td>
<td>2 channels</td>
<td>2 channels</td>
</tr>
<tr>
<td>Maximum output current 5mA</td>
<td>Maximum output current 2mA</td>
<td></td>
</tr>
<tr>
<td>Digital I/O</td>
<td>24 DIO</td>
<td>8 DIO</td>
</tr>
<tr>
<td>Digital Multi-meter Functions</td>
<td>DC Voltage, AC Voltage, DC current, AC current, resistance, diode, capacitance, inductance</td>
<td>DC Voltage, AC Voltage, DC current, AC current, resistance, diode</td>
</tr>
<tr>
<td>AC Voltage Frequency Range</td>
<td>up to 20 kHz</td>
<td>up to 2 kHz</td>
</tr>
<tr>
<td>Power Supplies</td>
<td>Maximum output current of +/-15V supply is 500mA; Maximum output current of 5V supply is 2A; Maximum output current of Variable Supply (0 to +/-12V is 500mA)</td>
<td>Maximum output current of +/-15V supply is 32 mA; Maximum output current of 5V supply is 100 mA; Maximum output current of Level Output (0 to +/-10V is 2 mA)</td>
</tr>
<tr>
<td>Physical</td>
<td>Dimensions: 34.3 x 28.0 x 7.6 cm; Weight: 1.9 kg</td>
<td>Dimensions: 13.6 x 8.8 x 2.4 cm; Weight: 0.164 kg</td>
</tr>
</tbody>
</table>

Table 3. NI Elvis II and NI MyDAQ Comparison. 5, 6
The price of myDAQ makes it a reasonable investment for the laboratory experiences, especially when the system will be used in more advanced classes in analog electronic circuits, digital circuits and other engineering courses with minor additions to the system ($25 - $50).

MyDAQ limitations and Additional Equipment

Since the myDAQ has only one digital multi-meter, students can use it as a voltage meter or current meter, but not both at the same time. For some of EE110’s lab experiments, it is necessary to measure both current and voltage at the same time. Consequently, two meters are needed: one to measure current and another to measure voltage. In other words, one additional digital multi-meter is needed for the students.

The myProtoBoard accessory board, shown in Figure 1, was selected to connect the NI myDAQ hardware. The myProtoBoard allows for easy use and to provide breadboard space to set up a variety of circuits. Students also need to have a component kit to do a number of lab experiments in the course. The ELENCO COMPONENT KIT, CK-1000 was selected since it provided various resistors, capacitors, semiconductors, LEDs, inductors and wires.

Based on the specification of NI myDAQ, labs from the on campus delivery of EE110 needed to be adjusted to meet be used with the new equipment. One limitation of myDAQ is the maximum output current is only 2mA. As an example of this limitation, one circuit is the Ohm’s Law lab shown in Figure 2. The current of the circuit is 2.12mA. The lab requires student to vary the voltage source 1V up to 10V to demonstrate Ohms law. If V1 is changed to 10V, current will be 21.2mA. Since myDAQ analog output cannot provide current larger than 2 mA, V1 will just drop to a voltage much lower than 10 V. Consequently, students will be confused with the results they see. So labs need to be adjusted by considering this limitation.
In summary, the additional equipment and components kit are listed in Table 4. Total cost for the myDAQ hardware and items listed in Table 4 is approximately $420.

Given the identification of affordable laboratory equipment, the next section describes lab experiments, the course delivery and its implementation.

<table>
<thead>
<tr>
<th>Name</th>
<th>Vendor</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>myProtoBoard</td>
<td><a href="http://www.studica.com">www.studica.com</a></td>
<td>$44.99</td>
</tr>
<tr>
<td>Basic Parts Kit for NI MyDAQ</td>
<td><a href="http://www.studica.com">www.studica.com</a></td>
<td>$59.95</td>
</tr>
<tr>
<td>Amprobe AM-250 Industrial Digital Multi-meter</td>
<td><a href="http://www.amazon.com">www.amazon.com</a></td>
<td>$79.85</td>
</tr>
<tr>
<td>60W Soldering Iron Kit</td>
<td><a href="http://www.amazon.com">www.amazon.com</a></td>
<td>$15.51</td>
</tr>
</tbody>
</table>

Table 4. Additional Lab Equipment for EE110 course

Design of Lab Projects

The lab session in the “EE110 Introduction to Engineering” course includes both synchronous and asynchronous sessions. Each student is required: (1) to watch short videos related to the labs, (2) to read lab manuals and (3) complete each lab step-by-step at their own pace. Each week, a one-hour online synchronous chat session will be held dedicated to addressing student questions arising from the assigned lab experiments. In addition, the required chat sessions are recorded for students who cannot attend the live chat sessions. At the end of each lab chat session, there will be assigned graded problems the students need to submit related to the lab. This approach encourages students to attend the chat session, and benefit from the experience of the instructor and other students.

Usually students are required to follow three steps when conducting lab experiments in a campus setting as shown in Table 5. All of the steps are important in supporting student learning. Students completing labs online are expected to complete the same steps, resulting in the same student learning outcomes and meeting course objectives.

<table>
<thead>
<tr>
<th>Step 1</th>
<th>Hand calculation and design based on theorem.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 2</td>
<td>Simulate the circuit based on the hand calculated design; compare the result from hand calculation.</td>
</tr>
<tr>
<td>Step 3</td>
<td>Build the circuit on breadboard, and test the circuit, and compare the result from simulation and hand calculation.</td>
</tr>
</tbody>
</table>

Table 5. Steps in Lab.

Although the course has the nine labs, the paper will not describe all the labs in detail due to paper space limitations. The section provides further details on selected labs. The first lab “Circuits Laboratory Introduction” was designed to help students become familiar with the hardware and software associated with myDAQ. Since students in this class usually do not have previous experience with electronics lab, the introduction started with myProtoBoard as shown...
in Figure 3. The myProtoBoard is easily connected to myDAQ to measure electrical variables using the myDAQ software instruments. Figure 4 illustrates the use of Labview software instruments from National Instruments (NI) to obtain the DC Level output coming from the myDAQ hardware. Figure 5 shows the measurement of DC current using the myDAQ and Labview’s virtual multi-meter. The next two labs include basic digital logic and circuits. The digital logic labs complement analog circuits described next in terms of the RC circuit.

Figure 3. Introduction to myProtoBoard

Figure 4. Testing DC Level Output

Figure 5. Measure DC Current.
The lab experiment for Week08 is an RC circuit using Multisim. Multisim is a circuit analysis tool similar to PSPICE with embedded software instruments such as an oscilloscope and multimeter. Students learn to use Multisim to simulate the RC circuit in Figure 6 and learn how to use an oscilloscope.

![Figure 6. RC Circuit Simulation](image)

In support of this lab, a short video “A Tutorial and Multisim Simulation on the RC Time Constant” was created to help enhance the student learning opportunity. The link of this video is uploaded to department’s YouTube channel, STEM Videos for the Flipped Classroom with the following link: [https://www.youtube.com/watch?v=t7ZJhzAx9JE](https://www.youtube.com/watch?v=t7ZJhzAx9JE).

To provide a memorable and practical lab experience for the student, a capstone experiment involves building a fully operational function generator from a kit. As shown earlier in Table 1, the last two labs are dedicated to the assembly and testing of a function generator during weeks 9 and 10. Students need to solder, assemble and test the ELENCO Function Generator Kit.

When considering labs involved with soldering, the engineering department was concerned about safety. The engineering faculty debated whether or not to include such labs in the online delivery. But CTU’s engineering students do need the skills of soldering, circuit assembly, and integration of various circuit functions required for their capstone courses. In addition, building a functional piece of equipment further triggers student interest in engineering and provides motivation to pursue and complete their degree programs.

**Pilot Stage for Introduction to Engineering Course**

The engineering faculty completed the first three stages of development shown earlier in Table 2. The pre-pilot stage was taught during Fall 2015. The pre-pilot class tested the online lab experiments, but still used the traditional lab equipment in the classroom and the components stored in the lab cabinet.

Professor Guo taught the pilot course in Winter 2016. In the pilot stage, the online teaching environment attempted to simulate the online environment. The flipped method for lab instruction was applied to the “Introduction to Engineering” lab. In this pilot lab, the students used the myDAQ and supporting equipment described earlier, with the exception of the
secondary power supply, and digital meter. Before starting the labs, students watched videos and read lab manuals for themselves and no lecture was provided by Professor Guo. As students begin doing the lab assignment, they can ask questions and also seek help during the simulated chat session during class.

However, there were some important differences between the piloted lab and the ‘real’ online lab. The instructor has a chance to see students’ circuits set up and can help students debug and troubleshoot the circuit in the piloted labs. In addition, students still need to interact with each other and collaborate in the lab.

Students Response and Feedback about the Pilot Course

At the end of the 2016 Winter Quarter, the Department Chair and Dean of College of Engineering held a Pilot Focus meeting that served as an end-of-course feedback. The course instructor was not present in the meeting in order to promote open discussion with the students. Students in the piloted class were interviewed about the effectiveness of the course. Eleven students registered for the class at the beginning of the quarter where one student dropped class during the middle of the quarter. Four out of the ten students in the class attended that meeting. The notes in Table 6 below summarize the student feedback.

From the summarized interview notes in the Pilot Focus meeting, students appeared satisfied with the videos, PowerPoint slides sets, assigned reading material and problem sets overall. The students thought that the myDAQ equipment and software instruments are very effective for lab experiments. Students also mentioned that the maximum allowed analog current must be considered in the lab design.

Students also expressed their concern of the effectiveness of the labs when they are fully delivered online. The department addressed this reasonable concern by stressing the importance of online and attendance of synchronous chat sessions when both instructor and students are together online at the same time to address questions raised by the students. However, more short videos may be needed to support students in learning all of the elements of the labs. In addition, troubleshooting tips need to be written for debugging each lab. Additional documents to be created include a troubleshooting procedure and checklist for students to follow before requesting help from the instructor during the online session. For example, here are steps that the students need to consider before coming to the chat session: (1) did the student follow the troubleshooting checklist? (2) did the student check with their lab partner for correct wiring of the circuit, including proper connections with power or perform the checklist with their partner? and (3) did the student post their questions on the discussion board and check for answers from other students experiencing the same issue?
1. Errors in the course are distracting said one student; but the student consensus was that the errors are very few in this course.

2. The MyDAQ-based lab equipment is very effective notwithstanding the issues of which we were aware such as insufficient drive current from the MyDAQ internal power supply and the need for an external digital multimeter to complement the internal one so that both voltage and current may be measured simultaneously. One student said that he noted a distracting lag between his commanding a function and the realization of that command.

3. Videos and slide sets are well done and useful. There is a good balance between paper and online content.

4. The problem assignments are well done and useful.

5. One student said that the course is very intense. Snow days should not be allowed. You fall behind.

6. They wondered if online labs would be as effective as those done in class live and in person. There is a lot of person-person interaction in solving the problems with the labs. Kathy noted that if students will attempt the labs ahead of time and bring their issues to the chats, it should work well.

7. In response to one question as to whether they believed there might be a bias in industry against engineers who obtained their degrees online, they opined that there should not be but probably is. But they also said they are not yet engineers, do not work in those circles, and therefore do not know.

Table 6. Summarized notes in the Pilot Focus Meeting

Comparison of Students Learning Outcomes in Face-to-Face Course and Pilot Course

Figure 7 compares accumulated lab grades of the ten remaining students for the pilot course to the lab grades from previous campus-based course taught by the same instructor. From the histograms, campus based lab students have higher grades than the grades from piloted course simulating the online delivery. After comparing the grades with attendance rate shown in the histograms on Figures 7 and 8, there exists a correlation between grades and attendance rate. Three students who failed the labs in the piloted course attended only 61.9%, 52.4 % and 19.1% of the classes. All the students in the face-to-face course attended 68% or more of all the classes. Students who failed the labs in the piloted-class missed many lab chats session during the 11 weeks. This preliminary data shows the importance of attending the Question-and-Answer (Q&A) chat sessions when it comes to lab experiments.

![Figure 7. Pilot and Face-to-Face Lab Grades Histograms](image1)

![Figure 8. Attendance Histograms of Pilot and Face-to-Face Course](image2)
Challenges to Teaching EE and CE Engineering Labs Online

One challenge when it comes to laboratory experiments is “Teamwork”, as indicated in the ABET student outcomes an ability to function on multidisciplinary teams.” Engineers need to work with people having different background and personalities. In the campus-based “Introduction to Engineering” lab, students usually work in small teams (two students in one team). In that way, students can start to learn how to work in a team, even though it is a small team. Students cooperate and help each other build and debug circuits. Students must communicate in various ways and help their partner. However, for the online environment, promoting teamwork becomes harder.

Another challenge for online lab is lack of instructor’s immediate support in debugging student circuits. When students do lab work and test circuits on campus, instructors can observe how the student performs an experiment, how students help each other find errors in the circuits and offer further guidance in their debugging efforts. However, for an online environment, it is difficult for instructor to observe the process of building the circuits, and offering immediate feedback. The instructor is presented with the “completed” circuit, when students upload a picture or video about their lab experiment, but circuit components and wires are not easy for the instructor to see. For example, a connection may not be actually connected even though it appears connected. When circuits are connected incorrectly, then safety should be of concern as well.

Safety is always the number one important thing while working in a laboratory environment. Even in the electronics lab with experiments involving relatively low voltages and currents, usually equal or less than 15V, the faculty frequently sees and smells ‘smoke’ coming from student circuits during the lab sessions. Students often don’t pay attention to the low power ratings of a resistor or students place the polarized capacitor in the wrong direction. In addition, students occasionally touch the tip of the hot soldering iron by accident. In an online environment, it becomes difficult if not impossible for an instructor to observe the safety of the student. Address the safety concerns of the student remains a critical issue.

Conclusions and Recommendations

The preliminary results for the piloted lab course, “EE110 Introduction to Engineering”, show that teaching engineering labs is very challenging when delivered online. But, if done appropriately, teaching online engineering labs could be successful. Several suggestions for online labs are listed below:

- One-hour synchronous chat session each week must be assigned to lab discussion
  - Students need to do lab first and follow troubleshooting procedures
  - Bring their questions and concerns to the chat session
- Need to record chat sessions from lessons learned by other students
- Students who could not attend the synchronous chat session must submit questions before the chat, and must view the recorded chats. Instructors need to keep remind students that they must attend the lab chat sessions.
- Need to provide debugging tips for each lab to help students troubleshoot the circuits
  - Develop and provide a troubleshooting checklist and other relevant resources

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Before coming to chat session, students need to follow a troubleshooting checklist

- Safety issues need to be addressed in each lab
  - Student need protection tools, for example, goggles
  - Develop a safety checklist including best practices when soldering and assembling circuits
- Must consider the limitations of myDAQ hardware when developing lab exercises
  - For example, the maximum analog output current is only 2mA
  - The “-” input of Oscilloscope is floating
- Require students to upload the pre-lab and the screenshot of circuit implementation
- Use online collaboration tools such as “google hangout” to promote communication among the students while fostering teamwork and team discussion
- Students must record a short 5-10 minute video demonstration for one of the last 5 labs
  - This helps verify and validate student understanding
  - Instructor selects which labs to record

Overall, the full-time engineering faculty at CTU gained valuable understanding and insights when developing laboratory assignments for online delivery. These lessons learned will prove useful when moving toward full operation of delivering engineering labs for all courses in an online environment.

References


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Dr. Jing Guo is a Professor in Engineering College at Colorado Technical University. She is the course director in circuits and electronics area. She taught variety of underrated and graduate courses including capstone design in Electrical and Computer Engineering area. She worked as a Subject Matter Expert (SME) of “EE110 Introduction to Engineering” Online Course Development.

Kathy Kasley, Chair of Engineering

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Kathy Kasley earned her BS in Mathematics from Ursinus College, a Master’s Degree in Mathematics at Villanova University, a Master’s Degree in Electrical Engineering from the University of Colorado in Colorado Springs, and her Ph.D. in Electrical Engineering from the University of Colorado. Dr. Kasley is a Professional Engineer, and has a Consultant-Evaluator for the Higher Learning Commission of the North Central Association of School and Universities for over 15 years. Dr. Kasley has taught mathematics and Engineering at high school, and at the university level for over 25 years. She has served as an instructor, academic advisor, ADA student counselor, and dean or chair of Engineering.

**John Santiago, Professor of Electrical and System Engineering**

Professor John Santiago teaches courses in electrical, computer and systems engineering after retiring from the USAF with 26 years of service in 2003. He began teaching at CTU the following year. His interests include: interactive multimedia for e-books, interactive video learning, and 3D/2D animation. Professor Santiago recently published a book entitled, “Circuit Analysis for Dummies” in 2013 after being discovered on YouTube. Professor Santiago received several teaching awards from the United States Air Force Academy and CTU. Last year, he was awarded CTU’s Faculty of the Year for Teaching Innovations. Professor Santiago has been a 12-time invited speaker for celebrating Asian-Pacific American Heritage Month.
Flipped Classroom Method in Teaching
“Introduction to Engineering” Course Online
Dr. Jing Guo and Dr. John Santiago
Colorado Technical University (CTU), College of Engineering

Abstract

This paper presents a flipped classroom method used in developing and delivering an online course entitled, “Introduction to Engineering”. The course includes a combination of mini-lectures and labs. Two one-hour chat sessions held synchronously are used where: (1) instructors need to hold one chat session for answering the mini-video lectures, reading material and problem sets, (2) and another hour for addressing lab questions. Four full-time faculty created multimedia content and follow-up exercises for assessment of student learning outcomes. During the asynchronous lab session, students are required to read the lab instructions and watch short videos before beginning the lab exercise or project. A pilot class simulates the online course with the newly developed content. The flipped classroom method shows promise based on student feedback and comparing student learning outcomes between the pilot class and the face-to-face course. The feedback from student surveys is discussed as well as suggested improvements of online course instruction.

Keywords

Online, Flipped Classroom, Short Videos, Adaptive Learning

Introduction

CTU is a private for-profit university with a primary student body composed of working adults. Online learning provides the flexibility for students to manage their time amidst a very busy schedule balancing work, family and school. One of the most important things for online teaching is to provide the same quality of instruction (if not better) in achieving learning outcomes when compared to students who have face-to-face teaching. This paper presents the flipped classroom method used in develop the course entitled, “Introduction to Engineering”, delivered totally as an online course using both synchronous (chat sessions) and asynchronous (discussion boards and email) e-learning and support.

The “Introduction to Engineering” is an 11-week long freshman course. It is a required course for both electrical engineering and computer engineering students. The course includes a combination of lectures and labs, covering one topic and one lab during each week. The flipped classroom method is used in both synchronous and asynchronous sessions. Synchronous online chat sessions mean that both the instructor and students are online together at the same time. Instructors are required to hold two one-hour chat sessions involving Q&A: one chat session addresses answering questions about the videos, assigned readings, and homework problems. Another one-hour chat session is reserved for answering lab questions or exercises. Each week, assigned readings and several five to ten minutes videos of each topic are created using screen recording software by experienced professors for asynchronous e-learning. Each short video is...
followed by a set of exercises. Students are required to watch the videos and complete the exercise before going to the Q&A chat session. The graded review questions for each topic are designed to assess student learning outcomes. Students are required to attend the chat session (or if they cannot attend, then watch the recorded chat session) to receive an assigned task after the session is completed. During the asynchronous lab session, students are required to read the lab manual with images illustrating how the equipment is used. The students need to watch short introductory videos about the lab before starting the experiment or exercise.

Using the flipped classroom approach from an online perspective, the paper describes a pilot class attempting to simulate the online course with newly developed content. The flipped classroom method appears to have promise based on comparing student learning outcomes between the pilot class and the face-to-face traditional and ground course. The feedback from student surveys shows further promise with the online flipped classroom approach and is also discussed in later sections along with suggested improvements of online course instruction.

The next section describes the flipped classroom model used for delivering the online instruction.

**Flipped Classroom Model**

The term “flipped classroom” is mostly attributed to two chemistry teachers from Colorado, Jonathan Bergmann and Aaron Sams, who pioneered the use of screen casting and video podcasting in 2006 to deliver content for their high school science classes. It wasn’t until September 2010, when Daniel Pink wrote an article about Karl Fisch, did the method become known as the flipped classroom. Kerr reviewed 24 studies about using the flipped classroom model for an undergraduate engineering education. Most of his studies reported high satisfaction with increased performance in a flipped classroom environment. Kerr also mentioned that “the flipped classroom format can encourage skills that are useful for students’ future careers, such as self-regulation and life-long learning.”

The flipped classroom changed the teaching strategies from instructor-centered instruction to one that is student-centered where students are responsible for their own learning. Just like every kid is different, every student learns differently. Students can learn at their own pace with the flipped classroom but must submit assignments on time. This method may flip students from passive learners to active learners thereby increasing student engagement.

In traditional face-to-face classrooms, an instructor gives a lecture, teaches students about concepts and theorems, and explains examples. Then students do homework and exercise outside of the classroom. But this approach is an inefficient way for student learning based on authors’ teaching experience, especially for our current student body. Most of CTU’s students are working adults with family and kids. They usually work during the whole day and come to school at night. The two or three hours of lecture during class period will lead students in becoming disengage and less inattentive, especially during the late evening class (8:15 p.m. to 10:50 p.m.), and in extreme cases, they fall asleep. It was found that short 5 to 15 minutes lectures followed by short assessment exercises completed by students prove to achieve better learning outcomes. This teaching approach is embedded in our flipped classroom method.
This face-to-face teaching philosophy and experience forms the basis on leveraging technology for online delivery using the flipped classroom approach.

**Converting Face-to-Face Courses for Online Delivery by Using the Flipped Classroom**

Our traditional face-to-face undergraduate engineering courses results in 4 to 6 class contact hours per week. The face-to-face teaching approach discussed in the previous section was used successfully for several years. In other words, there is much similarity between CTU’s face-to-face engineering teaching philosophy with one that is described as the “the flipped classroom”. For example, the outline of steps for the face-to-face lecture class is listed in Table 1.

<table>
<thead>
<tr>
<th>Step 1</th>
<th>Instructor introduces or presents a theorem, provide and solving an engineering example for 5 to 10 minutes.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 2</td>
<td>Assign an engineering problem to students, and them some time (usually 10 to 15 minutes) to think and solve the problem.</td>
</tr>
<tr>
<td>Step 3</td>
<td>Instructor and students work together to discuss and solve the problem.</td>
</tr>
<tr>
<td>Step 4</td>
<td>Go back to Step 1; repeat this process for the next engineering theorem in class.</td>
</tr>
</tbody>
</table>

Table 1. Steps of course construction in face-to-face traditional classroom

The feedback from students and the evaluation of their past performance of learning outcomes showed that this approach effectively improved their engagement. Students learned by doing and thinking. When students think about and solve problems by themselves, they may struggle at first. But later, whether students can figure out the solution or not, they will become more curious about how to solve the problem and engage themselves learning more during the discussions in class.

The flipped classroom and adaptive learning teaching approach was applied in developing the online version of “Introduction to Engineering”. At CTU, four full-time engineering professors developed the online version of the course working together to create engaging multimedia content. The online “Introduction to Engineering” is still 11 weeks long, and each week there are two to three assignments: two one-hour chat sessions hosted by the instructor each week to address questions on the problem solving exercises and lab assignments. As mentioned in earlier sections, both synchronous and asynchronous methods for student-instructor interaction are used in this course. Asynchronous e-learning mean students need to complete assignments at their own pace while meeting submission deadlines. For synchronous learning, the instructor needs to meet with students online twice a week to conduct one hour chat sessions answering student questions. Usually, we anticipate one chat session is reserved for answering questions about problem solving based on the weekly readings, videos or other multimedia content, and another hour for questions about the lab.

At the beginning of the quarter, students are provided a syllabus. Each assignment has a deadline in the students’ portal, a platform for delivering the course and weekly assignments. Each assignment has one or more course objectives. Each week two or three assignments will be given to students. The first assignment is always titled as “#AA Active Assignments Week #”, for example: “07AA Active Assignments Week 7”. An example of describing an assignment
is shown in Figure 1. Assignment “07AA Active Assignments Week 7” provides an overview of the work that needs to be competed in week 7.

<table>
<thead>
<tr>
<th>Assignment Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>In week 7, students need to finish the following assignments:</td>
</tr>
<tr>
<td>1. Assignment [WK07 Intellipath Type Questions], and upload your assignment;</td>
</tr>
<tr>
<td>2. Assignment [WK07 Lab], and upload team lab report.</td>
</tr>
<tr>
<td>3. Assignment upload Unit 7 Final Questions (please check the learning material: [Unit 7 Final Questions]), and upload the answers of questions under this assignment (07AA Active Assignments Week 7)</td>
</tr>
</tbody>
</table>

**Figure 1. 07AA Active Assignments Week 7**

As shown in Figure 1, Week 7’s work started from “WK07 Intellipath Type Questions.” Intellipath is an adaptive learning platform and a personalized learning technology which can be viewed as an intelligent tutoring system. It customizes learning for students based on students’ pre-determined knowledge state on a particular subject or topic. Intellipath was adopted in CTU’s existing online courses such as math courses. By using this platform, students report that they can move quickly through the course material on what they know and focus on what they do not know, so they are not left behind or doing repeated work. Students gain confidence in demonstrating their knowledge and proactively addressing their weak areas on a specific topic. Students’ outcomes show that Intellipath is a good adaptive learning tool. We plan to implement some of the engineering course assignments by using Intellipath in the near future initially consisting of generating random homework problems for practice that appears differently for each time the student goes through a learning module. The design of WK07 Intellipath Type Questions followed the teaching methodology implemented by the Intellipath Technology.

In the assignment “WK07 Intellipath Type Questions”, several short videos and the corresponding PowerPoint notes that explain the engineering concepts and applications are provided. Based on the extensive experience with face-to-face teaching for adult students, long lectures are inefficient since the working student often arrived in class tired after laboring all day. Thus, short mini-lectures usually lasts about 5 to 15 minutes and recorded using Camtasia. Each video is followed by several engineering questions. Students are required to finish this assignment and prepare the questions they want to ask during the chat session: preferably before they go to the one-hour chat session for problem solving. Students are highly encouraged to go to the chat session. Then students need to complete an assigned and graded task or problem once the session is over. By assigning a graded task during the chat session, students will be more motivated to attend the chat session. This approach was necessary after discussing with faculty from other departments having problems with students not attending the chat sessions and were not mandatory. For the College of Engineering, the chat sessions are required and will not provide a lecture, but only discuss the problems or questions students may have. Chats are recorded since some students cannot attend the synchronous chat session. However, they still need to watch the recorded video to receive the assigned task from the chat session.
“WK07 lab” in Figure 1 has also a flipped lab. In this case, students are required to watch short videos related to the lab asynchronously. They need to follow the lab instruction and perform the lab by using National Instrument’s (NI) myDAQ kit. Examples of Lab 7 Complex Circuit Analysis are shown in the Figures 2 and 3. Students need to follow the lab instruction step by step to finish the lab. Students also need to complete “Unit7 Final Questions” since this assignment is used to assess student learning outcomes.

**Complex Circuit Analysis**

*Colorado Technical University*

**Requirements:** Follow the lab instruction, fill in tables and answer questions.

**Objectives:**

After performing this experiment, you will be able to:

1. Measure the current and voltage in series and parallel circuit
2. Verify that the total resistance of a circuit in series is the individual sum of the resistors.
3. Check Kirchhoff’s voltage law for circuits connected in series.
4. Recognize the features of parallel resistive circuits.
5. Check Kirchhoff’s current law.
6. Simplify Complex Circuit
7. Measure the current and voltage in complex circuit.

**Parts and Equipment List**

1. NI my DAQ
2. Wire kit.
3. Resistors: One 470 Ω resistor, one 1kΩ resistor, one 4.7 kΩ resistor.
4. External Variable DC Power Supply (The DC Level output of myDAQ can only provide 2mA max current, so cannot provide 6V to the last circuit).

**Summary of Theory**

**Figure 2. Lab 7 Complex Circuit Analysis example 1**

**Figure 3. Lab 7 Complex Circuit Analysis Example 2**

The challenge of the flipped lab is “debugging the circuit”. Freshman students with limited knowledge and experience struggle while troubleshooting circuits. In face-to-face labs, problems are easily solved by using the help from instructor or other students during class. In the online
environment, providing help to the students in troubleshooting and debugging their circuits will become much more difficult. The reason for the one-hour chat each week is to dedicate and address lab questions raised by the students. During the chat session, students can upload an image or video to show and demo their circuit. Other students and the instructor during the chat section could provide help with one another solving and troubleshooting circuit issues. This chat session is recorded for students to review, especially for those who cannot attend the session. Also, the instructor can provide a discussion board to address lab questions by students and where the instructor or other students can help each other get through the lab.

After explaining the philosophy and implementation of the online flipped classroom, a description on how content was created is discussed next.

**Video Creation and Screen Recording Tools for Implementing the Flipped Classroom**

One of the must-have design tools for implementing a flipped classroom is video and screen recording software. For example, the Khan Academy model is a successful model of the flipped classroom which uses screen recording software. One important reason for the success is the good quality of instruction found on the video. For the online flipped classroom approach, there is very limited or no lecture provided in the synchronous chats sessions. High quality instructional videos are used to provide information and explain engineering concepts in order to engage students’ learning. Three video creation and recording software are compared in Table 2.

<table>
<thead>
<tr>
<th>Features</th>
<th>ADOBE CAPTIVATE&lt;sup&gt;5&lt;/sup&gt;</th>
<th>TECHSMITH CAMTASIA</th>
<th>TECHSMITH JING&lt;sup&gt;6&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Allows the user to create interactive simulations of software programs</td>
<td>• Takes full-motion video simulations&lt;sup&gt;5&lt;/sup&gt;</td>
<td>• Record What You See (and Do)</td>
</tr>
<tr>
<td></td>
<td>• Takes detailed screen capture simulations</td>
<td>• Great for streaming video content&lt;sup&gt;6&lt;/sup&gt;</td>
<td>• Videos are limited to 5 minutes for instant, focused communication.</td>
</tr>
<tr>
<td></td>
<td>• Allows for complex student interaction; giving them the opportunity to go down the</td>
<td>• Easy to post to file sharing sites, such as YouTube&lt;sup&gt;5&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>incorrect path and learn from mistakes</td>
<td>• Hot Spots&lt;sup&gt;7&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Complex and varied activity and testing options (multiple choice, hot-spots, drag and</td>
<td>• Ability to collect and report tests scores.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>drop, matching)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price</td>
<td>$1,099</td>
<td>$299</td>
<td>Free</td>
</tr>
</tbody>
</table>

Table 2. Video creation software comparison

For developing the course content, Camtasia was selected as our video creation tool based on the tradeoff of interactive features<sup>7</sup>, performance and cost. More examples on the use of Camtasia
elearning features could be found in the paper “Leveraging Internet Marketing Technologies and Green-screen Techniques for Developing Engaging STEM and Online Content”.

Camtasia was used to create short lecture to explain the theory behind the lab experiments. The next section describes affordable hardware to conduct the experiments.

**Selection of Lab Equipment**

In order for students to conduct a lab experiment, normally they will need a DC variable power supply, function generator, multi-meter, and oscilloscope. However, the department needs to find portable and inexpensive kits for online students that have similar functions found on the hardware equipment used in a traditional lab classroom. The department investigated educational lab equipment from National Instruments. The department compared the main specifications of equipment NI Elvis II and NI myDAQ. The comparison is given in Table 3.

<table>
<thead>
<tr>
<th>Main Laboratory Specifications\Instrument</th>
<th>NI ELVIS II</th>
<th>NI MyDAQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Input</td>
<td>8 differential or 16 single ended channels</td>
<td>2 differential or 1 stereo audio input channels</td>
</tr>
<tr>
<td>Analog Output</td>
<td>2 channels</td>
<td>Maximum output current 5mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum output current 2mA</td>
</tr>
<tr>
<td>Digital I/O</td>
<td>24 DIO</td>
<td>8 DIO</td>
</tr>
<tr>
<td>Digital Multi-meter Functions</td>
<td>DC Voltage, AC Voltage, DC current, AC current, resistance, diode, capacitance, inductance</td>
<td>DC Voltage, AC Voltage, DC current, AC current, resistance, diode</td>
</tr>
<tr>
<td>AC Voltage Frequency Range</td>
<td>up to 20 kHz</td>
<td>up to 2 kHz</td>
</tr>
<tr>
<td>Power Supplies</td>
<td>Maximum output current of +/-15V supply is 500mA; Maximum output current of 5V supply is 2A; Maximum output current of Variable Supply (0 to +/-12V is 500mA)</td>
<td>Maximum output current of +/-15V supply is 32 mA; Maximum output current of 5V supply is 100 mA; Maximum output current of Level Output (0 to +/-10V is 2 mA)</td>
</tr>
<tr>
<td>Physical</td>
<td>Dimensions: 34.3 x 28.0 x 7.6 cm, Weight: 1.9 kg</td>
<td>Dimensions: 13.6 x 8.8 x 2.4 cm, Weight: 0.164 kg</td>
</tr>
</tbody>
</table>

Table 3. NI Elvis II and NI MyDAQ Comparison

By comparing these two pieces of equipment, obviously, NI ELVIS II has much better performance. ELVIS II has a variable power supply, and can provide maximum output current up to 500mA. On the other hand, NI myDAQ has a Level Output, which could be used as a variable power supply, but the maximum output current is limited to only 2mA. ELVIS II’s +/-15V supply also provide much higher output current when compare to myDAQ. But the price of ELVIS II is more than 10 times of myDAQ…too expensive for most students. The physical size of ELVIS II is much bigger; and its weight is much heavier.

Based on this comparison, the department decide to select the NI myDAQ for the course “Introduction to Engineering”. Students starting their engineering study will find myDAQ to be...
affordable when compared to the Elvis II system. The students will be informed that myDAQ will also be used in future analog circuits, digital circuits and electronic courses.

Now that the hardware equipment has been identified, the process of preparing the course content for online delivery is described next.

**Stages of the Online Course Delivery**

To ensure the quality of the course, the transition from face-to-face instruction of “Introduction to Engineering” to the online delivery of instruction, the department followed six stages as shown in Table 4.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre Design Stage (April - June, 2015)</td>
<td>Set up schedule and assign design work to the four full time professors; make decision on development tools and lab equipment.</td>
</tr>
<tr>
<td>Design Stage (July-September, 2015)</td>
<td>Four professors coordinate development the online EE110 based on the weekly schedule of submitting content.</td>
</tr>
<tr>
<td>Pre-Pilot Course Delivery (October-December, 2015)</td>
<td>Test online course material to EE110 traditional ground students. Correct errors and typos in the material and improve the quality of the course material.</td>
</tr>
<tr>
<td>Pilot Delivery (January-March, 2016)</td>
<td>Simulate the online environment with face-to-face students with no lecture; receive feedback and evaluation of the course for continuous improvement of the course.</td>
</tr>
<tr>
<td>Hybrid Delivery (July-September, 2015)</td>
<td>Continue to simulate the online environment and test delivery of online instruction. Students come to class three hours each week instead of five hours for the pilot class.</td>
</tr>
<tr>
<td>Online Delivery (October-December, 2016)</td>
<td>Fully online delivery of EE110.</td>
</tr>
</tbody>
</table>

**Table 4. EE110 design and delivery stages**

*First three stages.* The Engineering Department completed the first three stages. During this time, four full-time professors developed the online course material. The material was fine-tuned and improved based on the feedback of face-to-face students. Short video lectures were produced using Camtasia including demonstrations of software instruments, interactive PhET and Matlab/Simulink simulations.

*Pilot Stage.* Professor Guo taught the pilot stage course in Winter Quarter of 2016. In the pilot stage, the online teaching environment had been simulated. Students still met five hours per week in class. But in the pilot class, there was no lecture. Students need to go to portal and figure out the work they need to complete for the weekly assignments. Students watch videos, and do problems that followed each video. For lab exercises and experiments, students need to follow the lab manual, watch the video and review PowerPoint notes of the lab in order to complete the assigned labs. Chat sessions are used to discuss about the questions and concerns students may have about the assigned engineering problems and another hour is dedicated to answer questions about the lab.
The pilot class simulated the online teaching at some level since there were some significant differences between the pilot class and the ‘real’ fully online class. The instructor still had opportunities to see students set up circuits and can help students debug their circuit. Since students still came to class, they knew each other well, and always helped each other in understanding the engineering concepts and solving problems. As a result, students will need to collaborate, possibly through their own chat session or discussion boards to post questions where other students help each other moderated by the instructor.

With the simulation to deliver online content completed, the next section compares the student learning outcomes between the piloted class with the traditional face-to-face instruction.

**Correlation of Student Learning Outcomes and Attendance**

Eleven students registered for the piloted course at the beginning of 2016 Winter Quarter. One student dropped class in the middle of the quarter. The histogram of students’ final grades of the ten remaining students in the pilot course and the grades from previous face-to-face course (Fall 2014) taught by the same instructor is shown in Figure 4.

![Figure 4. Grades Histograms of Pilot and Face-to-Face Course](image)

![Figure 5. Attendance Histograms of Pilot and Face-to-Face Course](image)

From the histograms in Figure 4, the face-to-face students have higher average grades than the piloted course. Figure 5 shows the attendance for each class. After comparing the grades with attendance rate histograms as shown in Figures 4 and 5, correlation between grades and attendance rate was found. The three students failed the pilot course attended only 61.9%, 52.4%, and 19.1% of all class hours. All the students in the face-to-face course attended 68% or more of all class hours. For the students who missed class during the piloted version, they missed many chats session during class. These results from the piloted course appear to show that the chat sessions will become a very important component and that the online flipped classroom approach has promise to be effective for online delivery. Discussions with faculty from other departments revealed that attendance of chat sessions is an issue. To help motivate students to attend the chat session, a graded problem will be assigned after the chat session. The chat session will be recorded for students who are unable to attend so they can find out what the assigned task is and complete it.
After looking at the student learning outcomes, the next section provides results of end-of-course feedback from students.

**Students Response and Feedback about the Pilot EE110 Course (Winter 2016)**

One assignment in Week 11 includes a section: “Please provide 2-3 paragraphs that answer the following questions:

- What did I not expect in this course, and was pleasantly surprised to learn/receive?
- What did I expect in this course, and was provided new direction?
- What did I find in the course that was the most challenging?
- What did I find out that I can use to improve in the next course?”

Six out of ten students submitted this assignment, and answered the question. Students’ comments about this section are listed in Table 5 below.

Based on the students’ comments in this assignment; we can see that five out of six students feel the course met their expectation, and they were happy about what they learned from this course. One student had lower expectations, and he did not like the flipped classroom method, and still hope to use the traditional lab equipment. Students also pointed out that the typos and errors existing in the course material were distracting, and need to be fixed.

| Student #1 | “In this class I got a better understanding of many electronic theories than what I have gotten in classes before this one. I believe that I should have taken this class before some of the classes like Digital Design 1 and Circuits 1. If I had taken this class, I do not think that I would have struggled as much in the other classes. What I have learned in this class gave me a better understanding of logic gates, circuit design, and testing circuits. I have realized in this class that I really like putting the function generator together and seeing that it works. I now know that I need to improve on my soldering skills. To me that was the best part of the class.

For me the most challenging part of the class was doing Boolean Algebra and soldering the function generator. Once the labs get updated for MyDAQ I think this class will be great. I think everyone in the class should have to buy one to be able to do homework and labs. Sometimes work interferes with my school schedule or if you get sick you can still keep up with the labs from home. Overall I believe this class is very informational I learned a lot and now I have a better understanding of circuits.” |
| --- | --- |

| Student #2 | “To be perfectly honest, I already knew most of the material in this class. However, working on only analog equipment in the past, the material on digital circuits and Boolean algebra was new. I enjoyed this portion of the class and learned a lot. I look forward to learning more in this area in future courses.” |
### Student #3

“This was a great course; I would have to say since we actually learned about Circuits and were able to build them in labs. This is very helpful since I took a class prior to this and I was somewhat lost. I think if I had taken this course first I would have had a better grasp on the topic. Along with the fact that I took a higher level course the Boolean algebra is something that I did expect to learn in this class. The teacher did a great job of showing little tricks in order to simplify circuits. Through the entire course I found only one thing to be challenging and that was definitely the Boolean algebra. The short cuts and things that we were taught were very helpful but it was definitely a very challenging topic. Finally the one thing that I did learn that I can and will use in future courses are how to trouble shoot a circuit that isn’t working properly.

Overall, I feel that this is a great class to have prior to any other courses in order to get a solid foundation and understanding of what’s going on now and in the future.”

### Student #4

“When I started this course I didn’t expect lower level math to be involved. I was surprised to learn that I was able to take to Ohm’s Law very well as it became a staple for the rest of the term. I also didn’t expect that simulations would play a major role to understand the basics of engineering. I was surprised to find out how well the simulations explained the validated things like electric fields. I expected out of this course was for it to be somewhat difficult to complete if I wasn’t able to show up to every class. What I found to be the most challenging in the course was the transition to online which had it bugs. I would assume that since we were the first class tested under these conditions that the next time around it won’t be half in class and half online. I would say in order to be successful without any hiccups next term the issues like not being able to upload assignments should be fixed. I would also say that you would also need to just proofread all of the assignments to ensure that different values aren’t referred to like it initially asking for a 5 ohm cap and at the very bottom of the paper saying 10 ohms. All in all I really did enjoy this class and felt it would be a great step toward someone that is going to work in the engineering field.”

### Student #5

“I was very happy to have this class as an introductory class into engineering. It shows that there is a lot to learn yet achievable with enough studying. One thing that I was pleasantly surprised was the building of the signal generator. I really like how it was hands on and with a few short weeks of class you understood what all the components do as you then solder them into place on the signal generator. I expected to have a brief understanding of the components prior to the class but was surprised to learn how in depth we got with them.

I found that the most challenging aspect was the application process once all the information is given then applying that to the lab. Sometimes it was
easy but me being a complete amateur at building on the bread board it was one thing to learn about it but then completely different once given the bread board to test it. To improve in my next course I plan on using my brief understanding of the how the bread board works and to always test or model you circuits before applying them.

Student #6

“I really had higher expectations for this course than what I got out of it. I expected in depth lectures and knowledge on basic electronics but what I got were recorded videos that did not fully explain the concepts and labs I was tasked to complete without prior guidance as to what we were testing. I expected that test equipment such as multi-meters and oscilloscopes would be introduced, operations explained, and then had their functions demonstrated so that we could continue to build upon these tools through our electronics careers.

The challenges for me were interpreting the labs especially when a couple of them had unclear objectives of what we were meant to accomplish. There were also errors in the labs which suggest that they had not been tested. In our first lab the wires in the photos were in the incorrect positions of the board, yet if this lab had been constructed and tested… shouldn’t it have easily been identified that the wires were wrong before the photos were taken because the LEDs would have failed to light.”

Table 5. Student feedback for Winter 2016

At the end of the 2016 Winter Quarter, Chair and Dean of Engineering College held a “Pilot Focus meeting” that served as an end-of-course feedback. The course instructor was not present in the meeting on purpose. Students in the pilot class were interviewed about the effectiveness of the course. Four out of ten students in the class attended that meeting. The notes in Table 6 below are summarized based on the student feedback.

1. Errors in the course are distracting said one student; but the student consensus was that the errors are very few in this course.

2. The myDAQ-based lab equipment is very effective notwithstanding the issues of which we were aware such as insufficient drive current from the myDAQ internal power supply and the need for an external digital multi-meter to complement the internal one so that both voltage and current may be measured simultaneously. One student said that he noted a distracting lag between his commanding a function and the realization of that command.

3. Videos and slide sets are well done and useful. There is a good balance between paper and online content.

4. The problem assignments are well done and useful.

5. One student said that the course is very intense. Snow days should not be allowed. You fall behind.
6. They wondered if online labs would be as effective as those done in class live and in person. There is a lot of person-person interaction in solving the problems with the labs. Kathy noted that if students will attempt the labs ahead of time and bring their issues to the chats, it should work well.

7. In response to one question as to whether they believed there might be a bias in industry against engineers who obtained their degrees online, they opined that there should not be but probably is. But they also said they are not yet engineers, do not work in those circles, and therefore do not know.

**Table 6. Summarized notes in the Pilot Focus Meeting**

From the summarized interview notes in the “Pilot Focus Meeting”, students were satisfied with the videos and slides sets, and think that myDAQ based equipment is very effective for lab experiments.

The collected feedback from the surveys and results from student learning outcomes will be used to provide continuous improvement of this introductory course.

**Continuous Improvement of the Course**

Just like traditional face-to-face course, online course needs continuous improvement as shown in Figure 5. The course development stage provided the original course material. After the development stage, each stage in Table 4 provides inputs to next stage offering suggestions and improvement to the course material as shown in Figure 5.

**Conclusion**

The preliminary results from the pilot “Introduction to Engineering” course show that the flipped classroom method has promise to be successful in developing and teaching the online “Introduction to Engineering” based on feedback from end-of-course surveys. Based on the experience from this pilot class, several suggestions are listed below for future continuous improvement of the course.

- Course Material typos and errors need to be corrected.
- Two hour chats sessions are very important to improve students learning outcomes.
- Students’ success is highly correlated with the attendance to the chat session.
  - Continue to encourage or push students to attend the chat session (or at least ask questions in advance, and view the recorded chats).
Instructors need to keep reminding students about attending the chat sessions. To motivate students, instructors can insert “secret” questions with assigned credits in the chat session which may help push students to attend the chat sessions.

- Short videos are effective tools to engage student learning
- More videos should be developed, especially videos related to troubleshooting and debugging circuits
- Increase use of adaptive learning tools (for example, Intellipath) to enhance student learning in the future.

Overall, the full-time faculty at CTU gained valuable experience and insights when developing an engineering course suited for online delivery of instruction. These learned lessons will be prove fruitful as we move ahead delivering more engineering courses online.

References


Jing Guo, Professor of Electrical and Computer Engineering

Dr. Jing Guo is a Professor in Engineering College at Colorado Technical University. She is the course director in circuits and electronics area. She taught variety of undergraduate and graduate courses including capstone design in Electrical and Computer Engineering area. She worked as a Subject Matter Expert (SME) of “EE110 Introduction to Engineering” Online Course Development

John Santiago, Professor of Electrical and System Engineering

Professor John Santiago teaches courses in electrical, computer and systems engineering after retiring from the USAF with 26 years of service in 2003. He began teaching at CTU the following year. His interests includes: interactive multimedia for e-books, interactive video learning, and 3D/2D animation. Professor Santiago recently published a book entitled, “Circuit Analysis For Dummies” in 2013 after being discovered on YouTube. Professor Santiago received several teaching awards from the United States Air Force Academy and CTU. Last
year, he was awarded CTU’s Faculty of the Year for Teaching Innovations. Professor Santiago has been a 12-time invited speaker for celebrating Asian-Pacific American Heritage Month.
Leveraging Internet Marketing Technologies and Green-Screen Techniques for Developing Engaging STEM and Online Content

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Abstract

The paper presents tools, approaches and preliminary results for online content creation of Science, Technology, Engineering and Mathematics (STEM) topics to capture student attention. CTU Engineering Department investigated software from the internet marketing niche in support of creating multimedia content for the online course delivery of ‘Introduction to Engineering’ in 2016. The engineering faculty created a YouTube channel to serve its video content. The content supports a flipped classroom approach as defined by the department from a totally online delivery of instruction. Preliminary results show student satisfaction with this teaching pedagogy. Ongoing improvements include investigating software tools and green-screen techniques to increase student engagement. For example, interactive video learning techniques with embedded ‘hot links’ within a video can promote student attentiveness. The teaching innovation allows students to have options or call-to-actions such as: watching more videos, perusing other forms of content, or taking a short quiz or other assessment activity.

Keywords

online flipped classroom, internet marketing technologies, e-learning, multimedia, green-screen techniques

Introduction

Colorado Technical University (CTU), a subsidiary of Career Education Corporation (CEC), has students consisting mostly of adult learners who are working full-time. CTU successfully developed and implemented a program curriculum consisting of day and night classes in electrical and computer engineering to accommodate the working adult. With day and evening engineering courses being 11 weeks in length, the curriculum and flexible program schedule allows students to successfully complete an ABET-accredited degree in either BSEE or BSCE. Engineering courses for obtaining an MSEE and MSCE degree are only offered in the evening.

CEC made strategic plans during 2015 to provide online delivery of undergraduate and graduate engineering courses. In response, CTU developed a long-range plan to deliver several engineering courses online. The engineering faculty decided to first develop a course entitled, Introduction to Engineering. The department adopted a flipped classroom approach for online content delivery described and defined in more detail later in this paper as well as describing how content was generated. The department started the planning of online content in April 2015.
Gaining Experience for Online Delivery of Engineering Content and Adaptive Learning

CTU has four full-time engineering faculty at the Colorado Springs campus and are newcomers in developing online engineering courses. Because the engineering faculty has its primary focus on teaching, the full-time instructor carries a typical workload of four courses per quarter. Consequently, each instructor has taught between thirty to forty different engineering courses, including math and physics during their stretch at CTU. However, with this recent online initiative, the instructors have been downloaded to 2-3 classes for one year to focus on content creation and instructional delivery.

To gain experience in developing and delivering online courses, four instructors (which includes the Engineering Department Chair and the authors) were all involved in creating content for a freshman-level course, Introduction to Engineering, during the Summer Quarter and Fall Quarter of 2015. Professor Guo was the lead professor integrating the content from other instructors. The planned rollout of the first course was intended to refine the content during these three quarters before delivering the polished version of the first course fully online in 2016.

During this development cycle, the department created a YouTube channel entitled, ‘STEM Videos for the Flipped Classroom’ and gained valuable skills and insights when creating and testing the content for online delivery. Figure 1 is a screenshot of the department’s channel.

The engineering content supports the flipped classroom philosophy defined by CTU and requires integrating it with CEC’s learning management system (LMS) and its adaptive learning (AL) software at Chicago. Throughout this development, the integration effort required frequent coordination to ensure a rewarding learning experience for the student. Results of CEC’s AL software with trigonometry and pre-calculus courses for the blended learning model appeared in the 2016 ASEE Conference. The engineering department intends to use the AL software to provide more practice in solving problems by automating and generating random homework problems for future development of engineering courses. For example, random values of circuit components in various network configurations are generated for each student. Here, students can solve a variety of circuit analysis problems that are different and not repeated for each student using different solution methods. After gaining some experience in generating and refining the online course content, feedback in regards to the content delivered in a pilot course is discussed next.

Feedback from Pilot Study of ‘Introduction to Engineering’ and Follow-up Activities

During the 2016 Winter Quarter, CTU held a Pilot Focus meeting that served as an end-of-course feedback in March. Face-to-face student group interviews about the effectiveness of the piloted course was discussed. The course instructor, Professor Guo, was not present during the group
interview in order to promote more honest feedback and a less threatening environment. The interview was conducted by the College of Engineering Dean and Engineering Department Chair. Table 1 are meeting notes summarizing the results from student comments. In general, the overall content and instructional delivery was well received. The content was further refined and developed during the quarter correcting minor errors identified by student feedback. Four students were able to make the focus group meeting when usually 7-8 students out of 11 are in attendance during class.

<table>
<thead>
<tr>
<th>STUDENT COMMENTS, WINTER 2016</th>
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<tbody>
<tr>
<td>1. Student consensus that errors were few but one student found it distracting</td>
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<tr>
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</tr>
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<td>7. In response to one of the question as to whether they believed there might be a bias in industry against engineers who obtained their degrees online, the students opined that there should not be but probably is. But they also said they are not yet engineers, do not work in those circles, and therefore do not know.</td>
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</table>

Table 1. Notes Summarizing Student Feedback On The Piloted Course, Introduction to Engineering

Several months before the focus meeting, one adjunct professor who taught the introductory course (Fall 2015) and quality-checked the course material reinforced comment 3 of Table 1. The adjunct approached Professor Santiago saying that student feedback on the videos and course content were very good and much appreciated by the students.

Due to workload and resource constraints, CEC decided to change its strategy and implement its near-term plan to deliver the graduate engineering programs online since they are relatively easier and have fewer courses to develop than the undergraduate ones.

Although the undergraduate plans were temporarily placed “on hold”, the Engineering Department wanted to leverage the success thus far from the piloted program. The full-time faculty are continuing to investigate and refine its online delivery methods as well as producing engaging content for future courses. For example, Professor Guo while teaching a second course in circuit analysis, is modifying the existing labs for the myDAQ hardware in preparation for the next round of content development. Professor Santiago is looking at approaches in using PowerPoint as an adaptive learning tool using hyperlinks and Office Mix described in the latter part of the paper. The paper will also elaborate on comments 3 and 6 explaining the engineering department’s teaching philosophy and explaining how content was generated. However, the ongoing challenge remains to carry on translating the face-to-face teaching style and active learning approach and making it suitable for online delivery of engineering courses. Professor Santiago’s had early experience with developing multimedia content suited for online instruction. His past experience which eventually led to implementation of the flipped classroom approach from an online perspective is described next.
Leveraging Past Experience to Implement Flipped Classroom Approach

Before CEC presented its 2015 strategic plan to deliver engineering courses online in 2016, Professor Santiago’s initial interest was already focused on developing and experimenting with interactive and multimedia textbooks (or e-books) back in 2003, shortly after his retirement from the U.S. Air Force that same year. Ideally, he investigated on developing multimedia textbooks consisting of videos and other media mixed with recordings about using engineering tools and interactive teaching platforms like Matlab/Simulink, Labview/Multisim, PhET and Algodoo. He investigated a number of internet marketing technologies that appear applicable for developing educational content and suited for online delivery. His research efforts led to uploading of experimental YouTube videos in 2008. His educational and creative efforts on YouTube led to a published book\(^2\) in 2013 described later in the paper. Professor’s Santiago experience in content generation with multimedia e-books is also discussed later sections. His past experience guided the engineering faculty for online delivery.

Leveraging Professor Santiago’s knowledge and feedback from engineering instructors, Figure 2 provides requirements and considerations for delivering online engineering content. Figure 2 also shows flow of multimedia content and overview of implementing the online flipped classroom approach. Before describing the detailed implementation of the flipped classroom, the next section describes the traditional face-to-face teaching philosophy to form the department’s online teaching philosophy.

**Traditional Face-to-Face (Ground) Teaching Philosophy**

Typical engineering courses taught at the CTU Colorado Springs campus are two to three hours long meeting twice a week. The teaching pedagogy uses a student-centered approach where they take active participation in their learning as opposed to passive one-hour instructor lectures in class. For example, one approach of instruction involving engineering problems a number of analytical concepts, such as circuit analysis or signals and systems involves the following steps:

- **Step 1.** Introduce and present a topic for 5 minutes. Motivate why this topic is important and relevant to the course keeping it short and sweet. Also show how information will benefit them or tell a relevant war story based on industry experience.
- **Step 2.** Solve an example engineering and analytical problem. This usually takes 5 to 15 minutes depending on the complexity of the problem
- **Step 3.** Have students struggle with another similar problem for 10-15 minutes.
Step 4. Solve problem together – 10-15 minutes. An instructor can have one of the students solve the problem on the whiteboard and appropriately guide the student to unravel the problem requesting feedback from other students as well.

Step 5. Break (5-15 minutes)

Step 6. Repeat process for the next hour

The above approach is not set in stone so that an instructor can adapt delivery of the material according to any student questions and needs. For the following hour, an instructor may have a short lab or hands-on exercise using Matlab/Simulink or PSPICE to reinforce the concept taught during the first hour. The above pedagogy is consistent with past teaching philosophies.  

After this explanation of the traditional face-to-face teaching, the flipped classroom approach is described next from an online perspective.

Detailed Description and Implementation of the Online Flipped Classroom Approach

When students first heard of CTU’s preliminary offering of delivering engineering courses online, most of their immediate responses goes something like this: “there is no way I’m going to take an engineering course online”. But after explaining the online and flipped classroom approach described below, most of their fears and concerns appear to subside and were less adamant on their position. As expected, some students remain skeptical since learning engineering is a challenge in a traditional classroom and face-to-face setting learning environment.

For online delivery, the overall goal is to develop effective teaching innovations and timely help students efficiently learn topics in STEM. One teaching approach consists of translating and transforming the teaching delivery taught in the traditional face-to-face classroom to one apt for online delivery of the course material. In other words, how can the engineering faculty leverage and use current e-learning technologies to implement and transform the face-to-face teaching style suitable for online instruction.

In Figure 2, the block labeled ‘Requirements and Considerations’ highlights and summarizes some of the key points in the earlier sections. Also, the next two blocks of Figure 2, labeled as ‘Multimedia and Interactive Content’ and ‘Implementation of Online Flipped Classroom’, are discussed next. The online delivery will use a flipped classroom approach as defined by the following three main concepts as depicted in Figure 2.

The first concept is to develop engaging and interactive multimedia content. This includes gaming techniques in the future as incentives after initial development of multimedia content. The initial phase consists of developing videos, assigned readings/homework and laboratory experiments.

The set of videos will provide a technical foundation made up of a series of short mini-lectures (usually lasting between 5 to 10 minutes for each video) followed appropriately with a series of short assessments to verify and validate student understanding. Students must view the interactive content outside the classroom while addressing the call-to-action or assignments from the video. These actions must be completed before the online chat session.
In a traditional classroom, the content would be delivered as lecture material. The instructor must reflect on what and how the face-to-face instruction was conducted and determined if it can be implemented for online delivery by leveraging available e-learning technologies. The videos should also include demonstrations or simulations by visualizing and applying the abstract math and engineering ideas to real-world problems. Video recordings on the use of engineering tools such as Matlab/Simulink, Labview/Multisim, PhET and Algodoo software, can serve as examples to demonstrate key concepts found in a particular course and developed for this first course. The video instruction can also include demonstrations of real-world applications. For example, in the capstone design courses and projects, students can use relatively inexpensive microcontrollers such as Arduino, Raspberry PI, and Beaglebone to serve as complementary hardware with the myDAQ from National Instruments. These affordable microcontrollers have been investigated or used by past student group projects. Instructors can also use myDAQ and the microcontrollers to demonstrate key concepts found in circuit analysis and electronics courses. To further promote user engagement, any student questions raised from the interactive and multimedia content can be addressed in the online and required interactive chat sessions.

From an online perspective, synchronous delivery means classroom time when the instructor and students are online together (commonly known as a chat or synchronous session). The conduct of the required Q&A chat sessions are discussed next.

*The second concept involves minimal or no lecture material presented during the online sessions when students and instructor meet synchronously on a weekly basis.* The engineering department determined that there is very little time to provide a thorough lecture-based material during online sessions. This concept allows more student engagement as a follow-up to the multimedia content presented during the week. The chat sessions are recorded. If students are unable to attend the chat session, then they must view the recording and turn in an assigned project or solve a particular homework problem before the chat session. These sessions should be reserved for addressing student questions based on the weekly online multimedia content, required readings or hands-on laboratory experiments or simulation exercise. The primary intent of the chat session is to provide more practice in showing students how to solve more problems while addressing student questions.

Before the chat session, the instructor can set up a discussion board where students can submit their questions. Other students can answer these questions as well and earn points toward a leaderboard providing incentives such as reducing the number of assignments that they need to do or earning extra credit points. The chat sessions are primarily student-centered activities based on problem-solving exercises/projects where most of the time is answering student questions. The primary goal during the chat session is to facilitate and save time for students in solving problems by showing more examples of worked-out problems of assigned homework. Questions on the use of engineering tools described earlier can be addressed here as well.

The synchronous chat sessions will also include an interactive whiteboard between the students and instructor. For example, a chat session may involve an instructor who completed step 1 in solving an assigned homework problem on the whiteboard. The instructor can then canvas the audience or select a student by asking: what’s the next step toward solving the problem? In addition, homework problems during weekly chat sessions, students may ask questions for assigned lab or hands-on activities for that week. If a self-motivated student does not need to
attend the chat session and has successfully completed assigned homework before the chat session, then the student gets credit or is excused from attending the session.

The final concept consists of hands-on projects to verify and validate the student understanding of concepts, analysis, design and building of their proposed solutions. Students need to do projects or lab experiments that are either a software simulation such as Matlab or laboratory experiment using myDAQ hardware with supporting instrumentation software as part of the course. CTU adopted National Instrument’s myDAQ as a learning tool to provide the hands-on experience in several engineering courses, including the ‘Introduction to Engineering’ which worked well based on student comments. Discussion boards can be used for students to collaborate on lab experiments and to address comment 6 of Table 1. Students should have the ability to start chat sessions among themselves with the Learning Management System to document their collaboration. In place of a written lab or research report for selected projects or lab experiments, each student is tasked to record a 5-to-10 minute video on selected projects or lab experiments whether performed in a group or individual setting. Chat sessions can be used to address student questions on the labs as well. Students can submit their lab questions on another discussion board the day before the chat session takes place. The instructor can use the information to prepare the chat session. Further details about applying this online flip classroom for ‘Introduction to Engineering’ can be found in another paper5.

On a precautionary note, using the online flipped classroom approach, students are viewing videos and reading course content on their own time outside the chat sessions. Consequently, the instructor needs to be careful of the student workload when assigning homework. The intention of the synchronous chat sessions, is to perform several worked-out homework problems and address student questions about the assigned homework, laboratory experiment or other student-centered activities and questions arising from the multimedia content.

As depicted in Figure 2, the results of CTU’s online flipped classroom philosophy uses a combination of synchronous chat sessions and asynchronous tools (discussion boards and emails). Synchronous chat sessions offer self-motivated learners who need more faculty interaction. For those who are unable to attend the synchronous chat sessions, the asynchronous approaches are available for self-motivated students and time-constrained with the realities of daily life6,7. Although the online content was tested through a piloted course with ground (or face-to-face) students, the online teaching pedagogy appears to be reasonable and promising, based on comments 2 through 4 of Table 1. Student feedback from comment 6 about online delivery of myDAQ labs is described in more detail by the authors in another paper8. CTU’s online teaching philosophy and implementation will continue to evolve as the engineering faculty gains more experience in delivering courses online.

For CTU engineering faculty, the major considerations and lessons learned when integrating the three concepts are that it’s very resource intensive, namely:

- Requires extensive time to build quality interactive and multimedia content
- Requires learning new skills to produce engaging videos or multimedia content
- Variety of video types and more engaging videos may be necessary requiring use of green-screen techniques, character animation, gaming techniques, kinetic text and whiteboard video in motivating students for a four-to-five year engineering program
• Requires learning new software such as Camtasia for video screen capture and video editing
• May require learning other content creation tools such as Adobe Products (Photoshop, After Effects, Illustrator, Premier, etc.) for visually appealing content
• Requires a dedicated team with appropriate skill sets to produce quality and engaging online content and instruction.

The engineering department intends to find more efficient ways when developing the course material. For example, if time is an issue in developing video content, then a team of instructors could spend their time researching, leveraging and curating other videos found on YouTube. However, some of the top engineering schools, have posted some of their traditional 45-minute or one hour lectures on YouTube, so viewing these videos will take time for both instructors and students. The CTU engineering department chose to develop their own content to suit its online needs of instruction for a particular course and when appropriate, leverage videos uploaded on YouTube or other video content providers. Since some portions of an hour-long YouTube video may not be relevant for the course, then it would be helpful to have video players to start and stop at the appropriate place.

Because studying engineering is very challenging for most students, especially when learning the technical content online, the delivery of the course needs to reward self-motivated students with quality content and instruction to keep students engaged in the learning process throughout the engineering program. Taking a long-term strategic view, eventually all engineering courses will be delivered online while ground campuses are for those in the local community who prefer some face-to-face instruction.

In summary, the full-time engineering faculty gained valuable experience in developing content appropriate for online delivery for the first course. The next section describes past experiences on developing and generating the course content. Links to YouTube videos created by the engineering faculty with hyperlinked text or images serve as examples in an attempt to provide a more interactive learning experience for the student. Some videos by Professor Santiago were created leveraging software coming from the internet marketing niche and combined with green-screen techniques. Due to space limitations, only selected internet marketing tools and video creation techniques (e.g. Camtasia) are highlighted as examples based on the department’s experience. Relevant and past experiments are summarized about developing engaging content as well as a number of teaching innovations that was experienced during the last several years.

**Create Interactive Content Using Camtasia and YouTube plus YouTube’s Analytic Engine**

Professor Santiago’s initial and continuing interest is the creation of interactive and multimedia e-books which served the department well in developing the course, Introduction to Engineering. He found software that converted a website having multimedia content into a standalone e-book. However, he quickly discovered that creating the multimedia content takes more time than he anticipated and that the file size of an e-book is very large to download or email during that time. However, with the birth of YouTube and the use of its embedding video feature, the file size of the e-book can be significantly reduced. For example, one set of videos for ‘Introduction to Engineering’ had a file size of 112 Mb for a particular learning module…too large to be sent to IT personnel at Chicago as an email attachment. Uploading the videos on YouTube and
embedding them within PowerPoint slide resulted in a file size of 1.2 MB. Using this technique results in about a 93-fold file size reduction which is small enough to email as an attachment. The embedded video technique can be adapted to provide personalized instruction for those students who request help through email.

Professor Santiago’s educational efforts on YouTube also led to publishing a reference book in circuit analysis\(^2\). During 2012, a literary agent contacted him after the agent researched and discovered Professor Santiago’s YouTube videos leading to publishing his book in April 2013. Future plans include producing a similar book having multimedia or a video-centric companion website. Based on this experience, course exercises could include students to upload YouTube videos about their laboratory experiments or capstone project. These videos can be used later as part of their electronic portfolio as they complete their engineering program.

Professor Santiago also investigated on the use of Adobe Acrobat. Unfortunately, he discovered Adobe pdf books currently do not allow embedded YouTube videos. Although, there is some third-party widget software that allows the integration, it requires more technical expertise to integrate the YouTube videos into pdf formatted books but is not particularly visually pleasing and user friendly when integration is completed. However, there is third party software, which converts a pdf into a digital flipbook that allows an instructor to insert online videos from either YouTube or Vimeo. Professor Santiago experimented only with the text-based version which functioned well online and is visually pleasing. Links to YouTube or other video websites can be inserted into the text-based flipbook since the digital flipbook that features embedded YouTube or Vimeo videos is more expensive. The multimedia digital flipbook with embedded online videos will be investigated and tested in the future which appears to be promising.

After acquiring some skills to develop an interactive website back in 2003-2004, Professor Santiago began researching multimedia creation tools from the internet marketing niche. Professor Santiago learned that entrepreneurs who are using videos to promote internet marketing or other affiliate products have been using Camtasia produced by TechSmith. The tool became one of the first and must-have video creation and video editing tool for Professor Santiago. For those who are not familiar with Camtasia, it’s basically both a video screen capture and video editing software that has many features to promote viewer engagement. Recently, other popular video editing software began incorporating this screen capture feature as well. However, Camtasia was originally targeted for the educational marketplace and evolved from being a program for software demonstrations back in 2005 to a full-featured educational tool in 2015. Despite the large number of current features, its learning curve is manageable based on faculty use of Camtasia. Table 2 lists key educational benefits & features of Camtasia, appropriate for keeping the learner attentive and establishing an interactive dialog with video. Performing screen capture with Camtasia has the advantage of requiring a relatively small initial capital investment and logistics when compared to a video recording studio.

Using keyword search tools from Google, Professor Santiago found that circuit analysis was frequently queried and there were few pages and video content (if any) on this subject at that time. He then experimented and developed videos in support of a first course in circuit analysis and a first course in differential equations (which is a prerequisite for a second course in circuit analysis involving ac circuits with capacitors and inductors).
Interestingly, Professor Santiago discovered that the recorded videos covering key concepts required approximately ten hours of recorded videos for each course. Based on this information and for analytically-based courses, about one hour of video recordings are needed each week to cover key concepts for the 11-week course. This makes sense and is consistent with CTU’s engineering face-to-face teaching philosophy. In other words, most of the face-to-face time in a traditional ground classroom setting is spent doing more practice in solving problems or hands-on lab activities. This led to the idea for online chat sessions dedicated to addressing student questions based on viewing videos, reading text material, doing lab experiments, and solving homework problems. Moderating the online discussion boards will also supplement the chat session approach to promote more student engagement. In terms of video content, it took only about 8.5 hours of recorded video lectures for ‘Introduction to Engineering’ course having numerous engineering lab activities than circuit analysis. So about 46 minutes of video content per week are needed for the ‘Introduction to Engineering’ course that is primarily laboratory based. Based on the experience of Professor Guo to teaching the laboratory content, she believes that more videos may be needed to provide additional help for students. For online delivery, a problematic issue is helping students troubleshoot their circuits. Hangouts, Skype or video chat sessions with either the instructors or with other students are possible solutions. Another means is the development of a troubleshooting checklist that students need to follow before requesting help from the instructor.

Professor Santiago introduced and taught the basic use of Camtasia to the CTU Engineering Department and made full-time faculty aware of advanced features to keep the learner attentive as they investigate its Camtasia’s features while developing the content for the course ‘Introduction to Engineering’.

Table 3 provides a high-level analytics summary of selected and experimental YouTube Channels. Experimental Channels 1 and 2 are personal channels of Professor Santiago and Channel 3 was created for the CTU engineering department (STEM Videos for the Flipped Classroom). In general, more videos with engaging content, results in more subscribers. Also, it takes time to build a subscriber list. Channel 3 was created during March 2015, but initial

Table 2. List of Key Features in Camtasia & Educational Use

<table>
<thead>
<tr>
<th>Camtasia Feature</th>
<th>Description</th>
<th>Educational Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Hot Spots</td>
<td>Students can choose a particular learning path and interact with video by clicking on buttons or characters.</td>
</tr>
<tr>
<td></td>
<td>Add-in to PowerPoint</td>
<td>Screen Capture of PowerPoint Presentation delivered in a micro-learning fashion and combined with cursor highlighter to keep learner attentive.</td>
</tr>
<tr>
<td>b</td>
<td>Ability to Collect and Report Test Scores</td>
<td>Create Quiz and Collect Results via email. Organizes them and sends a daily report of how students are doing.</td>
</tr>
<tr>
<td>c</td>
<td>Multiple video</td>
<td>Keep Learners attentive. Display screen recording inside one window, presenter talking in another and an animation to go along with the screen recording in the third.</td>
</tr>
<tr>
<td>d</td>
<td>Windows or Tracks removal</td>
<td>Overlay videos to create interesting learning scenarios. Need to avoid too many moving parts that will distract the learner.</td>
</tr>
<tr>
<td>e</td>
<td>Call-outs</td>
<td>Can be used to call attention to the learner on a key concept or call-to-action. Like calling attention to the learner on an area on the video.</td>
</tr>
<tr>
<td>f</td>
<td>Cursor highlighter</td>
<td>Can be used to keep interest to follow the animation of a hand-written sketch or text similarly found in a whiteboard presentation. Has potential for a Dopamine effect.</td>
</tr>
<tr>
<td>g</td>
<td>Pan and Zoom</td>
<td>Use to highlight an area of interest in the screen and to create variety in what’s being displayed and keep learner attentive.</td>
</tr>
<tr>
<td>h</td>
<td>Markers</td>
<td>Use to create a table of contents of portions of a long video.</td>
</tr>
</tbody>
</table>
postings of video content for the piloted program began in July 2015. CTU completed the final uploading of videos in March 2016 for the introductory course. Additional related and improved videos were posted afterwards.

The number of subscribers, likes, and dislikes can be used as a preliminary measure of engagement although more studies of other metrics (e.g. ratio of likes/dislikes, average viewer time, ratio of average viewer time/total time, etc.) need further investigation. However, the first and primary effort is the development of multimedia content and the process for online delivery. Data analytics provided by YouTube will be examined in the future to gain more insight about the metrics to improve the student learning experience.

Table 4 lists samples from the engineering department from the four instructors. Since most of the instructors are new to making videos online and using Camtasia, some of its useful software and e-learning tools may not have been used to create more engaging videos. However, the piloted students still felt that there was a right mix of videos and text based on comment 3 of Table 1. Future videos will incorporate the advanced features of Camtasia with Professor Santiago providing advice to other instructors on how to effectively use Camtasia’s advanced features. Although there are some videos using PowerPoint, a majority of the videos in Channels 1 and 2 are based on recordings of writing on a laptop tablet. These recordings can be viewed as

<table>
<thead>
<tr>
<th>Instructor</th>
<th>Topic</th>
<th>YouTube Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jing Guo</td>
<td>Circuit Simplification</td>
<td><a href="https://www.youtube.com/watch?v=HuVZod_jNyY">https://www.youtube.com/watch?v=HuVZod_jNyY</a></td>
</tr>
<tr>
<td></td>
<td>Digital Circuit Simplification</td>
<td><a href="https://www.youtube.com/watch?v=dKLfukK2zw">https://www.youtube.com/watch?v=dKLfukK2zw</a></td>
</tr>
<tr>
<td>Pamela Hoffman</td>
<td>Digital Circuits</td>
<td><a href="https://www.youtube.com/watch?v=YLE-IUDSM_A">https://www.youtube.com/watch?v=YLE-IUDSM_A</a></td>
</tr>
<tr>
<td>Kathy Kasley</td>
<td>IC Manufacturing</td>
<td><a href="https://www.youtube.com/watch?v=5DOrRS8jsso">https://www.youtube.com/watch?v=5DOrRS8jsso</a></td>
</tr>
<tr>
<td></td>
<td>General Number Representation</td>
<td><a href="https://www.youtube.com/watch?v=XpATuhF7zPE">https://www.youtube.com/watch?v=XpATuhF7zPE</a></td>
</tr>
<tr>
<td>John Santiago</td>
<td>Summary of Circuit Analysis</td>
<td><a href="https://www.youtube.com/watch?v=3DoQbYPAa0">https://www.youtube.com/watch?v=3DoQbYPAa0</a></td>
</tr>
<tr>
<td></td>
<td>Animation Humor – Crazy Scientist</td>
<td><a href="https://www.youtube.com/watch?v=BGp2fNRL1xo">https://www.youtube.com/watch?v=BGp2fNRL1xo</a></td>
</tr>
</tbody>
</table>

Table 4. Sample and Initial Videos from CTU’s Engineering Faculty
whiteboard or scribed videos which are popular and uploaded to YouTube during 2008. Videos in Channel 3 are done mostly in PowerPoint. Professor Santiago’s content consists of embedded YouTube videos and a mix of recorded PhET simulations, MATLAB/Simulink demonstrations, Algodoo and live videos. Some of the videos use green-screen techniques and kinetic text. There are also character animations found in Channels 1 and 2 as well at the IEEE CTU Student Branch Website.

In addition, the next section explains some scientific and psychological explanation on why whiteboard or scribe videos which is like doodling disguised as deep thinking are effective for instruction\(^9,10\). Results of sample whiteboard videos in YouTube are also described in the next section.

**Whiteboard (or Scribe) Videos and the Dopamine Effect**

Smy’s\(^9\) video blog shows Wiseman’s research explaining how scribe or whiteboard videos gain and hold attention as well as preliminary data shown back in Table 4. Table 5 shows the results from some of Professor Santiago’s popular videos. Whiteboard videos put people in a better mood rather than having the audience view a PowerPoint presentation reading all that text.

The reason why whiteboard videos are effective is based on the Dopamine effect mentioned and explained by Richard Wiseman in Smy’s blog article\(^9\). That is, whiteboard videos stimulate viewer anticipation. It’s like a crowd gathering around a street artist to figure out what is being drawn. Watching the image in a scribe video begin to emerge stimulates the brain. As the sketch is being drawn, the brain anticipates its final form. When the final form is exposed, the brain experiences a surprise releasing Dopamine. A sudden chemical release of Dopamine allows the viewer to experience pleasure which in turn increases engagement of the viewer.

<table>
<thead>
<tr>
<th>Video Title/Link</th>
<th>Date Uploaded</th>
<th>Number of Views</th>
<th>Likes</th>
<th>Dislikes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Signal Processing Tutorial: Discrete-Time Convolution Examples (Inverse z-Transform) <a href="https://www.youtube.com/watch?v=y2V3xW8YfzQ">https://www.youtube.com/watch?v=y2V3xW8YfzQ</a></td>
<td>20 Apr 2008</td>
<td>28,905</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>5. Simulink / Matlab Video Tutorial and Example - Low Pass Filter - Bode Plots (Part 2) <a href="https://www.youtube.com/watch?v=Ehb0E_i0bMk">https://www.youtube.com/watch?v=Ehb0E_i0bMk</a></td>
<td>3 Jul 2009</td>
<td>202,657</td>
<td>181</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 5. Sample Videos Using Camtasia
For engineering topics, the whiteboard video if done and delivered correctly will offer students an opportunity to experience an ‘aha’ moment when solving a problem as they proceed through the video. The whiteboard video essentially provides a near face-to-face experience simulating a face-to-face instruction. It’s as if the student has an over-the-shoulder professor guiding a complex problem throughout the process. Table 5 lists sample videos of whiteboard and PowerPoint presentations using animations as well as recordings based on Matlab/Simulink, PhET and Algodoo simulations.

The whiteboard videos can lose its Dopamine effect as with any teaching mode of delivery when the element of surprise or anticipation is diminished. So judicious use of the whiteboard video should be considered. That’s why other video types or other multimedia content should be mixed in with whiteboard type videos when delivering the content throughout the course. For example, in a face-to-face classroom setting, the instructor can use PowerPoint to save time in drawing figures and explain concepts during class, then use either Matlab/Simulink demos or a whiteboard to either emphasize a concept or address a student question. This diverse instruction for the face-to-face student can be translated to mixing content types, various video types, and different interactive assessment tools to help online students become more engaged in learning.

Today, there are internet marketing and affordable software allowing the educator to create professional-looking whiteboard sketch videos within minutes. Today’s software allows the educator to use green-screen techniques mixing video backgrounds in high-definition, kinetic text, 2D/3D cartoon animations and whiteboard sketches. The educator can combine these elements and styles creating a variety of videos. The time-of-investment in doing so is still unclear when compared with the easy screen capture of whiteboard videos. However, providing an original mix of video types will create variety so that the student does not experience the same mode of instruction repeatedly. Variety of appealing video types offers an element of surprise and viewer anticipation. Examples of types of videos with variety (some) that are interactive ones can be found on the following links on YouTube: (1) Video 1 show results, that combines green-screen techniques and video creation tools from the internet marketing niche using Camtasia. During the video is an interactive quiz with an ‘i-icon’ found in the upper right-hand corner with over 40 viewers taking the quiz. (2) Video 2 (Interactive Video Learning) shows sample video with a concluding section (or outro) with embedded hot links on images of the video to give students options to view other videos. You can also include hotlinks to take a quiz. (3) Teaching Innovations is a link of experimental innovations at IEEE CTU Student Branch Website, such as: digital flipbook, drag and drop assessment, and 2D/3D character animations.

**Embedded Videos, Quizzes and Interactive Web Pages in PowerPoint Using Office Mix**

Professor Santiago used a series of embedded YouTube videos in PowerPoint along with quizzes to create a seamless delivery of multimedia content without jumping between the YouTube website and PowerPoint application. Figure 3 provides a flowchart as an example of this approach when an online student downloads the PowerPoint slides.

Also, Figure 3 shows a ‘Table of Contents” found on slide 2 so students can have an option to select a subset of the 45-slide learning module if portions of the presentation is already familiar or seen earlier by the student. With the latest and recent add-in by Microsoft, called Office Mix, the instructor can also embed the quizzes or review questions in the PowerPoint learning module.
Microsoft developed Office Mix for the education market since most lessons and lectures are delivered by educators using PowerPoint. Office Mix can be viewed as a container to embed external apps within a slide. With Mix, Microsoft wants to fill the gap in building the educational content and how the content is being presented and delivered. In this way, the instructor does not need to jump back-and-forth between PowerPoint and the various apps used in the presentation. Mix can take the PowerPoint slides to create a cloud-based and interactive lessons having built-in tests.

Using embedded videos and Office Mix with PowerPoint, offers instructors not only the ability to present their material in engaging ways but to deliver online content through email for those students who need more personalized instruction. Microsoft provided online help for the educator to get started through their gallery on the Mix site containing a series of tutorial Mixes, which can be viewed online, or downloaded and played on a wide range of devices.

After installing the Mix plug-in, the educator will find a new Mix tab in the PowerPoint ribbon. Figure 4 is a screenshot after embedding an application on the slide using the Mix add-in. The figure shows one of the interactive PhET simulation models embedded onto the slide. The authors envision that more apps will be developed that’s compatible with the Office Mix add-in. In the future, it may be possible that a cloud-based Matlab/Simulink, Labview or Pspice may be in the works that can communicate with this relatively new add-in.

Conclusion

CTU’s engineering department successfully created engaging multimedia content to deliver an online course, ‘Introduction to Engineering’ in support on an Online Flipped Classroom. Also, preliminary results show the online flipped classroom as defined by CTU has promise once the multimedia content has been integrated into CEC’s LMS and adaptive learning (AL) system software. Base on the student feedback during the past year, there was a good mix between online video, text content and lab activities. The full-time faculty gained valuable experience and insights producing multimedia content. The engineering department anticipates the development of future courses will result in shorter timelines as more online courses are implemented in the future. A number of teaching innovations have been presented leveraging technologies coming from the internet marketing niche to create and deliver interactive and
multimedia content. The interactive features of Camtasia, the Microsoft’s Office Mix plug-in and the advancement of video players embedded on websites offers opportunities for instructors to rethink their delivery online in creative ways. Although the CTU full-time faculty learned how to develop technical content for online learners, there is still much to learn. The paper and its results attempts to help motivate STEM instructors explore with even more creative ways in delivering their content online. Learning engineering is already a challenge for most self-motivated students. So why not serve and reward them with engaging and interactive content that enriches their learning experience.

References

5. Guo, Jing and John Santiago, Flipped Classroom Method in Teaching ‘Introduction to Engineering’ Course Online, 2016 ASEE Rocky Mountain Section Conference, Cedar City, Utah, 2016

Biographical Information

Professor John Santiago teaches courses in electrical, computer and systems engineering after retiring from the USAF with 26 years of service in 2003. He began teaching at CTU the following year. His interests includes: interactive multimedia for e-books, interactive video learning, and 3D/2D animation. Professor Santiago recently published a book entitled, “Circuit Analysis for Dummies” in 2013 after being discovered on YouTube. Professor Santiago received several teaching awards from the United States Air Force Academy and CTU. Last year, he was awarded CTU’s Faculty of the Year for Teaching Innovations. Professor Santiago has been a 12-time invited speaker for celebrating Asian-Pacific American Heritage Month.

Dr. Jing Guo is a Professor in Engineering College at Colorado Technical University. She is the course director in circuits and electronics area. She taught variety of underrated and graduate courses including capstone design in Electrical and Computer Engineering area. She worked as Subject Matter Expert (SME) of “EE110 Introduction to Engineering” Online Course Development.
Comparison of Traditional Face-to-Face and Online Student Ratings of Two Online Delivered Engineering Technical Electives

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Abstract

Arizona State University delivers one of only two ABET-accredited, fully online baccalaureate degree programs in electrical engineering. This paper reports on the melancholy reception by traditional face-to-face students who enrolled in the online version of the courses, whereas the online students were pleased with the course and instructor as gauged by student evaluations. In some instances, reduced course and instructor ratings appear to be due to the online course being offered in accelerated terms, while other data indicates that the decreased acceptance may be traceable to lower course grades. In the latter case, the lower course grades may be attributable to students needing to adjust to online course delivery.

Keywords

Course length, student evaluation of instruction, online course.

Introduction

At the time of writing of this paper, there are only two ABET accredited fully online electrical engineering (EE) programs in the U.S., specifically, a bachelor of science in engineering (BSE) degree is offered by Arizona State University (ASU), and a bachelor of science (BS) degree is offered by Stony Brook University. As part of the development of two courses for the ASU online EE program, the recorded classes were initially deployed in half-semester long terms to both the online students and the traditional on-campus students. While the online students were accustomed to such accelerated terms and the Internet delivery, the traditional face-to-face students were not. This paper will report on the results of an inadvertent experiment resulting from the offerings of these two senior-level engineering technical electives. The end-of-the-course teaching evaluations completed anonymously by students are used to compare student perceptions about the course itself and the instructor.

Literature Review

There have been studies on the effect of class size, and course term length on student evaluations of instruction; however, there seems to be limited data with respect to the impact of course length.

Class Size: In 1984, Feldman presented data from 52 different studies and found a very weak inverse relationship between class size and the students’ overall evaluation of the course and its instructor. Bedard and Kuhn examined the impact of class size on student evaluations of instructor performance for all economics classes at the University of California, Santa Barbara.
from fall 1997 to spring 2004. They found that as class size increased, students gave decreasing ratings to the instructors.

Course Term Length: Rayburn and Rayburn investigated the span of classroom contact on student performance in a management accounting course. They found that students in the 16-week offering performed better on exam problems than those in the 8-week class, except that no significant difference existed with respect to the points earned on multiple-choice questions. In contrast, Anastasi found that academic performance was similar in summer and full-semester length courses, with instructor ratings being comparable also. Shaw et al. found no statistical difference in student achievement or engagement between six abnormal psychology online courses with half being taught in a 16-week semester while the other half were taught in an 8-week term. Interestingly, Austin and Gustafson examined a database of over 45,000 observations from fall, spring and summer terms from all classes at the University of West Georgia from spring 2001 through summer 2004. They found that intensive courses result in higher grades than traditional 16-week semester length course and that these higher grades reflect a real increase in knowledge, and they observed that the improvement benefit peaks at about 4 weeks.

Present Study

This study presents results from the offerings of two different senior-level engineering technical electives taught by the same instructor:

1. EEE 460 Nuclear Power Engineering, and
2. EEE 463 Electrical Power Plants.

The first fully online offerings of these two courses were made in 2015, with the second offering having already transpired for EEE 460 (the second offering of EEE 463 is presently occurring in summer 2016). The current fully online versions of the courses are produced in a recording studio using a green screen backdrop with only the instructor and producer present. Earlier Internet versions of the courses were recorded in a lecture room in front of on-campus students, and afterwards, streaming video was posted for graduate students in an online master’s degree program. The present offerings overlay the instructor on top of the PowerPoint slides as shown in Figure 1. The lectures include closed captioning and are accessed via the Blackboard portal, which provides a discussion board and a platform for homework submission.

Essentially, there are four cohorts of students within each course:

1. UGF2F: on-campus hybrid (normally face-to-face) undergraduate students,
2. GRF2F: on-campus hybrid (normally face-to-face) graduate students,
3. UGON: online undergraduate students, and
4. GRON: online graduate students.

A comparison of the demographics of the online and on-campus undergraduate students is given in Table 1. A significant difference is that the online students are likely to be more mature, based on their average age and percentage of veterans in the population.
It is noteworthy that all students viewed the same online recordings, took identical exams, and completed the same homework assignments. The on-campus students enroll in the hybrid version of the course which simply means that the midterm and final exams are administered to the group at a preset time in an on-campus classroom setting, and they potentially have the benefit of face-to-face access to the instructor during office hours. For the online students, the university has contracted with ProctorU, which is a live remote proctoring service that monitors the students using their webcam during the exam period and while the students upload written exam solutions to Blackboard. All students have access to the instructor via email, telephone and the discussion board. In the first semester, the online students were also offered the option of online office hours with the instructor via web conferencing software (Adobe Connect), but remarkably, not a single student took advantage of the opportunity.

The initial online offerings of these courses are summarized in Table 2. Although there was a one week difference in the length of the first EEE 460 offering in 2015 and the online
undergraduate students took the course in summer rather than spring, all other aspects were identical (including the exams). The fact that the second offering of EEE 460 in spring 2016 was over the full 15 week semester was motivated by the initial findings presented in this paper (specifically, that the accelerated nature of the course was too demanding for the on-campus students).

Table 2. Initial Online Course Offerings

<table>
<thead>
<tr>
<th>Course</th>
<th>EEE 460</th>
<th>EEE 463</th>
</tr>
</thead>
<tbody>
<tr>
<td>Term</td>
<td>Spring/Summer 2015</td>
<td>Spring 2016</td>
</tr>
<tr>
<td>Course length</td>
<td>7 or 8 weeks†</td>
<td>15 or 7 weeks‡</td>
</tr>
<tr>
<td>Enrollment at end of course (such that the students were sent the course survey)</td>
<td>50</td>
<td>69</td>
</tr>
<tr>
<td>Undergrad Hybrid</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>Undergrad Online</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Graduate Hybrid</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Graduate Online</td>
<td>79</td>
<td>93</td>
</tr>
<tr>
<td>Total</td>
<td>3</td>
<td>11</td>
</tr>
</tbody>
</table>
| Student withdrawals* | † The 8-week summer 2015 term was comprised of the undergraduate online students while the 7-week spring 2015 session included the other three cohorts.‡ The 7-week spring 2016 session consisted of the undergraduate online students whereas the 15-week spring 2016 semester included the other three cohorts.
|* The students withdrawing from the course are not included in the enrollment totals.

Student Evaluation of Course and Instructor

At the end of each course, students are asked to complete an anonymous survey about their opinions of the course itself and the instructor (the entire questionnaire is given in the Appendix). There are seven questions related to course evaluation, with the scale ranging from 2 (poor) to 5 (very good). There are nine questions probing the instructor’s teaching effectiveness (scale of 1 to 5). In addition, a single question asks about the overall quality of the course and instruction, and each student is also asked to rate herself/himself as a student in the course. The surveys are completed prior to final course grades being posted to student transcripts.

For the past decade (2005-2014), the author’s average teaching evaluation in these two courses was 4.78 ± 0.13 and the average rating of the two courses was 4.49 ± 0.17; however, the initial offerings of these two courses in 2015 saw a noticeable drop in these values as seen in Figure 2. This decrease motivated the present investigation. Several hypotheses for the drop are possible, including that the faculty member is just not as effective behind a camera; however, the author has been teaching with a recording camera in the classroom since 1989 (which might mean the instructor is just getting older).

EEE 463 Survey Results

The survey results from the EEE 463 course are presented first as that class was the most uniform in terms of the alignment of all the students in the same term but the data are from just a
single offering (as noted above, the second offering is presently occurring in summer 2016). In particular, from 2005 to 2014, the average instructor and course ratings were 4.74 ± 0.11 and 4.48 ± 0.21, respectively, whereas for fall 2015, those scores were 4.38 and 3.85. Thus, the instructor and course scores were about 3σ below the normal. The EEE 463 course has been taught fourteen times by the author since Fall 1993, but he did not teach the course in 2012–2014 (except for replaying lectures to online graduate students in 2012 and 2014), leading to a gap (observed in Figure 2) which might explain the drop in ratings, but a more detailed examination of the data was undertaken.

![Figure 2. Composite instructor and course ratings.](image)

Congruent with the standard deviation quoted above, Figure 3 shows that the instructor ratings are rather consistent except for the undergraduate on-campus rating in 2015. This indicates that only one—but the largest population—of the four cohorts was less satisfied with the instruction as compared to historical trends. This conclusion is further supported by Figure 4, which shows that only the on-campus cohort gave the course a reduced rating compared to the historical trends. The unhappiness of the on-campus students really reveals itself in the 2.87 overall rating of the course and instructor compared to the online student value of 4.75 (nearly a 2 point difference).

In the case of the undergraduate on-campus students, the amount of work in the accelerated terms seems to be the primary contributing factor to the student dissatisfaction with the course and to a lesser extent the instructor. The premise that the reduced ratings of both the instructor and course are strongly tied to the length of the course is further substantiated by open-ended on-campus undergraduate student comments such as “this amount of material in a half semester is crazy!!”. In fact, 7 of the 9 open-ended comments by the on-campus undergraduates complained about the doubled pace of the course; however, none of the online undergraduates made such a comment as the online undergraduate students are accustomed to 7.5-week terms and they are a
decade older than the on-campus students giving rise to other conjectures such as the online cohort being better time managers.

![Figure 3. Student evaluations of EEE 463 instructor by cohort.](image)

![Figure 4. Student evaluations of EEE 463 course by cohort.](image)

The challenging nature of the course is also exhibited by the number of withdrawals from the class. Of the 19 student withdrawals (see Table 2), 18 were on-campus undergraduates and the other student was an online undergraduate (i.e., 21% versus 6%, respectively). The final grade averages of the students are compared in Table 3. The correlation coefficients between the median final score and the instructor and the course ratings were 0.60 and 0.76 using the four
data of the cohorts. Focusing upon the undergraduate students, the final average of the online students was 6 points higher than the on-campus undergraduates, and the distribution spread was wider for the latter group. Other studies have found a positive correlation between grades and evaluations of courses and instructors. Thus, the lower grades may explain the lower ratings by on-campus students.

Table 3. Statistics of Student Overall Final Averages in the EEE 463 Course

<table>
<thead>
<tr>
<th>Cohort</th>
<th>Undergrad Hybrid</th>
<th>Undergrad Online</th>
<th>Graduate Hybrid</th>
<th>Graduate Online</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>70.3 ± 18.3</td>
<td>76.3 ± 11.3</td>
<td>84.0 ± 8.6</td>
<td>77.3 ± 19.9</td>
</tr>
<tr>
<td>Median</td>
<td>74.1</td>
<td>79.3</td>
<td>82.4</td>
<td>84.8</td>
</tr>
<tr>
<td>Max / Min</td>
<td>92.0, 0.0</td>
<td>94.5 / 50.2</td>
<td>97.6 / 70.0</td>
<td>92.5 / 54.8</td>
</tr>
</tbody>
</table>

As many seasoned instructors would suspect, some students have a tendency to procrastinate (but rarely do we have access to quantitative evidence). Figure 5 graphs the viewings of the EEE 463 lectures during fall 2015. The plot shows peaks in the number of views corresponding to homework due dates and examinations. The bimodal peaks associated with Homeworks 4 and 7 may be explained as follows. The Thursday that Homework 4 was due was the night of a collegiate (PAC-12) football game at ASU such that some students may have been compelled to finish the assignment a day earlier in order to attend the game. The day before Homework 7 was due was a national holiday (Veteran’s Day) giving them a chance to get ahead. An overall reduced number of views in the latter half of the term is expected as a result of the withdrawal of some students from the course.

![Figure 5. EEE 463 lecture plays by all cohorts during the 7.5-week fall 2015 term.](image)

**EEE 460 Survey Results**

Survey data for 2006–2014 reveal that the EEE 460 instructor and course ratings were 4.79 ± 0.15 and 4.54 ± 0.13, respectively. However, the 2015 and 2016 student evaluations for EEE 460 were approximately 2σ below the historical average (which was not as bad as the EEE 463 drop). Figure 6 shows that, similar to the EEE 463 survey results, the on-campus students were
not as happy with the instructor as the online students were. Likewise, Figure 7 shows the on-campus students were less pleased with the course compared to their online counterparts.

Figure 6. Student evaluations of EEE 460 instructor by cohort.

Figure 7. Student evaluations of EEE 460 course by cohort.

A significant difference in these sets of data compared to those for EEE 463 is that the 2015 offering of EEE 460 was in the half-semester term, whereas in 2016 the on-campus students took the online course over the full 15-week semester. Therefore, while the length of the course might be blamed in 2015, these survey results would tend to indicate that something else is
driving the instructor and course ratings down, at least from the on-campus student opinions. Also noteworthy is that the same lecture recordings were used in both 2015 and 2016, such that lecture content cannot explain any variability between 2015 and 2016.

With eight data points (4 cohorts and 2 years), no significant correlation was found between the students’ final median course score and the instructor and course ratings (in contrast to the four data points for EEE 463); see Figure 8. The online delivery was received positively with 3 of the 4 comments from the graduate hybrid section and 2 of the 9 undergraduate hybrid students indicating in open-ended comments that aspect was what they liked about the course in spring 2015. Furthermore, one of the BSE online students wrote that what (s)he liked most was: “Enthusiasm and explanation of the material was absolutely spot on. To hear an instructor say ‘stop and look at my hands’ during a lecture is an absolutely refreshing idea. Really made the experience like attending an actual lecture. Pausing for input, leads to engaging the thought process rather than rambling the material in a monotone voice.”

Although not relevant to survey results, the fact that the 2015 EEE 460 lectures were viewed during two different terms provided the opportunity to compare procrastination trends. Figure 9 and Figure 10 graph the views of the EEE 460 lectures during spring and summer 2015, when in the latter case only the online BSE students were enrolled. Although the online undergraduates were described earlier as more mature (and perhaps better managers of their time), these graphs reveal that lectures were watched by them more frequently when homework is due (it must be noted that some of this peak viewing could be attributed to replays to better understand how to solve the homework).
Discussion

Although this investigation is a work-in-progress some observations regarding student evaluations of the course may be possible. A conjecture is that in the case of accelerated terms, the normally face-to-face students procrastinated and may not have acclimated to the online delivery rapidly enough such that their grades suffered and this consequently led to lower course and instructor evaluations. It became clear from discussions with on-campus students that the lectures are sometimes viewed late at night when their attentiveness is not at its peak, and that
there is a difference between simply viewing the lectures (and perhaps multitasking on other items) versus sincerely watching the videos and taking notes like in a regular classroom setting. Several students mentioned that after the midterm exam, they had to make adjustments in how they were treating the online nature of the course.

The summer of 2016 is presenting a second opportunity to compare all 4 cohorts of students taking the EEE 463 course in the half-semester length version, while fall 2016 will provide the first chance to present the course in a full-semester length format for the on-campus students.

Appendix

The end-of-the course questionnaire consists of the following questions and answer options.

<table>
<thead>
<tr>
<th>Part 1: Student Evaluation of the Course</th>
<th>Response Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Textbook/supplementary material in support of the course.</td>
<td>5. Very good</td>
</tr>
<tr>
<td>2. Value of assigned homework in support of course topics.</td>
<td>4. Good</td>
</tr>
<tr>
<td>3. Value of laboratory assignments/projects in support of the course topics.</td>
<td>3. Fair</td>
</tr>
<tr>
<td>4. Reasonableness of exams and quizzes in covering course material.</td>
<td>2. Poor</td>
</tr>
<tr>
<td>5. Weight given to labs or projects, relative to exams and quizzes.</td>
<td>0. Not applicable</td>
</tr>
<tr>
<td>6. Weight given to homework assignments, relative to exams and quizzes.</td>
<td></td>
</tr>
<tr>
<td>7. Definition and application of criteria for grading.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Part 2: Student Evaluation of Instructor</th>
<th>Response Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. The instructor was well prepared.</td>
<td>5. Almost always</td>
</tr>
<tr>
<td>9. The instructor communicated ideas clearly.</td>
<td>4. Usually</td>
</tr>
<tr>
<td>10. The instructor or assistants were available for outside assistance.</td>
<td>3. 50% of the time</td>
</tr>
<tr>
<td>11. The instructor exhibited enthusiasm for and interest in the subject.</td>
<td>2. Occasionally</td>
</tr>
<tr>
<td>12. The instructor's approach stimulated student thinking.</td>
<td>1. Almost never</td>
</tr>
<tr>
<td>13. The instructor related course material to its applications.</td>
<td></td>
</tr>
<tr>
<td>14. The instructor's methods of presentation supported student learning.</td>
<td></td>
</tr>
<tr>
<td>15. The instructor's grading was fair, impartial, and adequate.</td>
<td></td>
</tr>
<tr>
<td>16. The instructor returned graded materials within a reasonable period.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Overall Evaluation of the Course and Instructor</th>
<th>Response Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>17. Overall quality of the course and instruction.</td>
<td>5. Excellent</td>
</tr>
<tr>
<td></td>
<td>4. Very good</td>
</tr>
<tr>
<td></td>
<td>3. Good</td>
</tr>
<tr>
<td></td>
<td>2. Fair</td>
</tr>
<tr>
<td></td>
<td>1. Poor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>General Information</th>
<th>Response Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>19. Is this a required course in your program of study?</td>
<td>Yes/No</td>
</tr>
<tr>
<td>20. What are the average hours/week spent studying for this course?</td>
<td>1; 2; 4; 8; 16</td>
</tr>
<tr>
<td>21. What is your class standing?</td>
<td>Grad student; Senior; Junior; Soph; Freshman</td>
</tr>
<tr>
<td>22. What % of the class meetings have you attended?</td>
<td>10–29; 30–49; 50–69; 70–89; 90–100</td>
</tr>
<tr>
<td>23. What did you like most about this course?</td>
<td></td>
</tr>
<tr>
<td>24. What did you like least about this course?</td>
<td></td>
</tr>
<tr>
<td>25. Comments</td>
<td>Free-format, open-ended textual essay</td>
</tr>
</tbody>
</table>
References


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Improving the Socratic Method of Teaching Through the Use of Interactive Lecture Experiences

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Brigham Young University

Abstract

It has been said that the most effective teachers use class time to help students think about information and ideas the way scholars in the discipline do. To this end, some use a Socratic Method to facilitate deeper thinking during class time. The implementation of a Socratic education model seeks to increase cooperative argumentative dialogue between individuals through the asking and answering of questions to stimulate critical thinking. Unfortunately, teachers are in constant competition with distractions face by students in the classroom. Increasingly, these distractions come from electronic devices. The purpose of this paper is to demonstrate how interactive lecture experiences can improve the Socratic method of teaching. This may be accomplished through the electronic devices that ironically often act as detractors from learning. This study reports the positive benefits that can be gained from the use of real time, electronic, interactive questioning in the classroom. However, it will also provide the disadvantages of opening the classroom to the use of these tools. Topics such as passive and active learning, virtual discussion boards, anonymous instant feedback, and in-class electronic testing will be discussed. Outcomes of these interactive lecture experiences from use in actual classroom and workshop settings will be given. This study adds to the body of knowledge by giving real solutions to challenges faced by teachers confronted with distracted and disengaged students. The findings of this study will help teachers improve the way they engage students, assess learning, and improve presentation of class materials. This paper also serves as an example of how interactive polling software can be used to enhance classroom discussion.

Keywords

Socratic Method, Interactive Polling, Blooms Taxonomy

Introduction

The Socratic method of teaching has been around as long as there have been teachers to teach. Modeled after the philosopher Socrates, this method focuses on providing the student with questions, not answers. Ability is then gained through a focus on reasoning and disciplined thought (Paul et al. 1997). Over the years this method of learning has change very little, a Socratic questioner would seek to keep a focused discussion that is intellectually responsible using probing questions, periotic summaries, identification of what has not been discussed; all while trying to draw as many students as possible into the discussions (1997). “In a twenty-first-century classroom, no one person should ever be in control. The learning space should be one of inclusive ideas, inviting all parties to bring something valuable to the conversation. Once the
culture for learning is established, the teacher’s role is more of facilitator rather than ‘sage on the stage,’ blending in more readily with the learning that is happening in the classroom.” (Sackstein 2015).

One twenty-first century issue that a teacher must deal with is the issue of technology. Students have an increasing amount of access to the distractions of technology. It becomes the challenge of the twenty-first century teacher to either embrace technology or fight against it. This research study was performed to look at one possible way to embrace the use of technology in the classroom and use it as a tool to improve the Socratic method of teaching. The theory is that: “Technology is a necessary friend and tool to these explorers of new learning. Teachers shouldn’t fear it, but rather embrace it and meet students where they are. Students of the twenty-first century require flexible environments with ever growing capacities.” (Sackstein 2015). This paper discusses some of the observed advantages and disadvantages of using a technology enhanced interactive lecture experience in the classroom.

**Methodology**

This paper follows the use of interactive questioning using technology in three settings; the first is in a school classroom of over 40 students, the second a training session of over 50 industry professionals, and the third is a small training session of 10 individuals. The observations of advantages and disadvantages involved with using this method may change among the studied groups. In all three cases the software used in the interactive questioning was Poll Everywhere. Multiple interactive questioning tools exist, each with differing costs and capabilities. Poll Everywhere was used because it meets the most basic functions of interactive questioning and using the basic program is free of cost. Interactive questioning allows for the instructor to project an image or question on the screen and have students interact with that image through the use of a basic cell phone, a smart phone, tablet, or laptop computer. The interaction engages the audience or classroom in real time with continuous updates to the screen.

The findings of the study are mostly observational; therefore, a qualitative method of analysis was used. However, there are a few quantitative methods used; one of the findings of this study is that it is simple to collect data from the study group using these interactive questioning tools. This data was then used to make basic quantitative observations. Descriptive statistics, however, are missing from the data set. For this circumstance inferential techniques are used to come to conclusions about the population (Vogt 2007).

**Findings**

In general, it was observed that the use of interactive questioning using the polling software Poll Everywhere was very effective. The authors feel it improved the environment of teaching by improving the aims of the Socratic method. Namely, keeping a focused discussion that is intellectually responsible using probing questions, showing the level of understanding in the group with questions and periotic summaries, identifying what is not fully understood, and drawing as many students as possible into the discussions. There were obvious advantages to using this method of interaction, but along with these there were disadvantages identified as well.
The level and effectiveness of classroom interaction was affected by the effectiveness of the questions being asked. Blooms Taxonomy is often used to develop questions that improve learning objectives (Bloom 1956, Anderson et al. 2001). Questions can be asked at a most basic level where the end objective is an ability to recall a specific answer. Figure 1 gives an example of the level questions in Blooms Taxonomy. Questions to the three groups used in the study were often at the most basic level. They were questions used to determine if the group understood a certain concept. This was useful in that the instructor could assess the current level of understanding and adjust the teaching according to what was needed. It did not, however, lead to in-depth discussions and what would be considered deeper learning brought about by analyzing, evaluating and creating as demonstrated in Figure 1.

An example of how interactive questioning can guide the direction of the discussion is the use of an introductory or gateway question. In each of the classroom settings participants were asked to answer a self-assessment question. The question in this case was: “How would you rate your understanding of CPM scheduling?” The results were shown on the screen in real time and a general feeling of how the group felt they understood the topic was observed. This was unanimous so students didn’t feel pressured to answer a specific way. After the gateway question, a question demonstrating a level of understanding was provided. In this case students were asked to identify the number of float days that could be used by an activity. A CPM schedule was provided which would give anyone with experience in CPM scheduling the ability to answer the question easily. The right answer was then provided. What was interesting to note was the level of confidence among the groups questioned. The small group of industry professionals rated themselves fairly low in their understanding of CPM scheduling. The results to the basic question also showed that they did in fact need a refresher in CPM. It should be noted that it was the purpose of this group to receive CPM training. The group of university students showed a moderate understanding of CPM in their self-assessment; this was met by a greater percentage of participants that were able to answer the follow up questions correctly. The large group of industry professionals rated their understanding of CPM as very high, but in contrast, not a single individual was able to answer the follow-up question correctly. The instructor was then able to teach according to the level of need, and the students became more self-aware of their own ability.
Another example of using questioning to assess the level of understanding can be seen in Figure 2. Here instruction had just been given as to how the view through an auto level could be used to estimate the distance of rod being read. The students were asked to indicate how far away the rod was by clicking on an image on their smart phones, tablets or PC computers. Their answers were hidden until all had indicated and the image in Figure 2 then showed the answers. Both the students and the teachers could immediately identify how well the student understood this concept. This guided the direction teaching, further questions, and discussion needed.

One benefit of using interactive questioning is the creation of visual content specific to the individuals currently in the classroom. In each of the classroom settings the question was asked: “What is the purpose of a schedule?” The students could then type in an answer and this would be automatically populated on the screen. There are many options for how this could be populated. In Figure 3, a word cloud was used. Using this method, there is an automatic visual that can facilitate the beginning of an in-depth discussion of the topic. In the example of the word cloud, a limitation would be that the visual only populates one word, and its size in the visual is based on the number of times it is submitted by the students. When using this type of questioning a word cloud may be best when you ask participants to use one word to describe something.
What is the purpose of a schedule?

![Figure 3. Word Cloud for Schedule Purpose](image)

A powerful tool was used in the large industry professional setting that allowed the instructor to gather information about the participants in the room. In this instance participants were asked about the location of the project they were working on. Figure 4 shows these locations. The instructor was able to use this information to improve the discussion in this case to include discussions involving international topics and applications relevant to those areas.

![Figure 4. Descriptive Questioning](image)

As a part of the classroom experience, and in anticipation of this paper, participants were asked about their experience using this form of questioning. Figure 5 gives the results of this survey. The majority of the participants felt that using the interactive questioning improved learning. Thirty-four percent, however, did not think it improved learning. Some of the reasons for this are discussed later in the paper.
When asked about the advantages of using interactive questioning, the participants responded with a variety of observations. Table 1 provides the identified advantages along with the response rate. In this case, students can add their own response or vote on the response of others if they agree with what another student has written. This type of questioning and response allows can allow for improved interaction with students and can be helpful in identifying where the discussion could go. A teacher could ask a question such as “What topic would you like to review today?” Students could then begin to list topics they need help on or vote for topics that others identified. The topic with the highest priority could then be selected for further discussion.

Table 1. What advantages do you see to using interactive polling in a lecture?

<table>
<thead>
<tr>
<th>Response rate</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Fun!</td>
</tr>
<tr>
<td>6</td>
<td>Not afraid to make mistakes</td>
</tr>
<tr>
<td>5</td>
<td>I can steal my answer</td>
</tr>
<tr>
<td>5</td>
<td>It keeps my mind stimulated and engaged</td>
</tr>
<tr>
<td>5</td>
<td>Attention grabber</td>
</tr>
<tr>
<td>5</td>
<td>Each person is engaged, unlike a discussion where only one person can talk at a time.</td>
</tr>
<tr>
<td>4</td>
<td>Everyone can work out problems</td>
</tr>
<tr>
<td>4</td>
<td>Answers can be biased to what everyone else says</td>
</tr>
<tr>
<td>4</td>
<td>Funny responses</td>
</tr>
<tr>
<td>4</td>
<td>Fun to interact</td>
</tr>
<tr>
<td>4</td>
<td>It encourages participation and engagement in the questions</td>
</tr>
<tr>
<td>4</td>
<td>Very involved</td>
</tr>
<tr>
<td>4</td>
<td>I don’t fall asleep</td>
</tr>
<tr>
<td>4</td>
<td>More interaction</td>
</tr>
<tr>
<td>3</td>
<td>I get a chance to work the problem out myself first</td>
</tr>
<tr>
<td>3</td>
<td>I can see how well I understand the problem compared to other students</td>
</tr>
<tr>
<td>2</td>
<td>I have to think</td>
</tr>
<tr>
<td>1</td>
<td>Teacher can know who has an idea of what is happening in class</td>
</tr>
</tbody>
</table>
In addition to the advantages noted above, the participants also identified disadvantages to using interactive questioning. Table 2 identifies some of the disadvantages. One of the most obvious disadvantages was that students could write whatever they want. Evidence of this can be seen in the responses given such as “Bingham is the man!” and “YOU CAN Write Whatever YOU WAAAAAAANNNNNNNNTTTTTTT.” Participants are not held personally responsible for their answers and this could lead to some potentially embarrassing moments. Although there are ways to reduce this type of feedback through the use of a monitor that approves the postings; it adds one more thing to worry about. Answers used in this format are associated with a specific student; however, the more advanced software platforms do allow for tracing of responses by participant and even grading based on the response.

Table 2. What Disadvantages do you see to using interactive polling in a lecture?

<table>
<thead>
<tr>
<th>Response rate</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Bingham is the man!</td>
</tr>
<tr>
<td>6</td>
<td>It is hard to take it seriously, especially when your answers are not graded</td>
</tr>
<tr>
<td>3</td>
<td>People are anonymous so they act dumb</td>
</tr>
<tr>
<td>3</td>
<td>YOU CANT Write Whatever YOU WAAAAAAANNNNNNNNTTTTTTT</td>
</tr>
<tr>
<td>3</td>
<td>Limited time to think of the answers</td>
</tr>
<tr>
<td>2</td>
<td>You can fall behind</td>
</tr>
<tr>
<td>2</td>
<td>My phone does not work</td>
</tr>
<tr>
<td>2</td>
<td>Low battery</td>
</tr>
<tr>
<td>2</td>
<td>Easy to slack off</td>
</tr>
<tr>
<td>2</td>
<td>You can steal answers</td>
</tr>
<tr>
<td>2</td>
<td>Easily Distracted</td>
</tr>
<tr>
<td>1</td>
<td>It drives the speed of the lecture</td>
</tr>
<tr>
<td>1</td>
<td>Technical difficulties</td>
</tr>
</tbody>
</table>

Some top disadvantages of using interactive polling, is the idea that if questions are unanimous, there is no incentive to take it seriously. With the three groups tested in this study, each used the questions as a sounding board for jokes or funny comments. Even in the most professional environment of industry professionals, the interactive lecture was often derailed by off topic comments or answers. Users of these technologies need to be aware of this issue and manage the amount of distractions they allow. This could be done by establishing early the culture of the learning environment, through monitoring by TA or helper, or using software that identifies the participant and creates accountability. In any case, feedback from class participants can be helpful in assessing the amount of learning that is taking place.

In a classroom traditionally run as a lecture, one of the authors of this paper dedicated the whole class period to interactive questioning. This was used to assess understanding of some difficult mathematics problems, identify and teach in the areas needed, and observe the learning experience. Figure 6 gives a summary from the students’ view in this lecture. The word cloud gives insight into some of the advantages and disadvantages of using the interactive questioning in a classroom setting. As shown in the figure, classroom feedback is mixed with most student
feeling the lecture was something like “engaging” or “interactive” while a minority of students felt it was more “monotonous” or “confusing”.

Figure 6. Insight into Interactive Lecture

Conclusions

The Socratic method of teaching will continue to be used as an effective tool for learning. It involves the use of questions to facilitate learning discussions. This study has been an observation of using the technology that often leads to distraction in the classroom as a tool to improve learning through the Socratic method. The use of interactive questioning using technology was observed to have some advantages and some disadvantages. It was found that using higher levels of questioning as demonstrated in Blooms Taxonomy could lead to improved discussion through interactive questioning. This study also found that the culture of the classroom needs to be managed in order to reduce the distractions caused by off topic or comical remarks that can result from the open questioning format. The use of software to allow for these virtual discussion boards does improve the number of class participants and has the ability to improve quality of discussion. It can be a worthwhile tool used to guide the instructor in the most needed direction to assess learning or collect real-time data and feedback from students. Using interactive questioning is viewed positively by the majority of participants and can have a great ability to improve learning. Further research may be needed to determine the most effective ways to implement the technologies of interactive learning to have the greatest effect in the classroom.
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Enhanced Experiential Learning in the Unit Operations Laboratory

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Abstract

In most Chemical Engineering departments, the Unit Operations Laboratory is used to deliver hands-on experience with experimental equipment to students that have completed junior-level transport phenomena lecture courses (Fluid Mechanics, Heat Transfer, and Mass Transfer). At the Colorado School of Mines, this laboratory is delivered as an intensive six-week summer course. Students work in teams on a variety of experiments that illustrate principles in fluidic, thermal, and chemical systems. Students engage in two eight-hour laboratory work days each week. The course is designed to deliver experiential learning; students generate an experimental design to achieve broad-based objectives, and perform extended experimental work with long laboratory times. The active phase of learning that is naturally present in laboratory work is enhanced by providing latitude to the students in their experimental plans, and by allowing them to reflect on their lab experiences when repeating an early experiment at the end of the Session.

Keywords

Experiential learning, unit operations laboratory.

1. Introduction

The curricula of most Chemical Engineering departments in the United States include the Unit Operations Laboratory, an experimental laboratory focused on the application of typically junior-level courses such as thermodynamics, fluid mechanics, heat and mass transfer, and separations. Traditionally, this laboratory is offered during the junior (3rd) year at institutions offering 4-year degrees, and is usually organized over the course of two semesters or two quarters. The relatively late positioning of the laboratory among the typical required courses for the Chemical Engineering degree makes it a good candidate as a capstone course; students may practice open-ended experimental design and use their experimental work to perform detailed data analysis, to develop professional-grade thinking and reporting skills, and to demonstrate the ability to work on task-oriented teams under defined time constraints.

In the Department of Chemical and Biological Engineering at the Colorado School of Mines (CSM), the Unit Operations Laboratory is offered between the Fall and Spring semesters; students enroll in one of two six-week summer “field sessions,” each session providing laboratory resources and instruction for between 70 and 80 students working in teams of three. Students work in the laboratory twice weekly (either on Monday/Wednesday or Tuesday/Thursday splits) for eight-hour shifts, with different laboratory experiments performed during any given week. The laboratory experience is designed to build and enrich each student’s higher-order thinking skills and professional practice awareness. An emphasis is placed on experimental design, the collection and interpretation of data, and communication of conclusive
results in oral and written formats. Since the lab’s general format was adopted in the mid-1980s, instructors have provided particular attention to the careful examination of student thinking as an aid to teaching - including the use of Socratic questioning techniques at various phases of the laboratory sequence. The coaching role of the instructors allows them to oversee the student learning process – one that is based on a cycle of improving understanding through each student’s process of design, lab performance, data analysis, and their own appraisal of work done in the laboratory. Each student gains experience in all stages involved: pre-lab planning, execution of the plan in the laboratory, calculation and presentation of the main results, and evaluation of the quality of the data and the lab procedure that was originally selected. As a “final exam” of sorts, students perform their last assigned laboratory experiment by repeating an early experiment (with the same team members) by creating new experimental objectives based on previous experience with the lab module.

2. Experiential Learning Model

In this section, the experiential learning techniques used in the Unit Operations Laboratory at CSM are described. The experiential learning instruction style that is put into practice in the course is based on the four-step cyclical model described by Kolb. The four stages of learning, shown from a student’s perspective and in relation to a typical thinking taxonomy, are illustrated in Figure 1.

![Figure 1: (a) Experiential learning cycle, and (b) hierarchical thinking taxonomy.](image)

When a student group begins preparation for a new experiment, they bring the factual recall and comprehension gained from the prerequisite lecture courses (gray on the taxonomy diagram). Lab preparation begins with the initial experimental design; the practical equivalent to “Synthesis” at the top of the pyramid. Putting that design into practice in the laboratory (executing the plan) initiates the learning cycle.

The movement from lower-order to higher-order thinking (upward in Fig. 1b) is usually discussed as a one-way progression as the learner achieves greater mastery of a subject or
technique. However, the new approaches created at the level of Synthesis may themselves be used (Application) to obtain new results that may be determined (Organization) and evaluated for quality (Judgment). This cycle may be continued as long as there are new ideas synthesized for testing.

2.1 Composition: Experimental Design (Synthesis)

At the laboratory orientation session, students are presented with a detailed schedule of which experiments they will be assigned, which members of the class will comprise each team on each lab day, and when students will be designated as group leaders - each student serving as a group leader three times over the course of the summer. Recent enrollments have involved 36 students working in the lab on a given day, with twelve distinct experiments operating with 3-person teams. Before the laboratory work day, each student team familiarizes themselves with the experimental hardware and safety guidelines provided by faculty supervisors. The team meets to select measurement and modeling techniques, and to develop a complete experimental design. This design includes a listing of detailed experimental objectives, a strategy for data collection, and a selection of statistical analyses to be applied to the experimental data. Very brief written guidelines (including safety) for each experiment are available for reference, and faculty supervisors are available to coach or mentor the teams regarding questions that arise during their design development. Before entering the lab on the experimental work day, each student team takes part in a “prelab” report session with the faculty supervisor assigned to the experiment. The supervisor examines the team’s preparation for the laboratory by investigating all aspects of the experiment: theory, system operations, personnel assignments, safety concerns, working equations and correlations, data acquisition, handling of measurement uncertainty, data analysis, and evaluation of experimental objectives. While all group members participate to some degree, the supervisor primarily interacts with the designated team leader, and the prelab grade is assigned to that individual.

2.2 Experience: Hands-on Operation (Application)

Upon completion of the prelab report, the student team commences its laboratory work, operating without input from faculty or teaching assistants (potential safety issues excepted). Student teams, as directed by their team leader, are in complete control of the execution of their experimental plans. Whereas a typical laboratory courses scheduled during a Fall or Spring semester may be limited to three or four contact hours per week, the summer setting allows students to spend up to eight uninterrupted hours gathering experimental data. This has enabled CSM faculty to employ larger experimental modules than those found in most university labs – much closer to pilot-scale than the bench-top units available commercially. Table 1 shows the various laboratory experiments available as of the 2016 Summer Field Session.
In order to provide a foundation from which students may develop their experimental goals, some very basic (minimum) objectives are provided with the guidelines mentioned previously. For example, the Condensing Steam experiment uses double-pipe heat exchangers, internally cooled by water or ethylene glycol, with steam condensing on the outer surface of the cooled pipe. By variation of coolant flow, steam pressure, and exchanger size, the students are to use measured temperatures and flow/condensate rates to determine overall and individual heat transfer coefficients. These heat transfer coefficients are compared to predicted values from literature correlations, and dominant individual heat transfer coefficients are identified.

Certain experiments require students to perform hazard and operability (HAZOP) safety studies as part of experimental reporting, and course faculty provide a HAZOP workshop for students immediately after the initial orientation meeting. With the present scheduling strategy, each student performs at least two HAZOP analyses during the session.

The experiments are either built from the ground up by CSM laboratory personnel, or are heavily modified from stock manufacturer specifications. They are designed with flexibility in mind – such that they may be used in a variety of ways by the students according to their experimental design. For example, the pumps integrated into the Pumping Power and Efficiency experiment may be run individually, in series, or in parallel to provide a variety of options to students investigating a wide range of system power/flow operating conditions. At the end of the summer sessions, detailed feedback is requested from the students regarding how the experiments might be improved in terms of allowing new types of data to be acquired, or different analysis paths to be followed. Typical examples of these improvements include the addition of system monitoring hardware, the incorporation of automated data acquisition, or the redesign of fluid pathways.

2.3 Reflection: Determination and Communication of Results (Organization)

Upon leaving the laboratory, the team processes and analyzes the data, comparing results with appropriate theoretical models or empirical correlations. Statistical uncertainty analysis is stressed from the very beginning of the course. Two statistics workshops, which focus specifically of the handling of experimental error and the uncertainty in comparing model
predictions with data, are offered in the opening weeks of the course. A statistics homework assignment and exam allows instructors to gauge the competency of the students in these operations, and the error handling approach by the team is scrutinized in detail for each report.

Data reporting is required in the form of oral and written reports, completed in an alternating sequence. For oral reports, each team is required to prepare and deliver a twenty minute presentation describing their laboratory planning, experience, and results on the day following the laboratory work day. Students are expected to participate equally in oral report delivery, both in presentation of the team’s work and in answering questions from the audience (one or more instructors and at least one other student team). Draft written reports are submitted five calendar days, including a weekend, after the experiment is completed. The draft versions of the written reports are reviewed by both the experimental supervisor and a technical communication specialist. Draft review meetings with individual student teams provide feedback and suggested corrections to writing quality and technical content before a final version of the report is submitted by the team. Oral presentations are attended by other students in the course, and by one or more faculty supervisors. Students present four oral reports, and submit four written reports on experiments completed during the course. The final report (from a repeated experiment, as detailed above) is presented as an oral briefing with handouts designed by the students.

Successful reporting requires that the team carries out detailed calculations and uses measurements and calculated quantities in comparison with theoretical relations or empirical correlations of engineering parameters (e.g., mass transfer coefficients). Communication of the team’s findings requires clear figures and tables for displaying results, as well as calculation of error propagation and related statistical analyses. More critically, each team is required to provide logical explanations for any deviations of their results from expected values, and to develop conclusions based on their overall evaluation of the work.

2.4 Conceptualization: Objective Evaluation for Redesign (Judgment)

In oral and written reports, the student teams must draw conclusions from their results that relate to any discrepancies between observed and expected outcomes. Experiment supervisors deliberately continue the use of Socratic questioning in their communications with students in order to uncover evidence of higher-level reasoning: convergent, divergent, and (ultimately) evaluative thinking. These stages of experiential learning, while rare in engineering education, are the primary goal of the laboratory’s pedagogical structure.

Helping students to progress beyond the simple reporting of experimental results without significant analysis or reflection on the data is a complicated task for the course faculty. Reports developed early in the field session indicate that students are more concerned with finishing calculations than generating meaningful results that could have an impact beyond their laboratory experience. There is indeed a reluctance among the students to make conclusive statements; many students feel an insecurity with the requirement to take a definitive stand on the results of their calculations, likely resulting from a fear of having missed an important piece of information that would have led to a different (perhaps correct) conclusion. Students that have yet to move on from simple analysis (convergent thinking) to open-ended reasoning (divergent thinking) often provide tentative implications of trends that are clear to the trained
eye, yet which are not easily explained without a mastery of the physiochemical phenomena of the system. Helping students to take active steps to evaluate laboratory results critically and to make conclusive judgments about their analyses is a task best addressed by repeatedly coaching the students to adopt such a mindset.

In the late stages of the field session, as students begin their final series of experimental reports, they exhibit an increased proficiency for applying knowledge that they have learned in core chemical engineering courses (thermodynamics, heat and mass transfer, fluid mechanics) to their experimental systems. Additionally, the stated conclusions become specific and focused on understanding; students communicate what they believe that the data truly mean. They begin to indicate that they understand the limitations behind textbook equations and correlations that were once taken as Gospel.

This last evaluation of the body of work generated by the students allows them to improve their next experimental design and laboratory performance, beginning the experiential cycle anew. The cycle must always begin with an experimental design, without which any experimental work would be largely unfocused. The experiential learning cycle is repeated directly for each student when the final experiment of the session is repeated. However, it is worth noting that the lessons learned by each student enable the cycle to be repeated in principle even across different experiments – for example, evaluation of results from one experiment may lead the students to make more informed decisions about time management in the laboratory, or to try new methods for error analysis.

3. Student Course Evaluations

Detailed course and faculty evaluation forms are provided to the students at the end of every summer field session. The evaluations are completed during a course check-out meeting which involves a final concepts exam, final peer evaluations, “best teammate” awards, and return of the students’ laboratory notebooks for archiving. As a result, a 100% response rate is the most common. Data from these evaluations that relate to student assessment of higher-order thinking skills are shown in Table 2. The data appearing here spans the author’s time as an instructor for all summer field sessions from May 2012 – August 2015. The total number of responses included is 434.
Table 2: Student Responses to Selected Course Evaluation Questions (2012 – 2015).

<table>
<thead>
<tr>
<th>The Instructors Helped:</th>
<th>Disagree or Strongly Disagree</th>
<th>Neutral</th>
<th>Agree or Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Me to improve my knowledge</td>
<td>4%</td>
<td>9%</td>
<td>87%</td>
</tr>
<tr>
<td>Me to develop my communication skills</td>
<td>7%</td>
<td>3%</td>
<td>90%</td>
</tr>
<tr>
<td>By providing clear and useful feedback on oral/written reports</td>
<td>11%</td>
<td>15%</td>
<td>74%</td>
</tr>
<tr>
<td>Me to understand the experiments and overall course material</td>
<td>2%</td>
<td>7%</td>
<td>91%</td>
</tr>
<tr>
<td>Me to develop my “higher-order thinking” skills</td>
<td>3%</td>
<td>4%</td>
<td>93%</td>
</tr>
</tbody>
</table>

Clearly, there is overwhelming support for the instructional methods employed in this course, as well as the active-learning nature of the work itself. Comments on the course evaluations indicate that students appreciate having the freedom to make decisions about the work that they perform, and also value the fact that they were able to take ownership of the ways in which data was analyzed and reported. Some selections from among the comments of one recent field session (2014) follow:

- “This was the hardest work I’ve ever done, but very satisfying to know that I can prove myself under difficult time constraints.”

- “Having completed field session, we as a class will have a lot of advantages versus people from other colleges that don’t have the same experience.”

- “This was a valuable class in that it showed me what I am capable of accomplishing.”

- “I would never want to go through this class again. That said, I know I will be a better practicing chemical engineer with this ‘boot camp’ on my résumé.”

- “I learned more in this course than from my other ChE courses combined. It was intense – but the workload became easier as I realized the quality of work my teams did.”

4. Feedback from Alumni and Recruiters

Alumni from the Chemical and Biological Engineering Department at CSM have long indicated that the Unit Operations Laboratory was invaluable, with many indicating that it was the most important course in terms of preparing them for an industrial or consulting job. Annual alumni surveys include the question (which does not specifically mention the Unit Operations Laboratory): “Which aspects of your education at CSM were most valuable to you in your current career?” Selected responses from the 2010 survey appear below.
• “Without a doubt, the Unit Ops lab. The ability to write a report that doesn’t need extensive editing or give a talk that doesn’t embarrass my boss goes a long way towards building job security.”

• “Unit Operations was the best preparation I received at CSM due to its hands-on application of industry equipment as well as developing presentation skills.”

• “Professors could relate class material to real world experience. Field session was a great class which gave me a dose of what to expect as a professional in the field, presentation, and thinking about exactly what it is that we are doing.”

• “It pains me to say this, but the Unit Ops lab gave a great model of a real world working situation – fast paced, heavy loads, and a focus on professional communication.”

• “My job is very similar to the way field session was run. The teamwork aspect was maybe the most valuable learning experience to me – I need those skills daily.”

The Department’s Industrial Advisory Council, which includes company recruiters that are not CSM alumni, has been very supportive (in communication, as well as through donations) of the methods and learning objectives delivered in the Unit Operations Laboratory. Some representative feedback from the Council and other campus recruiters appears below.

• “We find ourselves hiring 2 or 3 Mines ChE grads each year, though we recruit in multiple states. The Mines grads hit the ground running, head and shoulders above other new hires in terms of presentation skills and critical thinking.” (Schlumberger)

• “I trust the new grads from Mines to handle problems that aren’t completely defined yet – they don’t mind diving right in and finding out what needs to be done.” (Baker Hughes)

• “We hire a lot of Mines kids, and they know how to work. I don’t need to tell supervisors to watch their progress marks every month, and they don’t waste anyone’s time.” (Ball Aerospace)

• “Our experience with CSM chemical engineers has been fairly limited, but very positive. They come in as top communicators, and are known to be problem solvers.” (Honeywell)

5. Conclusions and Recommendations

The Chemical Engineering Unit Operations Laboratory, in its present format, is the product of nearly thirty years of pedagogical focus on building our students’ abilities of learning by doing, communication, design, and open-ended problem solving skills. Faculty best accomplish these goals not by lecturing or posturing as authority figures, but rather by coaching and probing the thought processes of students as they work to define experimental goals and describe the outcomes. We see a great improvement in these skills throughout the course of each field session. Although the workload is high and time constraints are significant, the students
demonstrate a greater mastery of the fundamentals of the chemical engineering discipline. The instructors of our laboratory have provided the following recommendations7 to educators interested in using their own laboratory courses to enhance student performance through experiential learning:

- The CSM field session is a rare example of an immersive class experience, but the techniques described here should translate well to laboratory courses that operate on a traditional semester- or quarter-based schedule.

- There is no perfect way to make students into better thinkers or communicators. Rather, we have found that setting clear, high expectations for students from the start and providing the proper student/faculty interaction standards are the best ways for helping students develop these skills.

- Preparation for laboratories (initial compositional work) and placing responsibilities on students that affect the evaluation of others (team values) are crucial to initiating effective experiential learning cycles.

- The development of skills through experiential learning is often slow, and will occasionally frustrate students that are unaccustomed to the instructional style. However, if the process is applied one step at a time, faculty may successfully raise student performance, expectations, and self-confidence.

References


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Teaching Ethics and Professionalism to Engineering Students: An Educational Dilemma

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Abstract

Hiring managers have typically focused on GPA’s and technical competence in their attempt to hire the best possible applicants for engineering positions. Now, because there are several technically well qualified graduates for each opening, hiring managers are increasing using interviews to focus on an applicant’s ability to effectively communicate, solve non-technical problems, and resolve ethical and professional issues. This paper addresses the challenges of how best to present these somewhat complicated and potentially confrontational topics and hopefully instill these abilities in engineering students who may not believe them to be valuable. The paper examines several teaching methods and their applicable to providing this instruction including the lessons learned as we endeavor to provide our students with a basis in professionalism, non-technical problem solving, and resolving ethical conflicts.

Keywords

Ethics, Professionalism, Economics, Case Study

I. The Opportunity

A few years ago the Department of Mechanical and Aerospace Engineering (MAE) at Utah State University (USU) began requiring all students, who have been accepted into our professional program, to take a course on Ethics, Professionalism, and Engineering Economics. The course is taught each year during the fall semester to typically 100 to 130 junior and senior students. It was established to help satisfy some Accreditation Board for Engineering and Technology (ABET) student outcome criteria.

These ABET criteria focus on abilities such as communications, non-technical problem solving, ethics, and professionalism. Specifically, this course attempts to address the following ABET student outcomes:

- An ability to function on multidisciplinary teams
- An understanding of professional and ethical responsibility

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The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

A recognition of the need for, and an ability to engage in life-long learning

A knowledge of contemporary issues

Given that these concepts are somewhat out of the norm of engineering topics, we wrestled with how best to convey this information to our students. Additionally, because this course is only one-credit hour, our goal was to develop an instructional method that was both efficient and effective. During the past few years we have tried several instructional approaches with varying results. This paper describes our efforts, lessons learned, and our path forward.

II. Early Efforts

We began this process believing that a fairly broad “view from 50,000 feet” approach would be the only practical method of providing all of the necessary information to satisfy the ABET criteria. As a result, during the first few years, the course was taught in a lecture format using primarily a textbook and publications from the American Society of Mechanical Engineers (ASME) as material sources. Other sources were occasionally referenced. The format included very little student interaction or problem solving.

The lectures during the first two thirds of the semester centered on the ASME codes of ethics and professionalism. Some instruction was also given on the need for lifelong learning. During the last third of the semester basic engineering economics concepts were taught. Approximately four weeks prior to the end of the semester the students were separated into groups of 5, tasked to evaluate an engineering oriented socio-economic problem, and as a group submit a 20 page paper at the end of the semester describing and defending their conclusions. Grading was based on homework, a midterm, and the paper.

Our college uses a student feedback process to collect their opinions on the effectiveness of the instruction they receive. During the first few years, student feedback ranged from “great course” to “ridiculous waste of time”. Much of the student feedback centered on the following:

The material was “just common sense” and not of great value,

Using a “textbook approach” was not really relevant,

Having a good foundation in ethics and professionalism was of value but the course did not substantially add to their skill set, and
The 20 page paper was considered by most to be “significant overkill” for a one credit hour course.

Based on this feedback we realized that while the subject matter seemed to us to be relatively straightforward, effectively teaching this material held some challenges. Since most of this type of learning is right-brained oriented, we realized finding instructional methods to effectively convey this information to analytically minded students is as much an art as it is a “by the numbers” process.

III. Second Iteration

Upon joining the MAE department two years ago, I was asked to teach this course. Given the student feedback from the previous years I began my course prep with the belief that the content needed to be more relevant to the students. I also felt I should begin the class by presenting a rationale for why these abilities would be of value to the students. Additionally, I wanted to create a more interactive learning environment.

A. Instructional Format

The first two semesters I instructed the class I began by asking the students in-class questions about their opinions on the importance of ethics and professionalism in the workplace. Most agreed both were important. Then I asked who they believed was responsible for maintaining an ethical and professional work environment. Surprising most said they saw this being the responsibility of management and not something an individual employee could or should do.

Based on these responses I provided mostly personal and anecdotal evidence from my years of business experience that being ethical and professional are individual responsibilities. This was followed by a few weeks of lectures on the ASME Code of Ethics and Professionalism with the students being asked some “opinion” questions. The emphasis of the instruction was on the individual’s responsibility to act in an ethical and professional manner. The importance of lifelong learning was also presented.

I incorporated a few case studies covering these topics. Most where the hypothetical and generic cases of the “What would you do in this situation?” type dilemma, easily found by searching the internet. Some cases were discussed in class and others given as homework assignments. Students were asked to individually defend their solutions to the cases. I then attempted to engage as many as possible of the 120+ students in the class discussions.

The engineering economics lectures came from basic business course lectures. Personal experiences were incorporated where appropriate. The students were asked to become familiar with a few commonly used business concepts. An attempt was made to help the students appreciate that by understanding some basic business principles they could be viewed as more
valuable to their managers. Grading was based on in-class participation, homework, a midterm exam, and a final exam.

B. Student Feedback

Although student responses to this new approach were somewhat more positive than the previous feedback, many students still did not consider the course to be worthy of its’ “required” status. While most believed that being ethical and professional were valuable, they felt:

- The case studies were too generic, detached from reality, and of little value,
- The economics discussions were more detailed than they would ever need during their careers,
- These soft skill capabilities were of little value to them because they will never be in the position of being part of or having to resolve the type of ethical or professional dilemmas presented in class, and
- They will have a successful career by just being technically competent.

Perhaps the most discouraging feedback was that a few students believed teaching anything related to business in an engineering program was a personal affront and a significant waste of time. These students viewed business majors with great disdain and wanted no association with anything business related.

This feedback helped me to understand that I faced a very wide spectrum of student attitudes and motivation concerning this course. This led me to conclude that while some progress had been made in making the course more relevant to the students I needed to continue revising it.

IV. Resetting Our Framework

After some mental gymnastics I realized that talking about my personal experience alone would not provide the necessary motivation for the students to embrace learning these subjects. Instead, I needed to provide substantiated and, where available, documented evidence that possessing these soft skills could indeed be beneficial to them.

In January I began my course prep for this upcoming fall semester’s class by evaluating the current engineering job market dynamics. My primary goal of this research was to better understand how hiring managers make their decisions. My rationale for this was that if I understand the hiring process I will better appreciate how these soft skills might affect a hiring manager’s decisions.
A. Abundance or Shortage

I began this evaluation by attempting to answer the following question:

Is the current engineering job market experiencing a shortage or an abundance of graduates entering the labor force?

There are two distinct directions of thought on this topic. One side argues we have a shortage of engineering graduates entering the market. This belief is:

- Widely held and proclaimed by many in industry and government, supported by citing a variety of findings, and
- Supported by our federal government and some state governments who have established several STEM related educational incentives.

A direct result of these efforts is that the number of graduating engineers has increased 26 percent from 2005 to 2014 resulting in over 99,000 bachelor’s degrees being awarded in 2014.

In contrast, the other direction of thought suggests there is no real shortage. A study published in The Atlantic in 2014 states:

“No one has been able to find any evidence indicating current widespread labor market shortages or hiring difficulties in science and engineering occupations that require bachelors degrees or higher, although some are forecasting high growth in occupations that require post-high school training but not a bachelors degree. All have concluded that U.S. higher education produces far more science and engineering graduates annually than there are S&I job openings—the only disagreement is whether it is 100 percent or 200 percent more.”

This study further suggests that an increasing number of graduates are chasing fewer opportunities and experiencing a flattening of salaries.

“Most studies report that real wages in many—but not all—science and engineering occupations have been flat or slow-growing, and unemployment as high or higher than in many comparably-skilled occupations.”

Additional support for these conclusions comes from the following published research as referenced by Hal Salzman in his analysis of the job market:

- What Shortages? The Real Evidence About the STEM Workforce published by Issues in Science and Technology in 2013.
B. Hiring Manager Attitudes

Understanding which viewpoint is predominant in the job market was key to my developing the most relevant information for the students. My initial belief was that one of these viewpoints should be supported by how hiring managers (both businesses and universities) interact with candidates. If there is a shortage of graduates, these managers would need to “sell” their company to prospective new hires. Conversely, if there is an abundance of graduates these managers would likely be more selective. To help focus in on the approach used by hiring managers I decided to examined three data sources.

1. Personal Experience

First, I reflected on personal experience as a former senior manager of an IT company. Typically our company received around 30 applications for each software or hardware opening we posted. My VP of Engineering would initially review and rank the resumes based on the candidates’ education and experience. We then conducted phone interviews with the top 10 candidates focusing on their ability to think through both technical and non-technical issues. From that group we selected 3 to 4 for in-person interviews during which we assessed their interpersonal and communications skills. As I thought through this process I realized we relied fairly heavily on non-technical attributes in making our decisions.

2. Industry Contacts and Advisory Board Members

As a second source, I reached out to my industry and academic contacts and also talked with members of our department’s Industry Advisory Board. Initially I asked how they selected candidates for job interviews. Some of their responses are as follows:

“We have several applicants for each job posting. Our belief is that they are all technically qualified by virtue of their degree. We tend to equal out their technical skills and focus on their interpersonal and communications abilities when making the hiring decision.” Project Manager of a large Aerospace Company

“We tend not to focus that much on their GPA. In fact if they have a GPA above 3.7 we usually sort out those candidates and focus on the other applicants. Our experience has been students with a lower GPA are more likely to have the broader skills that make for better employees.” Program Manager, National Lab

“I have been told by several hiring managers and company executives that, in general, engineering students are technically very capable but experience shows they lack the...
ability to solve real world business and interpersonal problems.”  Dean of a Midwestern School of Engineering

“When I ask company owners what we can do as a college to make our students more marketable, they tell me to enhance their soft skills because those abilities are the ones that differentiate the best and brightest.”  Dean of a Utah based School of Engineering

I then asked how they make advancement decisions. Their responses included the following:

“Our annual reviews consist of two parts: Technical ability and interpersonal/problem solving skills. We review the technical assessment for any major concerns and then set it aside. We then review the interpersonal and problem solving assessment to determine advancement.”  VP of Engineering, Logan based company

“Without question, our engineers who develop the ability to communicate well and solve non-technical problems will be the ones we pick to fill our management ranks.”  Director of an Aerospace Company

“Occasionally our engineers are asked to explain their projects to customers. Those with good communications skills are much better received and regarded.”  Manufacturing Executive

“The people we promote are 1 part technical, 1 part management, and 1 part business development.”  President of Utah based Systems Integration Company

Further, our advisory board in their annual recommendations consistently emphasizes the need for improvement in our student’s abilities to utilize these soft skills. This viewpoint is supported by feedback from attendees to a two-day National Academy of Engineering conference entitled “Pathways for Engineering Talent”:

“A point made repeatedly by workshop participants is that formal engineering education too often fails to provide all of the skills – especially so-called professional or soft skills such as communications and collaborations.”  

3. Student Experiences

I talked with a few students who were currently involved in, or had recently gone through, a job search. I first asked if they knew how many applied for the job(s) they were interest in. On average they said between 20 to 30 applicants. Next, I asked if the interviewer asked about their academic experience. Most said they were asked only one or two questions that were typically related to their senior design experience. Next I asked what the interviewers focused on. All of
the students responded that they were asked a number of questions related to their experience with:

- Solving non-technical personal interaction related problems,
- Thinking outside the box,
- Working in groups, and
- Solving business related problems.

C. The Path Forward

While my experiences and these interviews do not constitute scientific research, taken together with the published studies, the evidence does suggest the market has or is shifting from a sellers (graduates) to a buyers (companies and universities) driven process. One conclusion that seems fairly defensible is engineering graduates will face ever increasing competition for the best opportunities throughout their careers. The evidence also suggest employers are increasingly using non-technical skill assessments in making hiring and promotion decisions. The primary conclusion I derived from this analysis is students who develop non-technical problem solving abilities will have a competitive advantage.

V. Future Approach

Coming out of this analysis we developed the changes to the course content and teaching approach as outlined below. These changes will be given a “trial run” during the upcoming fall semester.

A. The Fundamental Objectives

We began by restating our objectives for the course as follows:

1. Students should grasp that having abilities to recognize and resolve ethical issues, work effectively in groups, and solve non-technical problems will be of real value in their careers.

2. The course material should be presented in a way that will have contemporary meaning to the students.

3. We will demonstrate that the ABET student outcomes associated with this course material are being met.

Our approach to meeting these objectives is described below.
1. Students should grasp that having abilities to recognize and resolve ethical issues, work effectively in groups, and solve non-technical problems will be of real value in their careers.

Early on I will attempt to set the stage that the job market is changing and the students can benefit by knowing and acting upon those changes. The first step will be to focus in on how they view their careers going forward. For the first homework assignment, I will ask the students to provide written responses to the following survey:

My career goal is to: (choose 1)

1. Work for a small company
2. Work for a large company
3. Work for an educational organization (University, college, K-12)
4. Start my own business

Becoming a manager or leader in my company or organization is: (choose 1)

1. A goal
2. Not a goal but would be nice
3. Not of interest to me

The primary reason I will receive salary increases or be promoted is: (choose 1)

1. My technical abilities
2. My ability to work well with others
3. My ability to make money for the company

When looking for a new job, my success will be primarily based on: (choose 1)

1. My technical abilities
2. Networking with people I know
3. My application and interviewing skills
4. Finding a good recruiter

Their responses will be tallied, anonymously shown to the class, and open to discussion. The hope is students will appreciate that:

- Their classmates are chasing the same goals,
They will be working for organizations who value money and the employees that help
them increase their organizational incomes, and

They understand their career success will be in part due to how they interact with others
to resolve issues, which requires some abilities with the soft skills.

I will then talk about the conclusions from the literature reviews and the interviews describe in
section IV to suggest that:

- The job market has shifted from a sellers (them) to a buyers (organization) driven
  process,

- The best jobs are becoming more competitive, and

- Employers are looking for individuals with experience in the soft skills in new hires and
  when making advancement decisions.

The intent will be to suggest that by developing these abilities the students will have a distinct
advantage in achieving their career goals. I also hope to suggest that they may benefit in the near
term by improving their odds at securing a good first job.

2. The course material should be presented in a way that will have contemporary
   meaning to the students.

   a. Updated Case Studies

I will seek to make the course material more relevant by updating the ethics and professionalism
case studies we use to reflect current events. For example;

- A case describing the recent Volkswagen emissions scandal will demonstrate how a few
  individuals’ unethical decisions can impact several groups, inside and outside of the
  company.

- A case on the recent oil spill in the Gulf of Mexico will demonstrate what happens when
  professional engineers forget their responsibility to society.

Case studies exploring dilemmas the students could face related to finding a job, working with an
unethical employee, skirting around engineering requirements to meet cost or schedule
objectives, or dealing with a difficult decision related to someone who works for them will also
be developed. One such dilemma, describe below, comes from an event familiar to the author.
Wood Products Company

A young engineer is in his third year working for a large wood products company in a small northwestern town. He approaches you, his manager who recruited and hired him, to talk about purchasing a home in the area. He has been a very good employee and a great asset to your group. He is currently living in a rental home with his wife and two small children because he did not want to buy a house until he was sure his position with the company was secure.

The engineer is scheduled to sign the final papers to purchase the house in the next few days and he wanted to talk with you to make sure there were no changes “in the wind” that might impact his employment. When he said he wanted to talk specifically about the purchase, you said you would get with him later that afternoon.

Two weeks earlier, you attended a senior management meeting in which the company CEO announced plans to close the facility where you work. Although profitable, your facility is not producing at the level necessary and its remote location and high transportation costs are major concerns. Its operations will be consolidated with a facility about 200 miles north. This decision will mean the largest employer in your small town will be closing down. The town’s economy could potentially collapse.

Everyone at the management meeting were told they could not, under penalty of losing their jobs, say anything about the closure to any of their employees until the formal announcement is made in about 3 months. In a separate individual meeting, you were offered a promotion to move to the new facility. You were also told it was not likely any of your staff would be asked to make the move.

What should you tell your employee?

Some cases will be resolved in class and others assigned as homework. The students will be asked to use a multi-step format for analyzing and resolving the case.

b. Integration With Senior Design

To help students appreciate that being a professional means knowing how to work effectively on teams, we plan to include discussions on working in groups and budgeting as it relates to their upcoming senior design project. Currently 50% of our senior design projects are industry sponsored. These sponsors typically require their projects to be completed on schedule, on budget, and result in the delivery of a working prototype.

For most students the senior design experience will be their first exposure to completing a “real” project. Therefore most do not have the necessary skills to understand and successfully complete the non-technical aspects of the project such as managing to a schedule, budgeting, or resolving issues as a team. Lectures will provide instruction on developing these skills.
I will also use previous senior projects as case studies to exemplify both good and bad group interactions. For example during one recently completed project, the students identified three significant changes to the prototype that would have made the commercial version of the product much less expensive to manufacture. However, since these changes were outside the budgetary requirements of the project, the team disagreed on whether to bring these changes to the sponsor’s attention. Even though two students on the team argued that the sponsor should be told, the other four did not agree and they eventually prevailed. They did however all agree to include the changes as suggestions for future enhancements in their final presentation. It came as somewhat of a surprise to the students that the sponsor would have preferred knowing about these changes prior to the final presentation and would have increased the budget to accommodate them. The sponsor stated the project would have been much more valuable with those changes.

c. Engineering Economics

Relative to meeting the following ABET student outcomes,

- The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- A recognition of the need for, and an ability to engage in life-long learning
- A knowledge of contemporary issues

I will develop a few discussions on basic economic principles. My approach will be to suggest that understanding these basic principles will help the students become higher value contributors in future project and business meetings and help them to better understand their company’s business and market trends. I will also suggest that a basic understanding of these principals could help them with personal financial decisions. Additionally, knowing these principals will help them to prepare for the Fundamentals of Engineering (FE) exam we require each student to take upon completion of the four year program. These principles will include:

- Time value of money
- Net Cash Flow
- Net present value
- Straight-line and accelerated depreciation
- Gross and net margins
- Breakeven analysis

Each principal has a numerical formula associated with it. Though most business use the Generally Accepted Accounting Principles (GAAP) versions of these formulas, the FE preparation manual versions differ, in some cases significantly, from the GAAP versions. We will use the FE versions.

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Several examples and case studies taken from current situations, such as the aforementioned Volkswagen case and previous senior design projects, will be presented and homework will be given. We will also attempt to make these case studies more relevant by including such topics as student loans, buying vs leasing an automobile, and justifying the purchase of engineering related equipment. The students will be asked to find solutions not only using individual formulas but also to intertwine those solutions to develop their recommendations to larger case studies.

d. Revised Teaching Approach

The course will be taught as less of a lecture and as more of a case oriented open discussion forum. As mentioned above we will use a framework that separates a case into multiple facets each of which must be considered and if possible resolved. This method is meant to help the students develop a broad approach to thinking through the problems rather than just believing there is just one correct “common sense” answer. The discussions in class will attempt to encourage student involvement and reinforce that all opinions are of value.

Using this method, I hope to encourage students to better develop and articulate their own approaches to handling “out of the engineering box” problems, and also to appreciate the merits of other ideas. However, taking this approach does create some concerns.

Previously I attempted to make individual in-class participation a requirement and to factor that participation into the student’s final grade. Aside from the difficult logistical issue of attempting to effectively call on each of the 120+ students during the semester, I came to realize some students are at best reluctant and at worst offended by being asked to express opinions in front of their peers. I also learned that no amount of encouragement in the form of grading or in extolling the future benefits of having acquired such skills will alleviate these concerns.

So, while I believe that for most students an open forum approach will be more engaging than a predominantly lecture style format, I will also provide a buffer for those students who may need it. At the beginning of the semester I will randomly form groups of 5 students each and ask the groups to evaluate the cases and be prepared to present their recommendations in class as a group. In this way, students who may be uncomfortable expressing individual opinions can couch their opinions as coming from the group.

Individual grading for the course will be based primarily on a midterm exam, a final exam, individual participation during class discussions, and group performance on homework assignments. The group performance grade will be determined primarily on their answers to the multi-step process, their recommendations, and their presentation in class. As an additional incentive, part of their group grade will be based on the students’ evaluations of each other’s contribution to the group. Individual participation during class will still be encouraged.

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e. Guest lecturers

Additionally, to keep the material and approach fresh, we will invite guest lecturers to talk about their areas of expertise. These may include presentations from patent attorneys, production managers, business owners, and recent graduates. These presentations will focus on the presenter’s real world experience with the topics of the class.

3. We can demonstrate that the ABET student outcomes associated with this course material are being met.

To meet this objective each homework assignment or exam will be tagged in the course records with the related ABET student outcome criteria. Our belief is that we will demonstrate sufficient correlation between this criteria and the content provided in the class such that we have in part or in whole met the respective criteria.

VI. Final Thoughts

Over the past few years and through some occasionally painful trial and error we have learned that not all knowledge is equal in the eyes of our students. As we shape our Ethics, Professionalism, and Engineering Economics course for the fall 2016 semester, we do so hoping that our efforts to make the content more relevant and engaging will result in greater student participation and learning. We also understand that some students will again disagree with us on the value of the course or will choose not to accept these concepts. Recognizing this, our hope then is that, worst case, our students will see value in developing an expanded view of the world and of their careers.

To help facilitate their adopting this expanded view we will incorporate a premise used by some educators. For example of the 200+ Masters of Business Administration (MBA) programs in the US only a handful require students to attend for a full two years, irrespective of the student’s background or experience. These programs are among some of the most prestigious in the country. The stated reason quoted by at least two of these programs for this requirement is that while they are endeavoring to provide specific business management knowledge, as importantly they are hoping to instill an ability in the student to learn how to learn which is best accomplished by working with the students for a full two years.

As an overarching goal, we will attempt to stimulate an interest in our students to think outside of the engineering box and to develop this desire to learn how to learn over their lifetime, whether the learning involves technical or non-technical problem solving. We do so firmly believing it will help our students to more successfully manage and to enjoy their careers.
References

1 Accreditation Board for Engineering and Technology (ABET) Criteria, General Criterion 3. Student Outcomes.

2 Brian L. Yoder PhD, “Engineering by the Numbers”, ASEE, 2014, pg. 11.


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Professional Experience

Director of Research Development – Mechanical and Aerospace Engineering (MAE) – Utah State University - Instruct Ethics and Professionalism Course in MAE Curriculum

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Masters of Business Administration – Brigham Young University – 1981

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Critical Thinking for Open-Ended Engineering Problems Through Written Reflection: A Case Study

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Abstract

Engineering classes are frequently assessed with closed-ended, well-defined problems with a “correct” answer. Open-ended and more complex problems complement this approach, and can develop an ability to synthesize and contextualize information, and to develop critical thinking skills. Assessing open-ended problems can prove challenging, as traditional grading methods for closed-ended problems are generally not feasible. One method to assess open-ended problems is to implement written homework reflections. This paper compares two offerings of a graduate course in structural engineering: the homework problems were similar, but written reflections were incorporated in the most recent offering. Student feedback revealed that the written reflections developed critical thinking and were an important component of the success of the course. The purpose of this paper is to stimulate discussion in the use of written engineering reflections for assessment of open-ended engineering problems and to provide grading strategies for faculty interested in adopting this technique.

Keywords
Written Reflection, Open-Ended Problems, Pedagogy, Critical Thinking

Introduction

Engineering courses generally assess course learning outcomes on homework assignments and exams through the use of closed-ended, well-defined problems that are characterized by having a single correct answer. These types of problems provide certain advantages for the instructor. For example, they may be graded rapidly and equitably through the use of a grading rubric that targets common mistakes and misunderstandings.

While these types of problems are certainly a necessary component of engineering education, student learning can be further enhanced through the use of problems that are open-ended and more complex than the well-defined problems. In these types of problems, students practice the art of making assumptions, which lays the groundwork for the development of engineering judgment.

Open-ended problems may certainly be related to design projects and project-based-learning, but are also readily incorporated in lower-level courses traditionally taught with closed-ended problems. Table 1 contrasts closed-ended and open-ended problems that are appropriate for a sophomore-level Mechanics of Materials course.
Table 1. Sample Closed-Ended and Open-Ended Problems in a Foundational Engineering Course

<table>
<thead>
<tr>
<th><strong>Sample closed-ended problem</strong></th>
<th><strong>Sample open-ended problem</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>A swing in a playground is suspended from a steel frame. The cables that support the swing are composed of a chain of connected oval steel links made of A-36 steel, each with a cross-sectional diameter of 1/4 inch. If a 50-pound child sits on the swing, what is the factor of safety with respect to tensile yielding of the steel that composes the connected oval links?</td>
<td>Find a piece of playground equipment that can be used to illustrate concepts of basic connection design covered in this course. Draw a free-body diagram of the piece of playground equipment when subjected to forces caused by children playing. Use appropriate factors of safety to investigate at least 3 different aspects of the design’s components and connections, and speculate on the probable properties of the materials used in the construction.</td>
</tr>
</tbody>
</table>

The open-ended problem is more likely to increase student engagement, broaden perspective on the course’s engineering topics, and develop critical thinking skills. Additionally, these types of problems can robustly support the attainment of several ABET student learning outcomes: “an ability to identify, formulate, and solve engineering problems,” “the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context,” and “a recognition of the need for, and an ability to engage in life-long learning.”

However, it is challenging to assess and grade open-ended problems fairly, equitably, and efficiently. It is apparent from the example above that traditional grading methods for closed-ended problems lose applicability to open-ended problems. The different solutions are both too time-consuming to be graded by the instructor in detail and too complex to be graded by a teaching assistant.

**Reflection as a pedagogical technique**

Reflection (also called reflective learning or reflective practice) is a pedagogical technique that can be used to close the loop on the learning process and to allow the learner to connect the content to a variety of other concepts and experiences. Through reflection, students “intentionally make meaning of experiences in service of future action.”

J. A. Turns, et al.¹ have consolidated and integrated a number of publications related to reflection practices in adult learning. The work of four theorists is emphasized: Dewey, Kolb, Schon, and Mezirow²,³,⁴,⁵,⁶.

The practice of reflection can take many forms. In this paper, it refers to written mini-essays written by students after performing computational homework assignments in response to specific prompts provided by the instructor. Reflective learning can also be evaluated through other activities, such as survey questions, activities that are computational in nature, and graphic presentations⁷,⁸.
In this paper, two approaches to assessment of open-ended problems are compared in a case study. This study illustrates the value of written reflections coupled with open-ended engineering problems – especially the utility of the reflections to help students develop and enhance their critical thinking skills.

Description of case study

Structural Preservation of Existing and Historic Buildings was taught by the author at Colorado School of Mines in two semesters: Spring 2013 (S13) and Fall 2015 (F15). A graduate-level Structural Engineering elective, this course builds on the typical design classes of Steel, Concrete, Timber, and Masonry, exposes students to archaic structural materials and methods, and gives them a set of tools for the structural analysis and intervention of buildings that contain such materials and methods.

Generally, the field of structural preservation requires more critical thinking than the contemporary structural design of new structures. Structural design, as taught in the academy, is akin to a cookie-cutter process, highly codified and constrained by building code requirements and procedures. Students are taught to apply building code provisions so that their design meets the applicable criteria. In contrast, the building codes for existing and historic buildings emphasize the importance of judgment and the ability to make appropriate assumptions when assessing these buildings. Accordingly, the course learning outcomes require students to:

1. select and apply appropriate contemporary and historic analytical methods for a given structural condition;
2. propose structural interventions that are sensitive to life safety, engineering principles, material conservation, building code requirements, sustainable retrofit practices, and preservation principles; and
3. leverage improved proficiency in critical thinking skills, technical writing skills, and graphic communication skills.

S13 Course Structure, Assignments, Grading System, and Student Feedback

In S13, the course enrollment consisted of twenty-two students. The course structure was primarily composed of traditional lecture slides and commentary, with one week of mini-field trips on-campus, where the instructor showed the students specific structural systems in campus buildings, and led interactive sketching and pair-share activities.

The final course grade was assigned based on the following weights:

- 10% Class Participation
- 15% Homework
- 20% Quizzes
- 35% Final Project
- 20% Final Exam
The homework assignments from S13 and F15 were very similar in content and structure; some assignments were identical. In both semesters, reading assignments and in-class lectures and presentations supplied students with a broad and general framework for the homework assignments. However, unlike most engineering courses, a nearly-identical problem was not supplied to the students. In both offerings, students were encouraged to make assumptions and to select appropriate analysis techniques. The instructor indicated that answers were expected to vary. Unlike closed-ended problems with “right” and “wrong” answers, solutions to open-ended problems are considered satisfactory (based on reasonable assumptions and without conceptual errors) or unsatisfactory. Variation in student responses was expected due to the simplicity or complexity of the analysis model and the assumptions made in the problem-definition stage.

Although the problems were similar in the two offerings, the assessment mechanisms varied greatly. The assessment mechanism for the homework in S13 did not include written reflection. Instead, a check / check-minus / check-plus system was implemented. The description of this grading method as issued in the course syllabus is as follows:

0 points: Student does not submit the assignment, or submits extremely poor work.
CHECK-MINUS (1 point): homework does not minimally fulfill the assignment requirement, or is sloppy, or is unprofessional, or contains major conceptual errors.
CHECK (2 points): homework minimally fulfills the assignment requirements, does not contain conceptual errors, and is neatly presented.
CHECK-PLUS (3 points): homework surpasses the assignment requirements and is exceptionally well-presented and professional.

The average of the scores ($n$) will be converted into percentage points per this function:

$$\text{average in percentage points} = \left( \frac{20}{3} \right) n^3 - \left( \frac{85}{2} \right) n^2 + \left( \frac{605}{6} \right) n$$

Thus, scoring all 3’s is equivalent to a 100%; scoring all 2’s is equivalent to an 85%; and scoring all 1’s is equivalent to a 65%.

From the instructor’s point of view, this was a liberating grading system that allowed relatively efficient grading by partitioning the student responses into three bins: a minority of students that submitted impressive work, the majority of the students that satisfactorily completed the assignment, and a minority of students (if any) that submitted low-quality work. Unfortunately, the student perception was very different, leading to seventeen of twenty-two students giving negative feedback on the course evaluations (minor spelling and grammar errors have corrected):

- **Homework is too ambiguous; additional instruction or examples requested** (seven of twenty-two students)
  - “Provide more instruction in homework and be more clear about assignment prompts (even when you don’t think it needs further clarification) – you are trying to make us think on our own, but without the background it’s nearly impossible to start.”
“Homework is way too ambiguous. We are told to “just try it” and then penalized for an incorrect answer.”
“…all actual calculations and interpretation in this class is left for us to figure out on our own in homework, you haven’t taught us anything.”

- **Grading system for homework is unfair or flawed** (five of twenty-two students)
  - “Actually grade the homework.”
  - “The only way to successfully achieve a check-plus as opposed to a check or check-minus on the homework is to have prior knowledge on the subject, but then, why take the class?”

- **Homework is too time-consuming** (three of twenty-two students)
  - “I devoted far too much time to busy work (homework) with little improvement in knowledge.”
  - “Don’t make the homework worth almost nothing (check system) and then make it a huge work load.”

This negative feedback was the primary impetus towards revising the homework assessment model in the F15 offering.

### F15 Course Structure, Assignments, Grading System, and Student Feedback

In F15, the enrollment consisted of ten students. In response to the course evaluation comments from S13, the course structure was modified to increase the proportion of the mini-field trips from one week to six weeks. These field visits were accompanied by traditional lecture slides and commentary, as well as other interactive in-class exercises, such as group work and pin-ups with discussion.

The homework weighting was significantly increased from 15% to 50%, written reflections were incorporated, the check / check-plus / check-minus grading model was discarded, and the instructor sought student buy-in by emphasizing the learning outcomes in class and in the syllabus, excerpted as:

> Engineering education research maintains that students internalize and retain concepts better if they are given time to reflect on what they have learned, thereby contextualizing the technical material. The technical work in this course will be initialized during class in pairs, and guided / supported by the instructor. Work that is not completed in the class shall be completed by individuals or groups of students after class. On Thursdays after class, the Instructor will email a series of reflection prompts. Reflections are due at the beginning of class on Tuesday. It is permissible to work on the technical assignment with another student, but each student must submit their own original reflection. Submit the typed reflection (generally 1-2 single-spaced pages) as the cover sheet and append the technical work. The Consortium to Promote Reflection in Engineering Education (cpree.uw.edu) says that “Reflection may take a little of your time, but the outcomes are generally positive. The chance to reflect can help you identify concepts that you may misunderstand, help you consider your identity as an engineering student, and inform your path going forward. Reflection is also a different type of learning experience that
provides you an opportunity to explain and make sense of what you know, or may not know. The exercise also helps improve communication with others about your knowledge and ability.”

The final course grade was assigned based on the following weights:

- 50% Homework Reflections
- 10% Presentation
- 15% Condition Assessment
- 25% Final Project

The problems worked by the students in F15 were similar and in some cases identical to the problems worked in S13, but the students’ perception was dramatically different, as evidenced in course evaluation comments (minor spelling and grammar errors have again been corrected):

- **Critical thinking was enhanced through open-ended problems** (five of seven students)
  - “The class fostered critical thinking and integrated analysis that we used in previous classes.”
  - “…[the] class really strikes the right balance of coming up with realistic problems that aren’t so open-ended that there’s no wrong answer, but still allowing us to really think about the problem.”

- **The reflections were effective / enjoyable** (four of seven students)
  - “I really enjoy the reflection homework because they are doing what they’re meant to do and that is to make us think. I believe that taking time to reflect on what we’ve learned does much more for us than just plugging and chugging homework problems can ever do.”
  - “…I actually really liked the homework reflections. While I was hesitant about them at the beginning of the semester, they provided a nice chance to actually articulate my thoughts and think about things on my own time.”
  - “…Even though the reflections were sometimes long and tedious, it definitely got me thinking about more than writing out equations or solving problems.”

### Comparison of student evaluations of teaching

Student evaluations of teaching can be used to characterize the students’ satisfaction with the course. In S13, the participation rate was 100%; seven of ten completed the evaluations in F15. (The reduced response rate is attributed to the change from in-class evaluations to an online survey.) The students’ responses to the following eleven ranking questions can be compared in Fig. 1 and 2.

- **Question 1.** The teaching methods used in this course are effective for promoting student learning.
- **Question 2.** The instructor explains the material clearly.
- **Question 3.** The instructor is available during office hours.
- **Question 4.** The instructor creates an environment that fosters student involvement in the learning process.
- **Question 5.** The instructor demonstrates a positive attitude toward helping students.
- Question 6. The instructor facilitates student learning.
- Question 7. Graded work reflects the content of the course.
- Question 8. The stated grading policies for this course are fair.
- Question 9. The course goals are clearly stated.
- Question 10. The course goals are being met.
- Question 11. Overall, this instructor is effective.

Figure 1. Course evaluation data, S13

Figure 2. Course evaluation data, F15
The course evaluation form also contains three open-ended questions that ask students to specify the aspects of instruction in the course that are effective for learning, to make recommendations to improve the instruction, and to input any additional comments that the student may have.

In S13, there were few overarching comments on the course. Some students did have a positive impression on the course, but many did not, such as one student who stated “This is not a course for grad students.”

However, the comments in F15 were universally positive, including:

- “Fantastic class. This is the type of class I expected to be taking in graduate school.”
- “I really enjoyed this class! It’s very different than other classes offered at Mines. Instead of it being extremely heavy in theory, codes, and calculations, this class was more critical thinking and applying our knowledge and understanding of structures to figure them out and analyze them.”
- “I just have to say that this was one of my favorite classes that I’ve taken in all my years at Mines as an undergrad and a grad student. I think the main reason for that is that we were expected to work on truly open-ended problems. We were able to make assumptions (and defend them) and come to conclusions for a problem that had no ‘right answer.’ While other classes try to do similar things to this, I think Susan’s class really strikes the right balance of coming up with realistic problems that aren’t so open ended that there’s no wrong answer, but still allowing us to really think about the problem.”

The overall positive experience of students in this offering might be attributed to self-selection bias (only seven of ten chose to fill out the survey), or the smaller section size and improved student-to-teacher ratio, or the increased number of field trips (a course improvement undertaken due to student feedback in the S13 offering that was also mentioned frequently in the course evaluation comments). However, it can be inferred from the comments of the seven participants that the written reflections seem to be an important component of the success of the course.

Sample Reflections and Grading Procedures

Each weekly reflection prompt consisted of three or four bullets from the instructor – most of which were multi-modal. That is, instead of having the students frame and solve the problem in just one mode (the computational mode that is typical in engineering education), a given prompt would also tie in other modes of evaluation and understanding.

In the comprehension and evaluation mode, students performed a reading or viewed a video and summarized key points, drew conclusions, and analyzed information. In the site analysis and evaluation mode, students were asked to visit a physical site (often a building on campus), and interpret that site through drawings and discussion. In the professional mode, students reflected on a wide range of professional skills, such as oral communication skills, written communication skills, cost analysis, ethics, design priorities, decision methods, etc. Reflection prompts can also be categorized as exercise effectiveness. In this mode, the instructor directly asks the students whether or not specific course activities are effective. These modes of evaluation and understanding are best illustrated through examples, as shown in Table 2.
<table>
<thead>
<tr>
<th>Prompt</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Table 2. Sample Multi-modal Reflection Prompts</strong></td>
<td><strong>Comprehension and Evaluation</strong></td>
</tr>
<tr>
<td>Read Rabun pg. 151-161. Complete the stress analysis of the un seasoned masonry wall under the gravity loads introduced in lecture on Tuesday 11/3. Use a graphic method similar to the diagrams in the textbook to plot the tension and compression stresses that you calculate on the exterior and interior faces of the wall. Tabulate key stresses from the top of the parapet down to the top of the footing and linearly interpolate between those values. Do you have any observations or comments on this exercise? Was this a useful exercise for you, or too simplistic?</td>
<td>x</td>
</tr>
<tr>
<td>What assumptions did you have to make in your analysis of the John Cabin Bridge? What sources did you use to develop the assumptions? What is the role of conservatism in making assumptions for historic structures?</td>
<td></td>
</tr>
<tr>
<td>On Thursday, we visited the Chauvenet Hall basement. List 3 &quot;nuggets&quot; (useful pieces of information) that you learned from the site visit. These could range from technical observations (&quot;I learned that rising damp can cause paint on bricks to blister&quot;) or skills/techniques (&quot;I learned to always open louvers&quot;) or site logistics (&quot;I learned that it is better to review the floor plans thoroughly before a site visit&quot;), etc. In other words, what did you learn on the site visit that wouldn't have been learned in a traditional lecture format?</td>
<td></td>
</tr>
<tr>
<td>In the YouTube link previously distributed, describe the problem that Robert Silman &amp; Associates was hired to address. What are the pros and cons of the solution presented? Give at least one example of how the speaker used tone and language to communicate technical concepts to a layperson audience.</td>
<td></td>
</tr>
<tr>
<td>Last week you drew a section through a steel beam and composite slab in the 3rd floor BBW corridor where you observed cracks perpendicular to the axis of the corridor. Say that you were the original designer, and that you knew about the architect's desire for ornamental sawcuts in the top of the slab. Describe your design approach to mitigate (or disguise) cracking and provide section drawings that illustrate your ideas. What are the rough cost implications of the decisions you made (a cost estimate is not required, just a discussion of what cost might be added to the project due to your design)?</td>
<td></td>
</tr>
</tbody>
</table>
For further illustration, here is the way that two different students responded to a specific reflection prompt in the *comprehension and evaluation* mode and the *exercise effectiveness* mode (minor spelling and grammar errors have been corrected):

Prompt: “Access the 2012 IEBC (International Existing Building Code) online. Familiarize yourself with the document by browsing the table of contents. Select one appendix related to structural analysis (A1, A2, A3, A4, A5, etc.). Browse the appendix to gain a rough understanding of the contents. Summarize the contents of the Appendix. Did you find this exercise interesting or surprising? Why or why not?”

**Student A:** “Section A5 of the International Existing Building Code focuses on ‘Earthquake Hazard Reduction in Existing Concrete Buildings.’ This section dictates a three-tiered approach to the analysis of existing concrete buildings for seismic deficiencies. The first tier is simply a report: a relative succinct summary of the building, observations from the design professional, earthquake design values, ‘quick-check analysis calculations,’ and a summary of all structural deficiencies. Tier 2 describes a more in-depth analysis of the building, including mathematical models, stiffness calculations, and other analyses that closely match modern day seismic design techniques. The code is very explicit about which buildings can and can’t be designed using a Tier 2 analysis. Any building that is too large or too irregular to be designed with Tier 2 must use Tier 3. Tier 3 is simply a reference to a particular section of ASCE 41. This section is a nonlinear analysis procedure that the IEBC requires for irregular, existing concrete structures.

I don’t know if I can say I found reading through the code *interesting*, but I do think it was a useful exercise to spend a bit of time on. I don’t think I’ve ever actually read through the code before. I’ve used a number of different codes in different design classes, but only as a place to get equations, limits, etc. from. I’ve never just read the sections from start to end. So in that way it was interesting, if a bit dry.”

**Student B:** “I chose to browse through ‘Appendix A5 – Earthquake Hazard Reduction in Existing Concrete Buildings.’ This appendix is, as the title suggests, meant to address the minimum standards for seismic resistance in existing concrete and concrete frame buildings. The first section, A501, mainly states that the purpose of the appendix is to ‘promote public safety and welfare by reducing the risk of death or injury that may result from the effects of earthquakes on concrete buildings.’ Section A502 describes specific characteristics of the type of concrete buildings this appendix applies to. Buildings with flexible diaphragms or a Seismic Design Category A do not apply. This section also lists the design codes that previously met the standards required of the appendix, meaning that if those codes were used for the design, the building complies with the requirements of the 2012 IEBC. Section A503 describes the three-tier procedure that is used for analysis in A5. Material properties and structural testing, observation, and inspection are briefly addressed in this section as well. The site ground motions to be used for each tier are discussed in Section A504. Sections A505, A506, and A507 each provide the methods required for analysis of a conforming building, one requiring linear methods of seismic analysis, and one requiring nonlinear methods of seismic analysis, respectively.
I found this exercise to be interesting. The code seems to make statements or requirements that contradict each other, allowing for many possible loopholes. I believe that one engineer could interpret the code differently than another engineer, which could cause conflict, or as I mentioned, allow for loopholes to be found in the code.”

Figures 3, 4, and 5 illustrate sample reflections from students in some of the other modes of evaluation and understanding.
Figure 4 – Sample Reflection, *Site Analysis and Evaluation Mode*

Figure 5 – Sample Reflection, *Computational Mode*
The grading procedure for the reflections is dissimilar to standard procedures for closed-ended problems, which typically consist of the creation of a rubric that specifies a point deduction for each error. Instead, a summative assessment of the student’s understanding was conducted by the instructor in two steps: a thorough reading, critique, and commentary on the written reflection, and an abbreviated skim through the supporting calculations and drawings. Depending on the class size, this approach can actually take less time than grading a closed-ended problem, after accounting for the time required to create a solution and rubric. The reflections were compared and partitioned into three or four tiers: oftentimes a tier for 95%, a tier for 85%, and a tier for 75%. Truly exceptional work was awarded 100%, and the tiers for a given week were adjusted according to student performance. The students are very appreciative of individual feedback from the instructor, and the course evaluation comments revealed that they perceive this activity to be more time-consuming than it actually is. Individual feedback to each student was typed in an electronic document that was keyed to the hard-copy submission. This method was quick and effective, in that it facilitated the ability to repeatedly copy and paste certain comments that applied to multiple students. The instructor printed the word document, cut out the personalized comments for each student, and stapled them to their submission, as shown in Figures 6 and 7.

![Sample Student Reflection with Keyed Grading Notes](image)

**Figure 6 – Sample Student Reflection with Keyed Grading Notes**

- a) Are they 2 cracks or could you say that they are 2 portions of one large crack?
- b) When you find yourself going to this level of detail in your description of a spatial phenomenon, you are probably better off just referring the reader to a sketch or annotated photo.
- c) Good observation.
- d) You are correct that the lower elevation of the surrounding paving is probably a contributing factor. But I wouldn’t attribute it to the additional subfloor constructed dead load that you reference. More on this in class...

**Figure 7 – Key for Grading Notes for the Sample Student Reflection**
Conclusions

The purpose of this paper is to stimulate discussion in the use of written engineering reflections for assessment of open-ended engineering problems and to provide grading strategies for faculty interested in adopting this technique. A comparison of the students’ responses on course evaluation forms in S13 and F15 yielded insight on how the pedagogical change impacted student learning.

Faculty that wish to adopt this technique to their courses are encouraged to provide timely personalized feedback to the students. The students seem to appreciate the feedback on the reflections more than the grade, as shown on the F15 course evaluation comments:

- “I don’t think this style of homework would work in a class with more students, but since Susan found the time to thoughtfully comment on all of our reflections, it became very useful.”
- “The feedback that you give us takes a lot of time on your end but is EXTREMELY helpful because it allows me to reflect on ideas/observations I may have missed.”
- “It was also nice that Susan gave specific feedback on these so we could see how we were doing on our understanding of the material.”

Faculty that wish to adapt this pedagogy to their own courses should also endeavor to establish a classroom culture in which students have freedom to learn through failure and to learn from peers while de-emphasizing grades. At the graduate level in particular, students want the freedom to make mistakes, to learn from the experience, and to gain confidence in their abilities. It is important to get student buy-in on the unconventional evaluation process on the first day of class by referencing a trust model: the instructor must trust the students to give 100% effort and commit to learning for the sake of learning, and the students must trust the instructor to evaluate them fairly and issue grades accordingly.

References

Susan M. Reynolds

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Macroethics Education in Engineering and Computing Courses

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Abstract

For engineering to reach its full potential to benefit society, students must be prepared to engage in broad considerations of macroethical issues, including the collective responsibility of the profession toward issues such as sustainability, poverty, and bioethics. This research explored the extent to which faculty report educating engineering and computing students to consider macroethical issues in their courses; over 1100 survey responses were received. Over 50% of the respondents taught students about professional practice issues and the societal impacts of engineering and technology in one or more of their courses; only 12% did not include any topics related to social or ethical issues in their courses. Faculty most commonly reported teaching these topics in senior capstone design (41%); 30% also taught these issues in graduate level courses. The majority of the respondents felt that both undergraduate and graduate student education on these issues was not adequate (67% and 80%, respectively).

Keywords

Ethics; societal impacts; sustainability.

Background

There is general consensus that engineers need to perform their duties in an ethical manner, carefully considering the broader positive and potentially negative consequences of their work.¹ This professional responsibility encompasses a broad range of topics. Topics that have traditionally fallen under the definition of ethics often focus on microethical concepts - personal and business related requirements that are commonly outlined in various professional codes of ethics.²,³ However, engineers should also consider their broader responsibilities to society as a whole in areas such as sustainability— encompassing what has been termed macroethics.⁴

There are numerous published examples of specific courses where students are taught about ethical issues – including traditional microethics and broader macroethical issues such as engineers’ responsibilities to society.⁵ These topics are required in some form in accredited programs given current ABET Engineering Accreditation Commission (EAC) and Computing Accreditation Commission (CAC) requirements.⁶-⁷ However, a broad understanding of how and where engineering and computing students are taught to consider these issues, and whether or not this education is adequate appears lacking. For example, recent modifications to the ABET EAC criteria specific for civil engineering programs seemed to reflect consensus that ethics education may have been insufficient.⁸ In order to provide greater clarity to understanding the scope of both micro- and macro- ethics education, a national study was conducted.
Research Questions

The questions that are explored in this paper are:

RQ1: What topics related to ethics, including macroethics / societal impact issues, are most commonly taught to engineering and computing students?

RQ2: In what types of courses are topics related to ethics and social impact issues taught to students?

RQ3: To what extent do engineering and computing faculty feel that undergraduate and graduate students in their program receive sufficient education about ethics and societal impact issues?

For each of these research questions, it was also of interest to determine if there were differences between different disciplines.

Methods

An online survey was used to gather information from engineering and computing faculty. The survey questions were developed based on published literature,9-12 followed by a pilot phase at three institutions that included preliminary versions of the survey questions in an online format and follow-up interviews with some individuals experienced in teaching engineering ethics.13 This process resulted in changing the terminology used in the survey to avoid the word macroethics, due to lack of clarity among survey respondents, among other revisions. Two revised surveys were then created using the online Qualtrics platform. Both surveys began with an informed consent statement, approved by the University of Colorado Boulder IRB. If the respondent consented to participate in the survey, a series of questions were then displayed. These were primarily multiple-select and multiple choice items. The “curricular” version of the survey started with questions on courses (what, where, how ethics issues were taught), then opinions on the adequacy of ethics education, then ethics education via co-curricular activities, and concluded with demographic questions. The “co-curricular” version of the survey included the same questions, but presented them in a different order; it started with questions on informal learning activities, then teaching in courses, then opinions on education sufficiency, and concluded with demographics. For the purpose of this study, a key demographic question was “engineering disciplines where you teach societal context and/or ethics”; 26 disciplines were indicated and faculty were free to check as many disciplines as applied, as well as ‘other’.

Email invitations to participate in the survey were distributed to a number of lists. The email indicated that the purpose of the study was to explore how faculty teach engineering and computing students about ethics and the social impacts of technology via both courses and co-curricular activities. The curricular survey link was emailed to lists including the American Society for Engineering Education (ASEE) ethics division and community engagement division. The link was also posted on the Online Ethics Center (OEC) for Engineering and Science website. The first author self-compiled a list of names from among NSF grantees and published authors with evidence of interest in ethics education; these 1165 people received personalized invitations to the survey. The initial lists may have included individuals from non-engineering disciplines, such as those from philosophy who teach and/or study engineering and computing students. An initial email invitation and one follow-up reminder were sent. The email to the
The co-curricular survey link was distributed to 5106 individuals who were current or former advisors and/or mentors of: professional societies (including the American Society of Civil Engineers (ASCE), Society of Automotive Engineers (SAE), Institute of Electrical and Electronics Engineers (IEEE), Society of Women Engineers (SWE), American Institute of Aerospace and Aeronautical (AIAA), American Institute of Chemical Engineers (AIChE), American Institute of Mechanical Engineers (ASME), National Society of Black Engineers (NSBE), Society of Hispanic Professional Engineers (SHPE), and others), engineering honor societies (including Tau Beta Pi, Chi Epsilon, Upsilon Pi Epsilon, Pi Tau Sigma, Omega Chi Epsilon, Eta Kappa Nu, and others), engineering service groups (Engineers Without Borders, Engineers for a Sustainable World, Engineering World Health, Bridges to Prosperity), engineering design competition mentors (US EPA P3, ASCE Concrete Canoe, Human Powered Vehicle, Solar Decathlon, Shell EcoMarathon, IEEE Solar Splash), and Research Experience for Undergraduates (REU) PIs/co-PIs; for more information see a conference paper focused on this study. The email that invited these individuals to participate in the research had a subject line such as “ASCE student chapter advisor”. The email informed faculty that survey was geared to explore whether faculty mentoring these activities taught students about societal impact and/or ethical issues via these activities, but also encouraged those who believed students did not learn about these issues via the activity to participate in the survey. The respondents to the co-curricular survey are less likely to hold a bias toward the importance of ethics and societal impact issues, and are more likely to represent average engineering faculty members. Among the 971 respondents to the co-curricular survey from Feb. 17 – April 1, 2016, not all completed the questions related to the curricular research questions in this paper; between 802 to 924 completed the course-based questions.

The response rates among the groups invited to participate in the survey were variable. For the four engineering service groups, the response rate ranged from 24-38%. For the professional and honor societies, response rates ranged from 20-43% for 14 groups, 10-19% for 18 groups, and below 10% for 5 groups (the survey timeframe for 4 groups only included an initial email, and no follow-up reminder). For design competition mentors, 5 of 6 groups had response rates of 23-33%; one group had a response rate of 15%. For the REU PIs and/or co-PIs, the response rate was 18%. For the curricular survey, the response rate among authors was 25%, among NSF grantees was 13%, and the general list emails to ASEE divisions was 3-4%. Because the same individuals were likely members of multiple ASEE divisions, as well as potentially receiving individual survey invitations, an overall response rate cannot be readily calculated. The respondents represented a wide range of institutions; the highest degree awarded at the institutions were: 7% from Bachelor’s, 13% from Master’s, and 80% from PhD; 71% public and 29% private. The lowest representation of respondents among the large engineering disciplines appears to be electrical engineering (compared to reported ASEE tenured tenure-track faculty, at most about 2.5% of electrical engineering faculty responded compared to 5.6% mechanical, 6.4% chemical, and 8.4% civil).
The data from the two Qualtrics surveys were exported to Excel. Chi-squared tests were conducted to determine if the responses from the two surveys were significantly different, and to compare responses among disciplines. Significance was inferred when the probability was 0.05 or less. Disciplines with over 100 responses to the course topic question were explored, with the exception of environmental engineering: mechanical (n=246), civil (n = 238), computer (n=180), electrical (n=138), chemical (n=122), and biomedical (n=115). Environmental engineering was not considered sufficiently distinct from civil engineering, as 58% of the 134 environmental respondents also indicated civil. Some overlap was also found among other disciplines, but they were considered sufficiently distinct for analysis. For electrical engineering, 41% of the respondents also taught computer engineering. For computer engineering, 32% also taught electrical engineering. For biomedical, 23% also taught mechanical, 19% chemical, and 18% electrical. Individuals teaching other engineering disciplines are also represented among the respondents, including aerospace, agricultural, architectural, biological, engineering management, geological, general, industrial, materials, mining, nuclear, and petroleum.

**Results**

The survey respondents were presented with 18 potential topics related to ethics and broader societal impact / macroethical issues (as well as “other” and “none”), and asked to identify which were incorporated into one or more of their courses; results are summarized in Figure 1. There were 1228 responses to this question. There were two topics that were incorporated into one or more courses by over 50% of the respondents: professional practice issues and societal impacts of engineering and technology. Both of these topics are very broad and vague, and as such it is not surprising that these topics are quite common. More specific topics were less prevalent. Four topics were taught by 40-49% of the respondents, and four additional topics were taught by 30-39 of the respondents; eight topics were taught in courses by less than 20% of the respondents.

Research Question #1: Topics. Only 12% of the respondents indicated that they did not teach any of these topics in their courses. In reality, it is possible that a much higher percentage of engineering and computing faculty do not include ethics-related topics in any of their courses. But given the survey invitation, those individuals were unlikely to respond to the survey. In this case, the co-curricular survey invited all mentors/advisors to take the survey on the basis of their co-curricular involvement. The survey invitation also stated “Even if you don’t believe the students learn about the societal impacts of technology or ethics through activities with [insert co-curricular name here], please take a minute to indicate that on the survey.” Thus, a larger percentage of the co-curricular survey respondents (13.5%) answered the course-based ethics survey question negatively (compared to 8.2% on the curricular survey). The additional 54 individuals who began the co-curricular survey but did not answer the curricular question (5.5%) may also have not taught those topics in their courses and thus skipped the question (among those, most stopped taking the survey entirely at that point).
It was found that there were differences in the frequency that some topics were identified between individuals who responded to the curricular versus the co-curricular survey. On average, respondents to the curricular surveys indicated 7 of these topics that they taught in their courses, compared to only 5 topics among the co-curricular survey respondents. Among the individual topics, 12 of the 20 topics had significantly different representation among the curricular and co-curricular respondents (Table 1). The only topic taught more frequently among respondents to the co-curricular survey was ‘risk and liabilities.' Also “no topics related to the societal impacts of technology or ethics in any courses” was reported by 14% of the co-curricular respondents but only 8% of the curricular respondents.
Table 1. Contrast in topic prevalence among different respondent groups

<table>
<thead>
<tr>
<th>Topics</th>
<th>Significantly higher, % higher</th>
<th>Highest discipline, %</th>
<th>Lowest discipline, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Professional practice issues</td>
<td>Curricular 18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Societal impacts of engineering and technology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering decisions in the face of uncertainty</td>
<td></td>
<td>Chemical 64</td>
<td>Computer 39</td>
</tr>
<tr>
<td>Safety</td>
<td></td>
<td>Chemical 72</td>
<td>Computer 37</td>
</tr>
<tr>
<td>Engineering code of ethics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sustainability and/or sustainable development</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethical failures/disasters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethics in design projects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental protection issues</td>
<td></td>
<td>Chemical 57</td>
<td>Computer 16</td>
</tr>
<tr>
<td>Responsible conduct of research</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk and liabilities</td>
<td>Co-curricular 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering and poverty</td>
<td>Curricular 33</td>
<td>Computer 30</td>
<td>Mech 20</td>
</tr>
<tr>
<td>Social justice</td>
<td>Curricular 27</td>
<td>Computer 26</td>
<td>Mech 12</td>
</tr>
<tr>
<td>Ethical theories</td>
<td></td>
<td>Biomed 27</td>
<td>Mech 17</td>
</tr>
<tr>
<td>Privacy and civil liberties</td>
<td>Curricular 26</td>
<td>Computer 33</td>
<td>Mech 10</td>
</tr>
<tr>
<td>No topics related to social / ethical issues</td>
<td>Co-curricular 5</td>
<td>Biomed 14</td>
<td>Civil 4</td>
</tr>
<tr>
<td>War, peace, military applications of engineering</td>
<td>Curricular 21</td>
<td>Computer 28</td>
<td>Civil 4</td>
</tr>
<tr>
<td>Other topics related to social, ethical issues</td>
<td>Curricular 16</td>
<td>Computer 16</td>
<td>Civil 4</td>
</tr>
<tr>
<td>Bioethics</td>
<td>Curricular 9</td>
<td>Biomed 42</td>
<td>Civil 5</td>
</tr>
<tr>
<td>Nanotechnology ethics</td>
<td>Curricular 6</td>
<td>Biomed 14</td>
<td>Mech 2</td>
</tr>
</tbody>
</table>

* For columns 2, 3, and 4, only statistically significant results are shown; colors help highlight particular majors

After combining the curricular and co-curricular responses, potential differences in six disciplines were explored. Overall, mechanical respondents averaged the lowest number of topics per respondents (5.8), while chemical averaged the highest (7.0). Comparing the prevalence of topics among the six disciplines, there were differences among 16 of the 20 response options. All disciplines were similar in the extent that four topics were taught in courses: professional practice issues, societal impacts of technology, ethics in design projects, and risks/liabilities. Table 1 shows the disciplines with the highest and lowest percentage of respondents teaching the topics with significant differences. Some findings were not surprising: biomedical engineering students were the most likely to be taught about bioethics (42%), followed by chemical engineering (12%), with other disciplines at 6% or less. The prevalence of the six disciplines across two topics, environmental protection and safety, are shown in Figure 2. This shows that different topics related to ethics appear to vary in the extent to which they are taught to students in different disciplines. This is clearly appropriate, as some topics have greater relevance in some disciplines.
Figure 2. Percentage of individuals teaching different disciplines who teach topics related to environmental protection or safety in one or more of their courses

Research Question #2: Courses. The second research question explored the types of courses where individuals reported teaching topics related to ethics and societal impacts; 1081 responses were received (this question was not displayed to those who indicated that they did not teach any topics related to ethics or societal impacts). On average, each person indicated 2.3 different courses. At some research intensive institutions this may represent the majority of courses taught, where typical teaching loads are about three to four courses per academic year. In contrast, at Bachelor’s institutions and/or among full time instructors, teaching loads may be six to eight courses per year. The most prevalent course types are shown in Table 2. About 40% of respondents indicated that ethics-related topics were incorporated into their senior capstone design and sophomore/junior level core engineering science/engineering courses that they taught. The results might largely reflect the extent to which these courses were taught by the respondents, rather than the predominance of ethical topics in these type of courses more generally. For example, it is assumed that one or more of these topics is likely incorporated into nearly all senior capstone design courses; the fact that 41% of the survey respondents (or more) taught capstone design is surprisingly high. In contrast, there are typically many more sophomore/junior level engineering science/engineering courses in curricula. Comparing the two surveys, respondents to the co-curricular survey more widely indicated that they integrated ethics topics in senior capstone design, and sophomore or junior level engineering science/engineering courses or design-focused courses.

There were differences between disciplines in the extent to which half of the course types were reported (Table 2). For example, 41% of those who taught civil engineering students reported teaching design-focused courses in the sophomore, junior, or senior year that included ethics topics, compared to only 27% of those teaching chemical engineering or computing students. Perhaps these types of courses are less common in those curricula overall, or when offered they may be less likely to include ethics-related issues. Which reason accounts for the difference is a question for future research. Few reported teaching a full course on engineering ethics, but this
was more common among computer engineering and the least common among chemical engineering. All disciplines included ethical issues with similar frequency in senior capstone design courses, sophomore and junior core engineering science or engineering courses, first year introductory courses, first year design courses, and humanities and/or social science courses.

Table 2. Types of courses where topics related to ethics are taught

<table>
<thead>
<tr>
<th>Course type</th>
<th>% all responses</th>
<th>Higher response type, % higher</th>
<th>Highest discipline, %</th>
<th>Lowest discipline, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senior capstone design</td>
<td>41</td>
<td>Co-curr 20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sophomore or junior core engineering science or engineering course</td>
<td>40</td>
<td>Co-curr 15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design focused sophomore, junior, or senior course</td>
<td>31</td>
<td>Co-curr 14</td>
<td>Civil 41</td>
<td>Comp, chem 27</td>
</tr>
<tr>
<td>First year introductory course</td>
<td>31</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graduate level course</td>
<td>30</td>
<td></td>
<td>Biomed 41</td>
<td>Elect 18</td>
</tr>
<tr>
<td>Professional issues course</td>
<td>17</td>
<td>Curricular 8</td>
<td>Civil, comp 25</td>
<td>Mech 15</td>
</tr>
<tr>
<td>Other</td>
<td>12</td>
<td>Curricular 11</td>
<td>Chemical 18</td>
<td>Civil 7</td>
</tr>
<tr>
<td>First year design</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humanities and/or social science course</td>
<td>9</td>
<td>Curricular 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full course on engineering ethics</td>
<td>7</td>
<td>Curricular 12</td>
<td>Computer 15</td>
<td>Chemical 7</td>
</tr>
</tbody>
</table>

* For columns 3, 4, and 5, only statistically significant results are shown

Different topics also appeared to be associated with particular course types. For example, in full courses on ethics, the engineering code of ethics (81%), ethical failures/disasters (82%), societal impacts of technology (82%), ethical theories (60%), and privacy/civil liberties (35%) were much more common than in other course types (37-64%, 45-65%, 57-70%, 18-30%, and 10-19%, respectively). Responsible conduct of research was the most common in graduate-level courses (52%) and much less common in all other types of courses (36-45%). However, many of the other topics were least widely reported in graduate-level courses; it is likely that a portion of the respondents did not teach any graduate level courses, since 7% of the respondents indicated that they taught at institutions where the highest degree awarded was a Bachelor’s degree (of n=1161). Overall, the greatest number of topics (9.8, on average) were taught by individuals who taught full courses on engineering ethics; the fewest topics (6.4, on average) were taught by individuals who reported teaching graduate-level courses.

Research Question #3: Adequacy of Ethics Education. The third research question explored the extent to which respondents felt students in their program received adequate education on ethical issues. First, the individuals who indicated they did not know (in the case of undergraduates) and/or it did not apply (in the case of graduate students) were removed from the data set (for undergraduates, 13% of respondents to the co-curricular survey, 13% of respondents to the curricular survey; for graduate students, 32% of the co-curricular survey respondents and 30% of the curricular survey respondents). The results for those who provided an opinion for undergraduates in their program (n=1047) are summarized in Table 3.
Table 3. In your opinion, do undergraduate engineering/computing students in your program receive sufficient education on the societal impacts of technology and ethical issues?

<table>
<thead>
<tr>
<th>Response</th>
<th>All, %</th>
<th>Higher response type, % higher</th>
<th>Highest response discipline, %</th>
<th>Lowest response discipline, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes, but too much; the time could be better spent on other topics</td>
<td>1</td>
<td>Co-curr 2</td>
<td>Mechanical 3</td>
<td>Chem, Elect 0</td>
</tr>
<tr>
<td>Yes, a sufficient amount</td>
<td>32</td>
<td>Co-curr 6</td>
<td>Civil 19</td>
<td>Chemical 11</td>
</tr>
<tr>
<td>A sufficient amount of ethics, but insufficient on the broader impacts of technology</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A sufficient amount on the broader impact of technology, but not enough ethics</td>
<td>12</td>
<td></td>
<td>Chemical 18</td>
<td>Mechanical 9</td>
</tr>
<tr>
<td>No, not enough</td>
<td>39</td>
<td>Curricular 24</td>
<td>Computer 41</td>
<td>Biomed 33</td>
</tr>
</tbody>
</table>

*Italics = differences not statistically significant in chi-square test*

The most respondents felt that the education of undergraduate students on ethical issues was not adequate (51%, based on adding the ‘no, not enough’ and the ‘…but not enough ethics’ responses), nor was education on broader impacts (55%, based on adding the ‘no, not enough’ and the ‘…but insufficient on the broader impacts of technology’ responses). Only 33% felt there was sufficient education of undergraduate students on these issues (combining the too much and sufficient categories). Significantly more of the curricular survey respondents felt that education in both microethics and macroethics was insufficient (57%; compared to only 33% of the co-curricular survey respondents). There were not statistically significant differences between disciplines in these opinions.

For graduate students, there was again general consensus that education on ethical issues was not sufficient (Table 4). Among those who responded to the co-curricular survey, 22% believed there was adequate ethics education for graduate students, compared to only 12% of the curricular survey respondents. There were also significant differences between disciplines for the perceived adequacy of graduate education on ethical issues (p = 0.003). This adequacy perception is expected to be influenced by knowledge of the extent to which these issues are covered in the curriculum, as well as a person’s individual opinion on what would constitute sufficient education. It is expected that faculty have different beliefs on what constitutes sufficient education on microethics and macroethical issues.
Table 4. In your opinion, do graduate engineering/computing students in your program receive sufficient education on the societal impacts of technology and ethical issues?

<table>
<thead>
<tr>
<th>Response</th>
<th>All, %</th>
<th>Higher response type, % higher</th>
<th>Highest response discipline, %</th>
<th>Lowest response discipline, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes, but too much; the time could be better spent on other topics</td>
<td>1</td>
<td>Computer 3%</td>
<td>Civil 0%</td>
<td></td>
</tr>
<tr>
<td>Yes, a sufficient amount</td>
<td>18</td>
<td>Co-curr 10%</td>
<td>Electrical 28%</td>
<td>Mechanical 15%</td>
</tr>
<tr>
<td>A sufficient amount of ethics, but insufficient on the broader impacts of technology</td>
<td>9</td>
<td>Biomed 15%</td>
<td>Computer 6%</td>
<td></td>
</tr>
<tr>
<td>A sufficient amount on the broader impact of technology, but not enough ethics</td>
<td>10</td>
<td>Civil 14%</td>
<td>Electrical 1%</td>
<td></td>
</tr>
<tr>
<td>No, not enough</td>
<td>62</td>
<td>Curr 17%</td>
<td>Computer 66%</td>
<td>Biomed 49%</td>
</tr>
</tbody>
</table>

*Italics = differences not statistically significant in chi-square test*

Summary and Discussion

The survey respondents reported teaching a wide range of topics related to ethics and societal impact issues. The frequency that most of these topics were cited varied between those who responded to the curricular and co-curricular surveys, and also varied among different engineering disciplines. The topics related to ethics were taught in a variety of different undergraduate courses, as well as graduate-level courses. The types of courses reported varied between the respondents to the curricular and co-curricular surveys. For about half of the course types, the frequency also varied among disciplines. In general, over half of the faculty believe that there are deficiencies in the education of engineering and/or computing undergraduate and graduate students in their programs on ethical and/or societal impact issues.

This paper presented the results from a large national survey. However, a number of limitations should be acknowledged. First, those who chose to respond to a survey about the education of engineering and computing students on ethics and societal impacts issues likely care more about these issues than those who were not invited to participate and/or did not choose to participate in the survey. Those invited to take the curricular survey were more likely to be biased toward the importance of these issues, given the lists to which the invitation was distributed. For the co-curricular survey, individuals are not expected to be biased toward societal impact or ethics education. Seeing the differences in the responses between the two surveys reinforces the notion that the curricular survey respondents were more likely advocates for societal and ethical education of engineering and computing students as compared to co-curricular mentors who may be more representative of faculty in general. Unlike to be significantly represented among the survey respondents are those faculty who care more about research than student education. The survey is on-going and additional respondents may reflect a wider array of experiences and attitudes. For example, if it is determined that particular disciplines and/or institutional types are not well represented, more targeted efforts will be devoted to encourage responses from those groups.

A second limitation of the survey results is the blurred line linking particular ethics-related topics to particular courses. For two of the research questions presented in this paper, individuals...
considered the myriad of courses that they taught. Tenure-track faculty at undergraduate/teaching-focused institutions and/or full time instructors may routinely teach six courses. Perhaps they integrate ethical and societal impact issues into only half of those courses, and among those three courses different topics in different courses. That level of detail is unknown. We also don’t know who among the respondents might teach a type of course and not include ethics/societal impact issues.

The surveys include a lot of additional information that was not analyzed and presented in the current paper. The goals of the larger study include identifying exemplars for teaching different topics in different courses using various pedagogies and assessment methods. Thus, many survey respondents provided some of this basic information for one or two of their courses. In response to an open-ended question, a number of the survey respondents indicated that societal impact and ethics issues should be integrated into courses across the curriculum. Given the large number of examples provided by survey respondents, it appears that there are opportunities to infuse these topics into any course. Touching on these issues frequently, even if not in-depth, may reinforce to students that considering societal impacts is an important part of the common activity of engineers in all settings. This approach may also be less intimidating to engineering faculty, as for the most part they have not been formally trained in teaching ethics. The list of topics described in this paper provide basic ideas, some of which are more common for particular disciplines.

A series of interviews are planned to explore promising macroethics education approaches, and a smaller number of examples will be selected as case studies for detailed study (including student and alumni interviews, classroom observations, etc.). The National Academy of Engineering has recently compiled a list of case studies of ethics education, and this may also give faculty who are interested in examples of effective teaching approaches. Thus, resources are already available and more are being generated to support faculty with an interest in teaching students about societal impact and ethical issues.

Acknowledgement

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**Angela Bielefeldt**

Professor Bielefeldt is a professor in the Department of Civil, Environmental, & Architectural Engineering at the University of Colorado Boulder, where she also serves as the ABET assessment coordinator. She routinely teaches a first-year introductory course for civil engineering, which includes learning modules on ethics and sustainable engineering. She has recently begun to teach a Professional Issues in Civil Engineering course, which reinforces ethics and societal impact issues for senior undergraduate students. Her engineering education research encompasses learning through service, social responsibility, sustainability, ethics, and retention issues for diverse students. She is also a licensed P.E.

**Daniel Knight**

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Daniel Knight is the Program Assessment and Research Associate at Design Center (DC) Colorado in the College of Engineering and Applied Science at the University of Colorado Boulder (CU). He holds a B.A. in psychology from Louisiana State University, and an M.S. degree in industrial/organizational psychology and a Ph.D. degree in education, both from the University of Tennessee. Dr. Knight’s research interests are in the areas of retention and program evaluation in engineering education. He also routinely teaches ethics in the context of design to students in the first year engineering projects course at CU.

Christopher Swan

Chris Swan is the Associate Dean of the Jonathan M. Tisch College of Citizenship and Public Service and an associate professor in the Civil and Environmental Engineering department at Tufts University. He has additional appointments in the Department of Education and the Center for Engineering Education and Outreach at Tufts. His current engineering education research interests focus on learning through service-based projects and using an entrepreneurial mindset to further engineering education innovations. He also researches the development of reuse strategies for waste materials.

Nathan Canney

Dr. Canney teaches civil engineering at Seattle University. His research focuses on engineering education, specifically the development of social responsibility in engineering students. Other areas of interest include ethics, service learning, and sustainability education. Dr. Canney received bachelor’s degrees in Civil Engineering and Mathematics from Seattle University, a masters in Civil Engineering from Stanford University with an emphasis on structural engineering, and a Ph.D. in Civil Engineering from the University of Colorado, Boulder. He is also a licensed P.E.
Adding a New Dimension to a Traditional Conduction Lab

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Utah State University Department of Mechanical & Aerospace Engineering

Abstract

We present an integrated experimental and numerical two-dimensional heat conduction exercise to provide analytical and visual validation of basic concepts. The advanced nature of heat transfer leads many instructors to spend a considerable time on numerical techniques. However, due to time limitations, these numerical approaches are often only applied to highly simplified problems within the course. To overcome these instructional barriers, we designed an instructional laboratory to study two-dimensional conduction. The experimental apparatus consists of a thin sheet of copper wired with an array of thermocouples and paired with temperature-controlled circulating baths capable of creating temperature differences across the surface. The system is operated with a LabVIEW VI to provide a temporal visualization of temperature over the surface. The exercise provides students with a chance to visualize and solidify fundamental principles while also strengthening related concepts such as the importance of experimental validation, error and uncertainty calculation and the power of numerical tools.

Keywords

two-dimensional conduction, heat transfer, numerical methods

Introduction

The lab assignment has always been an invaluable component of any engineering curriculum because the application of engineering methods requires more than a theoretical understanding of scientific principles. Feisel and Rosa write that for an engineer to successfully perform the function of their profession, they must possess a knowledge of natural principles that goes beyond mere theory. Conceptual understanding is strengthened when students are able to directly interact with a scientific principle through active learning rather than simply reading or hearing about it. Additionally, this exposure lends insight into the discrepancies between real-world application and theory. This paper outlines the creation of a new heat transfer lab which is more complex and configurable than currently available options. We also present student responses to a survey regarding lab effectiveness as well as suggestions for improvement.

Current state-of-the-art commercial conduction experiments include devices that demonstrate linear and/or radial conduction. A standard linear conduction apparatus typically consists of three cylindrical bars, with a constant cross-sectional area, clamped longitudinally end to end. The bar on one end of the assembly is heated while the bar on the opposite end of the assembly is cooled, driving the conduction process. The middle bar can be replaced by the user to vary material, length, and cross section. Thermocouples are placed at uniform intervals along all three bars. Radial conduction apparatuses are typically composed of a single metallic, disc-shaped, test element which is heated in the center and cooled along the outer edge, with thermocouples...
placed radially about the test sample. In both types of experiments, the samples are well insulated to reduce the effects of convection.

The main purpose of linear and radial conduction experiments is to allow students to verify Fourier’s Law of Conduction\(^8\) by determining the rate of heat flow through solid materials. The linear conduction experiments also allow students to determine the thermal conductivity of different materials and measure the temperature distribution for the steady state conduction of uniform, composite, and reduced cross section solids. Additionally, these experiments allow students to measure the effects of contact resistances between adjacent layers in the bar assembly.

These experiments are reasonably effective in demonstrating one dimensional conduction, however, from an educational standpoint they have several limitations. First, the devices provide a relatively limited number of configurations, meaning the data and analysis can be easily shared amongst the student population. Second, students often do not need a physical demonstration of one dimensional conduction to improve their understanding of the concept or the associated analysis. Finally, these experimental devices generally cost between $17,000 - $30,000, which is substantial given their limited educational value for the student.

The goal of this work is to develop an experimental apparatus that demonstrates two-dimensional transient conduction within a flat plate. Two-dimensional, rather than one-dimensional conduction, is chosen because it requires an analytical method that students have difficulty understanding when limited to book learning and lecture. Additionally, an optimal design would be capable of numerous configurations to discourage sharing among the student population, resulting in a greater degree of education value for the relative cost.

**Experimental Apparatus**

The experimental two-dimensional conduction apparatus has five main components: the conduction plate, the heat transfer blocks, the refrigerated/heated circulating baths, the insulated housing, and the data acquisition system (Fig. 1).

The conduction plate was machined from a 0.25 x 12 x 12-inch piece of 101 copper (99.99% copper content). The top side of the plate has milled, 1.5 x 1.5-inch square insets that form a 6 x 6 grid (Fig. 2 (a)). These insets provide discrete locations for the heating and cooling blocks to be placed. The back side of the plate has blind holes drilled in at locations corresponding to the nodes of the insets (corners of insets). The holes have Type J thermocouples (49 total) fixed in them to allow for temperature measurement with ±0.5°C accuracy.

The heat transfer blocks were made from two pieces of 6061 Aluminum that are welded together, measure roughly 1.5 x 1.5 x 1.0 inches, and are coated in silicone. The blocks have a passage for fluid milled into them and are connected to the recirculating heating/cooling baths via silicon tubing and a variety of NPT and barbed fittings (Fig. 2 (b)). The heat transfer blocks are supplied either hot or cold water from PolyScience Performance Digital (PD07R-20-A11B) Refrigerated/Heated Circulating Baths\(^9\). During operation, the blocks are placed in the various milled pockets of the conduction plate (with a thermal compound used to reduce thermal contact resistances) and provide the necessary temperature differences across the conduction plate.
Figure 2: Diagram of the experimental apparatus and its primary components.

Figure 1: Line drawings of (a) copper conduction plate, (b) aluminum heat transfer blocks and (c) the assembled components within the insulated housing.
A steel wall-mount electrical enclosure was used as the basis for the insulated housing (Fig. 2 (c)). The insulated housing has openings on the sides to allow access for the heating and cooling blocks and an opening in the rear for the bundle of thermocouple wires to exit the enclosure. Providing insulation to the bottom of the conduction plate is a 2-inch thick ceramic fiber blanket with a thermal conductivity of 0.06 W/m·K.

The data acquisition system includes a NI CompactDAQ (cDAQ-9714), three 16 channel NI Thermocouple Input Modules (NI 9123), and a user interface created using LabVIEW. A photograph of the complete system can be seen in Fig. 3. The total cost of parts for the apparatus is approximately $13,000. A cost summary for the experimental apparatus can be found in Appendix A.

**Student Experiment**

The conduction heat transfer apparatus was integrated into a lab assignment made to resemble a real-world, industry-based problem. Students were given a scenario in which they were working for a computer manufacturing company. The scenario included a new, thin laptop under development that is housed in a copper shell, which doubles as a heat-sync. The back panel of this machine was expressed as a Cartesian grid to simplify student analysis. Students were told that two processors, at discreet locations, were maintaining their respective squares on the metal housing at relatively warm temperatures. In a similar manner, cooling fans at two grid locations were maintaining cooler temperatures for their respective squares. Their VP of R&D was concerned that an additional, heat sensitive component, may have been placed too near the warmer processors. The exact assignment provided to students can be seen in Appendix B.

Students were asked to solve the problem in two ways, first by coding a numerical model for transient two-dimensional conduction in Matlab using a finite difference approach, and then by using the experimental apparatus. Students estimated the steady state temperature of each square on the Cartesian grid (laptop back panel) and the time to reach steady state through the iteration of numerical conduction calculations. Students assumed that the entire grid was initially at a temperature of 30°C and that specified (hot and cold) squares immediately changed to the prescribed temperatures at the start of the simulation. From this steady-state solution, students were to determine if the heat sensitive component was likely to be warmed beyond its safe operating temperature.

![Figure 3: Photograph of experimental apparatus.](image-url)
After a numerical estimate was achieved, students used the apparatus to verify their result experimentally. Students ran a pre-built LabVIEW program that obtained temperature measurements across the plate surface. Students then dialed the refrigerated/heated circulating baths to the correct temperatures. When the water reached the set temperature, students allowed the hot and cold water to flow to the heating and cooling blocks. The LabVIEW program provided a Cartesian grid output with temperature displayed with color variation. This configuration allowed students to watch the flow of heat energy from the initial temperature distribution, to the final steady state condition. This exercise provided a second conclusion regarding the heat sensitive component, as well as an experimental validation for their numerical estimations. The student’s models overestimated final temperatures by approximately 2-10% as they did not account for convective losses and assumed instant temperature change at heating and cooling blocks. Their models also under-predicted time to steady state conditions by more than 100%.

**Student Response**

Students were given a post-lab survey to evaluate the student opinion of assignment effectiveness. The survey consisted of a series of statements which students could respond to using a six-point Likert scale (1-strongly disagree, 2-disagree, 3-marginally disagree, 4-marginally agree, 5-agree, 6-strongly agree). A neutral option was not offered because we wanted students to decide which way they lean, rather than avoiding an answer to the question. Questions were designed to evaluate student ability, how effectively they felt the lab helped them learn, and whether the lab increased their interest in various topics. Questions and student responses are shown in Fig. 4. The average response value is indicated by a red circle, while red tick marks indicate a range of two standard deviations on either side, or the range in which 95% of the responses fell. 40 students responded to the survey.

The conduction lab and survey were administered to students enrolled in a thermo-fluids lab course at Utah State University taught during the spring semester of 2016. Heat transfer, computer programming and numerical methods are required pre-requisite courses. Questions one and two show that students feel that their understanding is above average for students in their situation. Based on the necessary prerequisite courses and student confidence in their own understanding, we feel it safe to assume that students have already been exposed to two-dimensional heat transfer and have a reasonable understanding of the material.

Questions three, four, and eight focus on whether the lab provided students with an increased understanding of two-dimensional heat transfer and a greater ability to visualize the process. Students generally agreed with this notion, especially in terms of visualization. Additionally, in question five, students generally agree that participating in a numerical and experimental heat transfer project was more instructional than a similar project performed on paper. Questions 6 and 7 indicate that the lab setting not only helped students to gain a better understanding of heat transfer principles, but also provided insight into the discrepancies between mathematical models and application, as well as the need for experimental validation. Many students were quick to observe that system losses and imperfect insulation were among the principle causes for the discrepancies between theoretical and actual results.
Figure 4: Student survey questions and summary of average response values.
Students were nearly indifferent regarding whether this experience more closely resembled a real-world problem than most of the assignments they receive in engineering courses (question 11), making this a point requiring improvement.

Questions nine and ten focus on whether the lab improved student ability as well as interest in computer programming, respectively. While both questions were answered in the affirmative, whether the lab increased student interest in programming was among the lowest scores received. While this could be due to the lab, computer programming is often something that even engineering students at Utah State mention they don’t enjoy, and may be a symptom of other factors rather than the lab itself. Responses regarding the lab were generally positive and most students felt that the lab improved their understanding of both two-dimensional heat transfer and computer programming; additionally, the lab provided insight into the differences between theory and application and the need for experimental validation.

Conclusion

We designed and constructed an experimental two-dimensional conduction apparatus allowing students to observe transient two-dimensional conduction first-hand. The apparatus was made to have several configurations and created at a low cost in comparison to commercially available conduction experiments. The apparatus was used in a lab scenario for students to validate their transient two-dimensional conduction model. After participating in the lab, students were asked a series of questions regarding the effectiveness of the lab in improving their knowledge of two-dimensional conduction and computer programming. The average student responses are generally favorable, indicating that students felt that the assignment improved their knowledge of two-dimensional conduction and computer programming. Additionally, students agreed that the assignment improved their understanding of the need for experimental validation as well as the discrepancies between application and theory. However, responses generally fell between marginally agree (4) and agree (5), indicating that there is room to improve the instructional effectiveness of the assignment. Additionally, the assignment could be improved by making the theoretical situation more realistic, and by adding component to make computer programming more appealing.

References


Jackson J. Graham

Jackson Graham received his BS and MS degrees in Mechanical Engineering from the University of Florida where he also worked as a lab instructor teaching sessions on rapid prototyping, subtractive rapid prototyping, and 3D scanning to engineering undergraduates. He is currently an Assistant Professor of Practice in the Mechanical and Aerospace Engineering Department at Utah State University where he teaches the senior capstone design and engineering graphics courses. He also works to develop new laboratory experiments to reinforce fundamental mechanical engineering concepts and enhance user interactivity at USU.

Randy C. Hurd

Randy Hurd received his M.S. in Mechanical Engineering from Brigham Young University in 2015 and is currently pursuing a PhD in the same field at Utah State University. His research focuses on investigating the impact dynamics of highly deformable spheres with the water free surface. With ideal impact parameters, highly deformable spheres are capable of rebounding off of the water surface in a manner similar to skipping stones, but with greater efficiency. Randy’s research seeks to better understand this phenomenon with the intent of optimization. Randy is also involved in promoting interest in STEM among adolescents and teenagers through a local educational outreach program featuring underwater robotics.

Tadd T. Truscott

Tadd received his B.S. in mechanical engineering in 2003 from the University of Utah. He received his Ph.D. in 2009 from The Massachusetts Institute of Technology for research in the field of hydrodynamics. During his graduate studies he studied the effect of wetting angle from surface treatments and dynamic effects on the water entry of spheres. Additionally, he helped pioneer a quantitative 3D imaging technique now known as Synthetic Aperture Particle Image Velocimetry (SAPIV). Tadd currently works as a professor at Utah State University where his research interests span the fields of fluid dynamics, micro-fluids, bio-engineering, imaging, flow visualization, photographic techniques, and microbiology.
## Appendix A: Summary of components and cost for experimental apparatus

Table 1: Summary of equipment, vendors and cost for experimental apparatus components.

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Part Name/Description</th>
<th>Part Number</th>
<th>Vendor</th>
<th>Cost/Each</th>
<th>Qty.</th>
<th>Total ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>101 Cu Sheet; .25”x 12”x 12”</td>
<td>89675K37</td>
<td>McMaster</td>
<td>184.16</td>
<td>1</td>
<td>184.16</td>
</tr>
<tr>
<td>2</td>
<td>6061 AL Bar Stock; 1”x 1.5”x 12”</td>
<td>8975K52</td>
<td>McMaster</td>
<td>15.00</td>
<td>1</td>
<td>15.00</td>
</tr>
<tr>
<td>3</td>
<td>6061 AL Bar Stock; .125”x 1.5”x 12”</td>
<td>8975K581</td>
<td>McMaster</td>
<td>2.15</td>
<td>1</td>
<td>2.15</td>
</tr>
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<td>4</td>
<td>Ceramic Fiber Blanket; 1” x 24” x 31”, 8lb density</td>
<td>Amazon</td>
<td>Amazon</td>
<td>49.99</td>
<td>2</td>
<td>99.98</td>
</tr>
<tr>
<td>5</td>
<td>Electrical Box; 16” x 16” x 7”</td>
<td>N1A16167</td>
<td>Mouser</td>
<td>140.58</td>
<td>1</td>
<td>140.58</td>
</tr>
<tr>
<td>6</td>
<td>Trim Molding; Need 10ft.</td>
<td>24175K21</td>
<td>McMaster</td>
<td>9.80</td>
<td>1</td>
<td>9.80</td>
</tr>
<tr>
<td>7</td>
<td>Teflon Rigid Tube; 7/16” OD, 5/16” ID x 12” HiTemp</td>
<td>8547K25</td>
<td>McMaster</td>
<td>15.00</td>
<td>1</td>
<td>15.00</td>
</tr>
<tr>
<td>8</td>
<td>Rubber Adhesive Backed Bumpers; 7/8”OD, 13/32” Tall, (x24)</td>
<td>95495K3</td>
<td>McMaster</td>
<td>8.53</td>
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<td>8.53</td>
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<td>9</td>
<td>Pull Handle; 10-32 Threads, Black Anodized</td>
<td>1568A72</td>
<td>McMaster</td>
<td>5.73</td>
<td>3</td>
<td>17.19</td>
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<tr>
<td>10</td>
<td>SS Button Head; 10-32 x 3/8”, Pack of 100</td>
<td>92949A263</td>
<td>McMaster</td>
<td>5.80</td>
<td>1</td>
<td>5.80</td>
</tr>
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<td>11</td>
<td>PVDF Barbed Wye Fittings; 1/4” ID Tube</td>
<td>53055K155</td>
<td>McMaster</td>
<td>3.77</td>
<td>4</td>
<td>15.08</td>
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<tr>
<td>12</td>
<td>SS Button Head; 1/4”-20 x 3.5”, Pack of 10</td>
<td>92949A556</td>
<td>McMaster</td>
<td>8.28</td>
<td>1</td>
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<td>13</td>
<td>SS Nyloc Nut; 1/4”-20, Pack of 50</td>
<td>91831A029</td>
<td>McMaster</td>
<td>4.69</td>
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<td>4.69</td>
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<td>14</td>
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<td>5357K31</td>
<td>McMaster</td>
<td>2.90</td>
<td>8</td>
<td>23.20</td>
</tr>
<tr>
<td>15</td>
<td>Expandable Sleevining; 0.75”-1.25” ID, 10ft., RED/BLUE/Black</td>
<td>9284K5</td>
<td>McMaster</td>
<td>7.15</td>
<td>3</td>
<td>21.45</td>
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<td>High Temp Silicon Rubber Tube; 1/4” ID, 1/2” OD, 25ft. RED/BLUE</td>
<td>51135K21</td>
<td>McMaster</td>
<td>27.00</td>
<td>2</td>
<td>54.00</td>
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<tr>
<td>17</td>
<td>NI Thermocouple Module; 16 Channel TC Input</td>
<td>9123</td>
<td>NI</td>
<td>1,185.00</td>
<td>3</td>
<td>3,555.00</td>
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<tr>
<td>18</td>
<td>NI Thermocouple Terminal Block; 16 Channel TC Block</td>
<td>196740-01</td>
<td>NI</td>
<td>36.90</td>
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<td>110.70</td>
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<td>19</td>
<td>NI Thermocouple Strain Relief Block; 16 Channel TC Strain Relief</td>
<td>779567-01</td>
<td>NI</td>
<td>27.90</td>
<td>3</td>
<td>83.70</td>
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<tr>
<td>20</td>
<td>NI eDAQ; 4 -Slot USB Chassis</td>
<td>9175</td>
<td>NI</td>
<td>820.00</td>
<td>1</td>
<td>820.00</td>
</tr>
<tr>
<td>21</td>
<td>Automatic Wire Stripper; Multi Wire</td>
<td>7221K24</td>
<td>McMaster</td>
<td>66.73</td>
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<td>22</td>
<td>Thermocouple Wire; 20AWG, 500ft., PFA Insulation</td>
<td>TT-J-20-500</td>
<td>Omega</td>
<td>245.00</td>
<td>1</td>
<td>245.00</td>
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<tr>
<td>23</td>
<td>PolyScience PD Bath Heater/Cooler; 7 Liter, LabView Support</td>
<td>PD07R-20-A11B</td>
<td>PolyScience</td>
<td>3,785.21</td>
<td>2</td>
<td>7,570.42</td>
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</table>

**Total:** 13,068.12
Appendix B: Text from student assignment

Suppose you are working for Apple Inc. in 2007. Life does not get much better. Below is a letter from your employer assigning you a specific task. For this lab you will fulfill this task and write a report to this employer outlining your approach, results and conclusions.

Dear capable employee and valued friend,

As you are likely aware, we are nearly finished with the development of our new ultra-thin, copper-housed MacBook Air. Development is right on schedule and the prototypes are working well. However, I just thought of a potential heat transfer problem with the design. While the copper housing works as an efficient heat sink, it may also distribute the heat in undesired ways. I have divided the base of the computer (beneath the keyboard) into grid-coordinates in order to clarify my explanation (below). The two indicated processors run at a constant temperature of 75°C and maintain their grid section at the same relative temperature. Two cooling fans are capable of maintaining their grid sections at 20°C. I am worried about the graphics card indicated below. If it reaches a temperature of 50°C it will significantly affect its longevity. Oddly, we don’t have any software capable of estimating 2D conduction? Could you write a program that estimates the temperature distribution over the housing considering the four grid points are maintained at constant temperatures? I would like a numerical transient calculation so that we can estimate steady state conditions, and the time needed to reach these conditions. When you make this it would be nice if you validated it your model experimentally. Report on the time and temperatures errors for your program. Send me a report on your procedure and findings. Finally, give me a recommendation on whether we can leave the graphics card in the current position or if we need to move it. I have indicated possible alternate locations in the diagram. I would prefer not to change anything, but if that location could be at 50°C for an extended period of time we have to put in the effort to make the change. I look forward to your conclusions.

Stephen Jobs, VP of R&D (The name is an unfortunate coincidence)
Benefits and Challenges of the China Megaconstruction Study Abroad Program

Clifton B. Farnsworth, Evan Bingham, and Justin E. Weidman
Brigham Young University

Abstract

International travel opportunities provide undergraduate students with valuable academic experiences not typically available through traditional coursework, including experiencing cultural diversity, increasing global awareness, and recognizing similarities and differences in professional practice. This paper describes the benefits of one such study abroad opportunity recently developed (the China megaconstruction study abroad), the key elements within the course, and explains the principal lessons students learned from this experience. However, this paper also describes the challenges experienced in recruiting students to participate in the study abroad program. Despite the student perception that the program was worthwhile, recruiting students to participate in sufficient numbers proved difficult. This paper also provides lessons learned regarding student perceptions of this study abroad experience. The lessons learned in this paper will be useful for programs involved with developing new study abroad experiences.

Keywords

Study Abroad, International Travel, China, Megaconstruction.

Introduction

In an ever increasingly competitive industry, there is a greater need for developing graduates with a greater understanding of global awareness, cultural diversity, and the ability to work in international markets. One of the best ways that this can be accomplished within an academic setting is to provide opportunities for students to participate in international study abroad opportunities, thus providing students with valuable academic experiences not typically available through traditional coursework. The Construction and Facilities Management (CFM) Program at Brigham Young University recently created the China megaconstruction study abroad course as part of initiative to increase international travel opportunities for undergraduate students within the major. Part I of this paper details the development of the China megaconstruction course, the principal objectives of the course, the key elements for student experience, and explains how these were accomplished. Part II of this paper details the challenges experiences in recruiting students to participate and student perceptions of this study abroad experience.

Institutions of higher education often include within their mission, aims, purposes, or objectives some mention of preparing students to have an impact upon the world. One accrediting body for construction engineering and management programs requires that students receive a sufficiently broad education where students understand the impact of providing solutions in a global and societal context and thus produce graduates prepared to enter a global workforce.¹ There are a number of benefits that have been associated with study abroad experiences. Shuman et al.² indicated that students that participate in study abroad programs “are better problem solvers,
have strong communication and cross-cultural communication skills, and are able to work well in groups of diverse populations and understand diverse perspectives. Further, students who spend time overseas tend to be more adaptable to new environments and have a greater understanding of contemporary issues and generating engineering solutions in a global and social context. Study abroad experiences have also been linked with helping students develop soft skills, such as flexibility, appreciation for diversity, open-mindedness, and being comfortable with international and global perspectives of engineering. Student feedback indicates that an international experience becomes a pivotal point in their education, and indeed in their lives.

Although other construction related study abroad programs to China have been reported, this study abroad program was unique in that it directly integrated students from a construction management program with those from a civil engineering program. As such, the China megaconstruction study abroad program became a single course in a multi-course college program. These other courses included China megastructures, China megacities, and China megawater, each course focusing on a different discipline within the context of the same study abroad trip. This integration included a culminating design project that required the construction management and civil engineering students to work together on the initial design of a skyscraper, including the tentative cost, scheduling, and conceptual design renderings. Key course elements for this study abroad program included China, mega, ideas and innovation, sustainability, teamwork and leadership, global awareness, character development, and technical excellence. These will be discussed in greater detail later in this paper.

Part I: Course Structure

The principal motivation in establishing the course was to have the students become familiar with construction processes and techniques associated with “megaconstruction,” including skyscrapers, large bridges, tunnels, subways, railroads, and generally large urban cities. This also included the management of the facilities post-construction. Another important element was to introduce students with the innovation being used in Chinese megaconstruction, including many aspects of sustainable construction. The course took place during a seven week spring term. Five of the weeks were spent on campus in the classroom receiving instruction and preparing to travel. Course content during this time focused predominantly on different types of construction techniques, specific challenges faced, and innovative solutions utilized in constructing the structures, facilities, and sites to be visited within China. The instructor prepared a number of lessons for the students and introduced them to these aspects, but much of the course consisted of the students researching various topics (as directed by the instructor) and then teaching each other through presentation. This was a very effective method for helping the students learn material because they already had a great deal of motivation to learn in this course. The culminating experience, of course, was the two weeks of travel. Having participated in preparing and presenting the course content on a very active and personal level made visiting the same places that the students researched that much more meaningful to them.

The travel itinerary for this study abroad course included visiting and seeing sites in seven different cities. With the theme of “mega” being adopted for this trip, the featured sites included some of the biggest skyscrapers, bridges, cities, and other engineered works in the world, both historic and modern. Table 1 shows a generic itinerary, including the cities and principal sites visited, that was utilized during the travel portion of this course. Some of these site visits

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included simply going and seeing the bridge or skyscraper, while others included an actual tour or walkthrough.

*Table 1: Principal Technical and Cultural Sites Visited*

<table>
<thead>
<tr>
<th>City</th>
<th>Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing</td>
<td>Beijing airport terminal 3, Wangjing Soho, Galaxy Soho, Phoenix Media Center, Linked Hybrid, New Poly Plaza, Arup Engineering Office, CCTV Building, World Trade Center 3 Building, Zhongguo Zun Tower, Hongqiao Market, Parkview Green, Great Wall, Olympic Sites, Tiananmen Square, National Center for Performing Arts, Great Hall of People, Forbidden City</td>
</tr>
<tr>
<td>Tianjin</td>
<td>High speed train, Tianjin World Financial Center, Eye of Tianjin Bridge, Haihe River Trip</td>
</tr>
<tr>
<td>Yichang</td>
<td>Bridges and tunnels along Huyu Expressway, Yiling Bridge, Xiling Bridge, Three Gorges Dam, Three Gorges Tribe, River Trip along Yangtze River</td>
</tr>
<tr>
<td>Shanghai</td>
<td>Shanghai Tower, Jin Mao Tower, Shanghai World Financial Center, Grand Theatre, Maglev Train, Nanpu Bridge, Lupu Bridge, Broad Pavilion, China Art Museum, Oriental Pearl Tower, Thornton Tomasetti Engineering Office, Yuyuan Bazaar, Shanghai Acrobats</td>
</tr>
<tr>
<td>Guangzhou</td>
<td>International Finance Center, Chow Tai Fook Finance Center, Leatop Plaza, CITIC plaza, Canton Tower, Pearl River Tower, Yajisha Bridge, Guangzhou Circle, a local factory</td>
</tr>
<tr>
<td>Shenzhen</td>
<td>East Pacific Center, Ping An Center, Shenzhen Stock Exchange, Shenzhen City Hall, KingKey 100</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>Tin Kau Bridge, Stonecutters Bridge, Honk Kong Convention Center, Central Plaza, Lippo Center, HSBC Building, Bank of China Building, Victoria Peak, International Finance Center 2, The Center, Union Square, Stanley Market, LDS Temple</td>
</tr>
</tbody>
</table>

The final project for this course included student teams preparing the preliminary design and renderings of a skyscraper to be submitted to the Council on Tall Buildings and Urban Habitat (CTBUH) student design competition. Because of the academic experience in using BIM software that the students in the BYU CFM Program receive, the construction management students were assigned the task in producing the renderings. Although the students began this project early in the term, they finalized the project upon returning home from China. It was amazing to see the transformation in achieving a much higher level of innovation, after having participated in the study abroad. Figure 1 shows an example structure designed and rendered by one of the construction management students for the final project. This specific project was designed as a greenplex, a series of skyscrapers interconnected via skybridges and enclosed by a protective ethylene tetrafluoroethylene (ETFE) exterior. Several of these elements were observed
in a number of different buildings visited in China, and certainly provided the inspiration for this design.

Figure 1: Example of Student Designed Skyscrapers

**Key Course Elements**

While the principal motivator in getting students to sign up for this course was the chance to visit China, the course itself included some key elements and objectives for providing educational components not readily achieved in other courses. This section identifies those key elements and explains how they were achieved through this study abroad course.

**China**

China is a fascinating country full of educational opportunities for a number of reasons. China is rich in history and culture, both ancient and modern. This is definitely an important element within the study abroad. Riding trains and busses with Chinese people is educational in and of itself for students not accustomed to large populated cities. Students were able to visit markets, restaurants, and simply experience very large modern cities. China is rapidly becoming a modern superpower in engineering and construction technology. Engineering excellence does not appear to be lacking within China, although construction execution and quality appear to be less important. Finally, urbanization in China is incredible. Tower cranes abound, not just on the handful of 100 story buildings being constructed, but the seemingly endless 30 story buildings as well. Other construction features and challenges include developing urban roads, rural mountainous highways, bridges, dams, subways, general infrastructure (sewer, water, power), and of course residential and commercial construction. There are very few places on earth where such a significant amount of urban construction is taking place within the major urban centers. For all of these reasons, simply traveling around China provides students with an opportunity to gain an appreciation for all that this country has to offer.

**Mega**

This is perhaps the key reason that this study abroad program was even developed. It was easy to include elements related to the design and construction of skyscrapers, large bridges, transportation systems, and other features associated with rapid urbanization, and then take the
students to see them. There could be some argument that the specific skills obtained by the students in this course may never be utilized again during their careers, not accounting for the higher level of learning available in this course. Students learned that if they can work with the biggest structures in the world, certainly they can tackle problems associated with normal every day type construction work. The format of researching the large structures before seeing them was a powerful teaching/learning experience. It is one thing to just go look at a large structure, but another experience altogether to be able to understand the design and construction features. The latter provides a much more meaningful experience. There is a feeling of awe related to the term “mega,” after having actually visited some of the tallest buildings, longest and highest bridges, largest dam, biggest cities, and fastest trains in the world.

Ideas and Innovation

This course provided the opportunity to gain new understanding about a number of different engineering and construction techniques for the design and construction of these mega-structures, that otherwise would not have been available within the standard curriculum. Innovative methods associated with climbing cranes, concrete formwork, innovate materials, architectural techniques for sustainability, benefits of mass transportation systems, a greater vision for what “green construction” can actually mean, and a comparison of construction methods used in the U.S. and China. A large focus was placed on sustainable construction practices in rapid urbanization. After visiting many of the biggest cities in China, students expressed the impression that we are more the same than different.

Sustainability

Chinese design and construction of major projects have adopted many technologies that are green and promote sustainable engineering, construction, and facilities maintenance practices, including reducing pollution, congestion, smart use of resources, etc. Many of these lessons came from simply visiting green structures. At the same time, however, there was also this counter feeling of anti-sustainable practices, such as with the destruction of environmental and cultural resources with the building of the three gorges dam, or even sloppy construction practices minimizing the cost effectiveness of true life cycle integration. Many of these provided fascinating case studies for discussion on ethics, environmental practices, and of course sustainable construction. The development of the final project included a focus on people, planet, and profit, and that experience alone was a key part of the sustainability aspects of this course.

Teamwork and Leadership

Students worked in groups throughout the entire course. The group interaction and dynamics allowed for some great lessons to be learned and experienced in teamwork. The entire experience of being together as a large group of travelers in a foreign place also provided another dimension of teamwork and togetherness. Students did very little “alone” related to this class, and so teamwork was a large component of accomplishing the assignments and participation in the travel. Leadership skills were developed through the team homework exercises. Students also gained a greater sense of confidence in their abilities to interact with others, especially in a global sense. Understanding that people are all the same, are working toward similar goals, and
have similar feelings, can instill within students a greater sense of being able to interact with others, an important leadership characteristic.

**Global Awareness**

There is no question that this experience provided students with global awareness. Visiting cities with millions and tens of millions of people helps students gain a greater understanding of what six billion people on this earth actually means. These students are the future in designing and constructing the infrastructure in our society, and this experience hopefully helped them gain a vision of what opportunities and challenges actually await them. Flying to the other side of the world helps provide a reference for the vastness and expanse of the earth. Driving through a city and experiencing very urban traffic problems, watching farmers wade through their rice fields, seeing burial plots alongside the roadway in a rural mountainous setting, riding in an extremely crowded subway car thinking it could get no tighter only to have fifteen more people get in at the next stop, watching parents hold their child’s hand as they walk through the mall, or seeing a family of three all riding a motorcycle are all small specific examples of the types of things to be seen within China that helped students realize that we as humans face similar problems and that the world, despite its expanse, is truly becoming a smaller place.

**Character Development**

This study abroad experience provided a number of character building moments. One specific example included visiting a factory and seeing people making everyday items that we take for granted, yet making very little. Another example that students commented on was seeing older people employed in sweeping the streets with nothing more than tree branches lashed to a stick. These are the types of things that student experienced that can help them gain an appreciation for what they have and commit to become better individuals.

**Technical Excellence**

Students participating in this experience were able to learn something of a technical nature that they wouldn’t have otherwise without this experience. Presenting several times throughout the course allowed the students to better develop their technical communication skills. Standing in front of somebody and telling them about something you learned is much more difficult and requires a greater level of understanding and effort than simply reading something in order to regurgitate it on an exam. Visiting engineering and construction firms gave the students a chance to recognize that what they had been learning really was a portion of the way that these structures are being designed and constructed in the real world. These included technical skyscraper elements like belt trusses, outriggers, and central cores, or for bridges the idea of arch, cable stay, suspension, and long beam methods of spanning. Construction techniques associated with each of these were introduced and provided an interesting level of technical detail certainly not encountered in other courses, such as the balanced cantilevered method of construction for arch bridges or climbing cranes and concrete forms in skyscrapers.

**Student Feedback**

Student feedback was collected and evaluated for predominant themes and trends. The following five elements were identified as the most dominant responses, apparently having had the greatest
impact upon the students. These are identified below (in no specific order), followed by representative student comments. The few students who enrolled in the China megaconstruction class generally described their experience as life changing, and expressed mild embarrassment that they had perhaps questioned whether or not to participate. Each student spoke highly of the experience, and in several formal settings indicated that it was one of the highlights of their undergraduate education.

**Chinese Construction Industry**
- When it comes to the architecture and engineering of the new China, it is world class.
- There are shiny new malls, sparkling office towers, expansive highways, and tower cranes as far as the eye can see. It’s overwhelming.
- There is nowhere in the U.S. that has the same caliber of megastructure. They just go big in China.

**Innovation in Sustainability**
- China is becoming a world leader in the evolution of building design and construction.
- This building incorporates many unique features of sustainability, including wind turbines and solar panels to generate power.
- Sustainability can improve the functionality of the structure.
- They’re pushing the limits and they’re reinventing the way we live.

**Quality of Construction**
- The Chinese may know how to build a building, but they certainly don’t know how to maintain them.
- It was hard not to notice that stair codes must have been very lax or nonexistent in some places because of the unevenness of the treads and the varying heights of risers within one flight.
- The level of quality is better in the U.S., but we seem to have less innovation.

**Safety**
- I rarely saw PP&E being used at construction sites and it was frightening to see workers at extreme heights not harnessed in or tied up to prevent from falling.
- Life safety measures are not as embedded into China’s construction culture.
- Most of the public buildings seemed to be only 90% completed because of the lack of final detailing in the buildings.
- The workers live onsite in what looked to be fairly poor conditions.

**Life Changing**
- I have gained a greater knowledge and appreciation for bridge design and construction, skyscraper design and construction, designing cities to the needs of people, thinking outside the box, seeing where we can improve our building efforts, seeing where we excel in construction, and thinking of how we can help China and the world improve design and construction.
- This trip was an unforgettable, once-in-a-lifetime opportunity.
- It was a cultural and educational experience that has changed my view on the world and the industry of construction.
Part II: Challenges with Recruiting Students

Although student feedback from the students who took the China megaconstruction course during the developmental year was extremely positive, it should be noted that recruiting students to participate proved to be very difficult. Because the group traveled and interacted with the other China mega courses from the college, it was feasible to take only a few students from the CFM program. However, to get a better understanding of why recruiting was so difficult, a survey was sent to the CFM students to explore their perceptions of the program. Approximately a third of the students from the program responded, providing sufficient response to generate a representative sample. Six simple questions were asked:

1) What is your impression of the China megaconstruction study abroad opportunity?
2) Did you consider participating with the China megaconstruction study abroad program?
3) What are the top three reasons that you chose not to participate in the China megaconstruction study abroad program?
4) Please identify all OTHER reasons (besides those mentioned in the previous question) that may have contributed to your decision not to participate in the China megaconstruction study abroad program.
5) Would you consider participating in the China megaconstruction study abroad program another year?
6) Do you have any additional comments about the China megaconstruction study abroad opportunity that may help us determine if this program should be continued in future years?

Figure 2 shows the impression that students in the CFM program had regarding the educational value associated with this study abroad opportunity. This perception is based solely upon any recruiting efforts that the students would have been exposed to. This included seminar presentations, information sessions, the college international fair, and one-on-one interactions. This response suggests that the majority of the students felt the program had educational value.

![Figure 2. Student impression of the China megaconstruction study abroad program](image-url)
When students were asked if they considered participating, 68% of the students replied in the affirmative. This number approximately corresponds to the percentage of students that felt the program had either great or moderate educational value.

Figure 3 shows the results for the reasons associated with students electing not to participate in the China megaconstruction study abroad program. The results from question 3 and 4 of the survey were combined into this single figure, because question 4 did not generate any additional types of responses beyond those initially identified in question 3. Further, the general proportion of responses was nearly identical between question 3 and question 4. Cost was identified as the principal barrier to participating in the program. Although the total cost of the experience (including tuition) was significantly reduced from university, college, and program supplements for study abroad opportunities, the final cost to students was approximately $3,500. Even though many of the students expressed interest in participating in the program, they further indicated the cost as being too high. It should be noted that there were a number of students that included cost related answers for each of the three principal reasons for not participating in the experience. For the sake of this data analysis, each of these was counted as a separate comment and included in the cost data shown in Figure 3. This is the only category that generated multiple responses from any single individual. However, because the students elected to put “money, money, money” as their top responses, the decision was made to allow this, thus inflating this category relative to the others.

Figure 3. Reasons associated with not participating in the study abroad program

The second most common response, the need to be involved in internships and work, was said by nearly as many students as cost. The study abroad program took place during the spring term (~first of May – mid June), a time when most construction and facilities management students are participating in summer internships. There is a culture in the construction industry demanding that students have quality internship experiences (multiple, if possible) for students to be able to compete for jobs after graduation. Students were aware of this, and it was not surprising then that students were leery of trading this valuable work experience for an educational opportunity that would probably not carry nearly as much value for a future.
employer. The third common theme generated by students was the idea that they would not get credit for the class. Students providing this response had already fulfilled the requirements for graduation that this course may have provided, and to participate it would have then been another class not counting for graduation. The next four responses were nearly identical in the percentage of times that they were identified. These included a general concern over the value of the content being provided in the course relative to future employment, leaving family behind (typically a spouse and/or child), not in line with current priorities (such as it was difficult to justify or seemed to just be a vacation), and finally a number of students acknowledged that they felt they just didn’t know enough about it. The final response category is related to cost, but included separately because a number of respondents specifically indicated concern over the value received for the money spent.

Despite all of the potential roadblocks provided by students, the responses to question 5 and 6, provide some hope that this program may still be able to generate enough interest to continue. 55% of the students that responded to the survey indicated that they would consider participating in the program another year if it were to continue to be offered. Interestingly, students providing additional comments, generated responses related to the same eight categories shown in Figure 3, and in approximately the same proportions. This is more than likely because students carried the same theme through all of the questions answered. However, although a negative tone was seen in the bulk of the responses for questions 3 and 4, question 6 had a surprisingly positive tone associated with the answers. Further students were providing potential solutions to working around the problems. Students provided some of their best feedback here. Representative student responses included:

- If the study abroad class was during winter semester, with the actual travel being done in the two weeks directly after finals, I think interest would increase. Then it wouldn’t conflict with internships.
- I would love to go and am planning on it next year if it is still around. I just need to make a little more money before I can go.
- It seems like a great opportunity, but I chose not to participate mainly for financial reasons and timing issues. At this point in my education I need to be finishing up my classes and working in the field. I think it would be a great program to continue. I wish I had known about it at an earlier stage in my career.

For this program to thrive, there are a number of clear obstacles that have to be overcome. It is understandable that not all students will desire to, or be in a life situation that will allow them to participate. However, there are some key lessons to be learned from the student survey responses. First and foremost, cost matters to students. The cost of this program is in line with the cost of other similar study abroad programs at BYU, and therefore not seen as being unreasonable. For students to elect to participate, the value of the program has to be demonstrated. Further, if students are exposed to the idea of the program earlier in their academic career it gives them more time to financially prepare to participate. Second, working around the spring/summer internship culture will continue to be difficult. However, two potential solutions include recruiting younger students not yet feeling the crunch to have to do an internship, and compressing the semester even further to get students out in the field. With regard to students getting credits toward graduation from participating, this too has to happen with early recruitment, so that students can schedule these credits accordingly. Although we
Conclusions

This paper explains some of the key elements of the China megaconstruction study abroad program, some of which are not easily achieved in standard construction curriculum, especially the travel itself and the integrated final design project. As identified in the student feedback, this study abroad experience provided tremendous motivation and thus increased the student’s ability to experience these key elements. Providing study abroad opportunities for construction students is an excellent way to increase their confidence, expand their global awareness, and can provide an experience that nearly each of them describe as being life changing. This paper demonstrates that study abroad opportunities are a unique teaching and learning tool and have a tremendously positive impact upon the educational experience of students.

On the other hand, despite the positive student feedback from those participating, recruiting for the program has been equally difficult. This paper has indicated that students are most concerned with the cost and the interference with internship and other employment opportunities. A number of potential strategies for overcoming the barriers of participation have been offered. For this particular international study abroad experience, it would be difficult to cut the cost down any further. It is anticipated that as some of the other barriers are overcome, that cost will become less of an obstacle for some. Another option would be to simply utilize the general concepts presented within this paper and incorporate them into a more economical part of the world. In light of the challenges with recruiting highlighted in this paper, the China megaconstruction program has been temporarily put on hold. However, with the feedback provided, we feel that we are in a position to once again offer this study abroad experience.

References


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Dr. Farnsworth is an assistant professor in the Construction and Facilities Management Department at Brigham Young University in Provo Utah. His main teaching focus is heavy civil construction. His principal research interests are construction/civil engineering interface processes and engineering education.

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Dr. Weidman is an assistant professor in the Construction and Facilities Management Department at Brigham Young University in Provo Utah. His main teaching focus is in human resource management, project management, and safety. His research aligns with his teaching, with a focus on organizational learning during the recession and the use of wellness programs in construction companies. He recently was featured in a national teaching journal for his work related to using the exhilarating game of marshmallow dodgeball in the classroom.
Network Programming – Beyond Sockets

Hugh Smith
Cal Poly Computer Engineering Program

Abstract

In this paper we present a methodology for teaching computer network programming. In typical Computer Networking textbooks used in networking courses the only coverage of network programming is a discussion of the sockets API. This approach seems logical since many times the students taking a Computer Networking course are upper division students who already know how to program. The problem with this approach is most students have not written asynchronous programs that need to work together to solve a problem as required in network programming. The methodology we present includes a process for breaking down the problem, developing state diagrams and then implementing state machines in C. This methodology consists of a number of modules that walk the students through this process. Our observations are that this approach has improved the completion rate and quality of the student programming assignment. We present the results of a student survey that indicates that this process is very helpful in implementing their final programming solution.

Keywords

Computer Networks, State Machines, Socket Programming

Introduction

This paper addresses an issue experienced with teaching students to write client-server based computer networking programs. While the students in the class are upper division Computer Science (CSC), Computer Engineering (CPE) or Software Engineering (SE) students they lack experience in writing asynchronous programs as required in client-server systems. While the students have a good understanding of how to use the socket API\(^3\) to allow their programs to communicate across the network, they have not been taught a methodology to implement this type of system. In addition, we have observed that the above average programmer can successfully implement a complex client-server program, many of the average programmers take three to four times as long to implement a much weaker solution. These solutions tend to be an organically written (program grows as they encounter new conditions) and are almost impossible to read and debug.

In many computer networking courses, network programming (typically called socket programming or client-serve programming) is glossed over. Many textbooks\(^1,2\) used in these courses cover the basics of using the sockets API to implement network programs. These textbooks also cover concepts such client-server systems and peer-to-peer communications. The issue with this approach is that while it covers the technical components of network programming (e.g. using the sockets API) it does not teach the students any techniques or process for actually creating (designing and implementing) networked systems.
The mythology I present in this paper consists of a number of modules. These modules work together to teach the students how to conceptualize the networking system they are implementing, how to document the system flows and how to develop state machines that meet the program specifications. These assignments consist of multiple design assignments and the implementation of a complex client-server system.

The overall process consists of developing packet flow diagrams (figure 1) based on the program specification and then using these packet flow diagrams to generate state diagrams. The process forces the students to create the state diagrams prior to implementing their programs. While state machines are well known in networking and digital design, we have found that typical CPE students do not carry over their state machine skills into their network programs. In addition, CSC and SE majors may not have any experience in state diagrams and state machines. Therefore, as part of the process the concept of state diagrams and how they may be applied to networking programs is presented to the students.

As shown in our results below, this approach has improved the completion rate and quality of the students’ programming assignment. In addition, I present the results of two student surveys that address using this methodology in developing programs.

In the remainder of this paper we present an overview of the course, the steps used to teach a formal process for networking programming and our results based on instructor observations, student grades and surveys of the students.

![Packet Flow Diagram implementing a Sliding Window Flow Control Algorithm](image)
Course Overview

The computer networking course is taken by senior level computing majors (CSC, CPE, SE). These students have had a minimum of four quarters of required programming courses. This includes CS1-CS3 where they learn C or Python and then Java. They are also required to take a Systems Programming course where they learn to use Unix systems calls similar to the Sockets API.

Cal Poly is on a 10-week quarter system. The computer networking course consists of 3-hours of lecture per week and 3-hours of lab. In the lecture we cover the major aspects of the protocol stack layers 1-4. The lab component of the course is similar to an Electrical Engineering lab. The lab is held in the Cal Poly Advanced Networking Laboratory. This laboratory has 15 workbenches. Each workbench consists of multiple PCs, switches and routers. The students are given a lab procedure and have 3-hours to complete the lab assignment. The students are then required to turn in a lab report.

In addition to the lecture and lab components of the course, the students are required to implement multiple programs in C. The final programming assignment is the focus of our work on function decomposition and includes teaching a process for implementing client-server programs. This programming assignment is an implementation of a reliable file transfer using UDP. The students are required to design their own reliable communications protocol using sliding windows. Their implementations must use the internet checksum for bit error detection and selective repeat ARQ for error recover and flow control. The students link in a library that provides a modified version of the socket API function sendto(). This modified version of sendto() is able to introduce errors into the data transmitted by the application by modifying bits and dropping packets based on a configurable error rate.

Issues and Observations

We have been assigning this file transfer assignment for over ten years and have identified a number of issues:

1) Lack of functional decomposition skills – The students do not follow any formal method for functionally decomposing their larger assignments into meaningful subtasks. There seems to be a number of reasons for this. This includes the fact that many of their assignments in earlier classes could be “designed” successful in their head and hacked together. In addition, the students have learned that it is the final product (e.g. a working program) that counts and not the process.

2) It is difficult to successful hack together client-server programs – While many of the programs in earlier programming courses can be finished by applying more time and effort, this is not true for a complex asynchronous set of programs like this programming assignment. Informal observations indicate that students spending 30+ hours on this assignment are less likely to finish the assignment than students spending 15-20 hours. The more they hack their code to handle special cases that were not considered during the design process the less likely they are to successfully finish the assignment.
3) Asynchronous programming is new to most students. For many students their past programming experience is a based on implementing single linear programs. Even in our Operating Systems course where students work with multiple processes the program flow tends to be linear.

For many of these students, switching into an asynchronous programming paradigm (e.g. found in distributed systems, parallel process, and client-server systems) is not natural and they struggle with how to begin their assignment. Even though state diagrams and similar concepts are covered in our digital design and architecture courses, the students fail to see how these concepts can be applied to networking programs.

4) Many of the popular textbooks used for teaching computer networks\(^1,2\) only cover socket programming from the API perspective. A methodology for going from a problem specification to a client-server implementation is not discussed.

**Our approach**

As discussed earlier the students are implementing a reliable UDP based file transfer client-server system. In order to walk the students through the process of designing this assignment we use a five-part process.

1) Packet flow diagrams – during discussion of different protocols (e.g. ARP, TCP) the students are show how to draw packet flow diagrams. Figure 1 shows an example of a packet flow diagram for a simple sliding window flow control algorithm. In this diagram the sender is sending data to the receiver and then processing acknowledgements and rejections as they asynchronously arrive from the receiver. The students actual design would require many different packet flow diagrams cover every possible packet flow. These diagram allow the students to depict the flow of information between multiple machines and to document possible error conditions and edge cases.

2) Mealy state diagrams/machines – The students are taught how to create state diagrams and implement mealy based state machines. Figure 2 shows a simplified state diagram for the sender of the data as shown in figure 1. The students are show how to use their packet flow diagrams to generate and validate their state diagrams prior to implementing the code for their state machine.

3) Stop and Wait design assignment – The students are then given a program specification for a reliable UDP based file transfer using a simpler stop and wait protocol for flow control and error recover. They are also given a series of design questions that walk them through the development of their packet flow diagrams. The final output of this assignment is a state diagram for both the client and the server that implements this reliable file transfer. This is only a design assignment and the students are not required to write programs to implement their state machines.

4) Instructor thought process and solution – After the students turn in their stop and wait design assignment, the instructor goes over his/her solution to the stop and wait design assignment. The instructor discusses mistakes made during his/her design process and design tradeoffs. The development of the state diagram is presented on the whiteboard with an on-going
commentary on the thought process being used by the instructor. In addition to sharing the state diagram a solution in C that implements the state machines for the state diagrams is presented.

The students’ design assignments for the stop and wait protocol are not graded in detail. It is up to the student to analyze issues with their solution based on the solution presented by the instructor. This allows the students to learn from their mistakes before they are required to actually implement a program (which is graded).

5) Programming assignment – The students are given a programming assignment to implement a reliable file transfer over UPD using selective repeat for flow control and error correction. This assignment is given in two parts.

a. Design assignment – Similar to the earlier stop and wait design assignment, the students develop packet flow diagrams and state machines that solve the file transfer problem. Similar to how TCP works, the students designed is required to include a connection establishment process, a reliable data transfer with flow control and a connection termination process.

While this design assignment is collected it is not graded and no solution is presented by the instructor. No feedback from the instructor is provided to the students prior to their implementation. The students learn from mistakes in their design as they code and debug their selective repeat based reliable file transfer program.
b. Working file transfer program – The students are then required to implement a working version of the reliable file transfer over UDP using sliding windows with selective repeat for flow control and error recover. The students are not required to implement their state diagrams and instead are allowed to choose how they want to implement their program.

Instructor Observations

For a subjective point of view, we are very pleased with the results of this process. There have been numerous comments from the students about using this technique in other courses (e.g. our parallel processing course and their senior project). Also a number of alumni have reported using this technique in the jobs after graduation.

The instructor notes that this process has made a noticeable change in student participation when discussing the selective repeat assignment in lecture. During these discussion, student questions

<table>
<thead>
<tr>
<th>Survey Question</th>
<th>Value (1-5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“I learned a lot from the two design assignments”</td>
<td>4.0/5</td>
</tr>
<tr>
<td>“I feel that the design assignments helped me to break down my implementation of program #3 into smaller/more manageable pieces (e.g. functions)”</td>
<td>4.18/5</td>
</tr>
<tr>
<td>“The design component of the course helped me feel more comfortable with the process for breaking down a large problem into manageable pieces.”</td>
<td>4.1/5</td>
</tr>
</tbody>
</table>

Table 2 Computer Network Course End of Quarter Survey (higher is better)
are more insightful and they indicate an understanding of the issues involved in this assignment. Student questions during office hour are more directed and show a better understanding of the steps needed to implement their program.

Grade and Survey results

While it is very difficult to isolate and measure curriculum changes, we have collected metrics from a number of sources:

1) Program grades – The grading rubric for this assignment has changed over time (e.g. extra credit, changes in point deductions) and we feel a direct comparison of program grades before and after the change would not be accurate. What has not changed is what it takes to get a zero on this assignment. Table 1 shows the percent of non-zero grades for the selective reject programming assignment for four quarters before the change and four quarters after the change (higher is better). Consistent with the instructor’s observations, the number of non-zero grades has increased since implementing this change.

2) During the spring quarter of 2016 the instructor performed a survey of the students that included questions regarding this design process. Table 2 shows the results of the three questions asked about the effectiveness of this process. This survey used a 5-point scale with 1 being strongly disagrees with the statement and 5 being strongly agrees with the statement (higher is better). The students’ perception of the benefits of this change match the instructors’ observations.

Concerning our observations prior to making this change (see section on Issues and Observations) these survey shows that the students recognize the benefits of this approach when writing their network programs. At least for network programming these results suggest that the students believe that decomposing the problem using the packet flow diagrams and state diagrams is helpful in successfully completing their network programs.

<table>
<thead>
<tr>
<th>Survey Question: For the following classes, how often did you perform a structured Top-down/Bottom-up Design when developing hardware and/or software.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Course</strong></td>
<td><strong>Value (1-5) 5 = Extensively</strong></td>
</tr>
<tr>
<td>Computer Networks</td>
<td>4.33/5</td>
</tr>
<tr>
<td>Operating Systems</td>
<td>3.53/5</td>
</tr>
<tr>
<td>Embedded Systems</td>
<td>3.60/5</td>
</tr>
<tr>
<td>Digital Design</td>
<td>3.13/5</td>
</tr>
</tbody>
</table>

Table 3: Senior Student Survey on Functional Decomposition (higher is better)
3) General Senior Survey – In an effort to address issues identified with our students’ ability to perform function decompositions of problems prior to programming them, our CPE office performed a survey of our senior level students. In this survey the students were asked for a given course “how often did you perform a structured Top-down / Bottom-up Design when developing hardware and/or software”. Table 3 shows the results of this survey for a number of upper division programming courses. This survey was also based on a 5-point (higher is better) scale. The results of this survey show that students recognize the focus on a methodology for network programming as presented in this course.

Conclusion

In this paper we present a methodology for teaching the design and implementation of asynchronous networking programs. This methodology walks the students through the process of understanding the problem through the use of packet flow diagrams. The students then create a state diagram that is able to process all of the possible scenarios identified in their packet flow diagrams. By first creating the packet flow diagrams the students are able to identify edge cases and verify that these conditions are handled correctly in their program.

We have found this approach to be helpful in teaching networking programming. The students recognize this benefit as shown through both the grades the students receive for the assignment and their subjective input based on class surveys.

In the future we plan on implementing this methodology earlier in the quarter and having the students use this methodology for multiple programming assignments. In addition, while it is clear that the students see a benefit in designing their network programs, it is also clear that this is not translated into them designing in other courses. We are in the process of increasing the use of functional decomposition of problems in earlier programming courses. While the technique used in this course (packet flow and state diagrams) may be applicable to a subset of courses, the idea of breaking down their programming assignments into meaningful pieces prior to implementing their assignments will benefit the students in many courses.

References


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Teaching Innovation in Materials Science and Engineering

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University of Utah, Department of Materials Science and Engineering

Abstract

The courses offered through the Department of Materials Science and Engineering (MSE) at the University of Utah have been strong in theory and characterization, which has been our strength as the only MSE program in the state of Utah. Industrial Advisory Board surveys, in combination with exit interviews, suggested a need to maintain these strengths while adding problem solving, design, and entrepreneurship into the curriculum. To address this request, two faculty members gained approval for a new course entitled Materials Innovation. The purpose of this course was to introduce MSE students to problem solving, the engineering design process, and technology commercialization. Students designed a project based on design constraints, material requirements, and user needs. Students made team decisions, developed prototypes, and presented their solutions to Industrial Advisory Board members to receive expert feedback. This paper discusses what worked well in the course, and lessons learned from our first attempt.

Keywords

Teaching innovation, materials science and engineering, engineering design process, creative problem solving

Introduction

Many undergraduate students choose to study engineering because they either have big ideas for potential inventions, or they want to be involved in the development of new ideas. As they enter their undergraduate courses, they are overwhelmed with courses that superficially appear disjointed, but ultimately provide the tools they will need to become successful engineers. These courses include chemistry, physics, math, and thermodynamics, among others. As such, there is a need for students to understand the way these courses that appear unrelated to each other can be used in the engineering design process.

In addition to the students’ needs, surveys from members of the MSE Industrial Advisory Board as well as exit interviews from students themselves have identified the need for MSE graduates to have skills in both problem solving, technology commercialization, and design. Some have suggested adding technical skills, including the use of SolidWorks and other design software into the curriculum. A hiring manager at US Synthetic went so far as to state that he needs people who can solve problems, stating that he would rather hire a really good art graduate who could solve problems than an engineering graduate who could not solve problems.

Moreover, recent initiatives at the University of Utah, such as the entrepreneurship certificate, would allow students to receive a certificate after taking business, engineering, and law courses related to entrepreneurship. However, very few courses are offered in the College of Engineering that satisfy the course requirement for this certificate. This is particularly surprising...
given the strong entrepreneurship climate at the University of Utah, which was recently ranked in the top twenty-five of undergraduate programs in entrepreneurship as well as consistently ranking in the top five universities for startup company spin-offs, as indicated in the Princeton Review.

One question is whether or not curriculum development could meaningfully address these challenges and deficiencies that likely exist at engineering colleges across the country. Fortunately, the topics of design, entrepreneurship, and problem solving lend themselves to student involvement and participation, which increase retention and have been shown to increase student academic performance and positively affect student personal gains with respect to their own social development, their practical competence, and overall general education¹. Student engagement and active learning in engineering suggests that students must become dynamically involved in the course content, which may occur in the form of inquiry-based projects or real-life problems. This method is most successful when it is student-centered or even student-driven, rather than faculty-centered.

Researchers have divided active learning into three forms: being active, being constructive, and being interactive. Being active means that students engage in activities that activate knowledge within the context of the course content. Being constructive means that students are engaged in activities that will promote the generation of knowledge beyond that which is presented in the course materials. Finally, being interactive means that two or more students are engaged in activities that generate knowledge beyond the content presented in the course materials².

To promote active learning, instructors across disciplines have adapted content delivery to replace traditional methods, including lecture with class discussions, problem solving, and flipped classrooms, among others³. The foundation upon which many of these engaged student learning methods include behavioral perspectives, specifically integration as mentioned above, teaching methods, and active learning; psychological perspectives, including student involvement and participation; psychosocial, where students consider the social context of their engagement; and holistic perspectives, which is constructive and based on student needs⁴-⁷.

One of the methods of student engagement is through the use of innovation and creativity. Researchers have determined that students improve in engineering knowledge through participation in innovation and problem solving, more specifically through rigorous, hands-on instruction⁸. This method improves motivation and self-regulation, which play a crucial role in success in science and engineering. Students who were more creative had a higher knowledge retention, which suggests that creativity is an integral process in knowledge acquisition and human intelligence. Furthermore, if creativity is to be used as an effective tool, students must practice using creativity in problem solving, be encouraged in their creativity, and they must work to develop their creativity. If creativity is to be developed, students must broaden their acquisition of skills that lie beyond their expertise, they must challenge the established ways of thinking, surround themselves with new people and environments, and they must capture novelty as it develops⁹.

Studies have shown that the general population does not normally associate invention or creativity with engineering; however, creativity in engineering is fundamental to the ability to solve problems. Furthermore, engineers cannot afford not to be creative as they approach new
problems. An unfortunate reality is that creativity is not a skill that is illustrated to prospective engineering students, but engineering students must be creative in their application of both technical and professional skills if they are to be successful\textsuperscript{10-11}.

Course development in innovation and creativity is not a new concept. Others across the nation have been successful in their development of programs. Therefore, the Department of Materials Science and Engineering at the University of Utah has developed a new course to engage undergraduate students by fostering creativity and demonstrating the connections between the technical content and its future applications in the context of technology commercialization.

The purpose of this work is to present the results of a new course, MSE 5050 Materials Innovation, which was taught at the University of Utah during Fall 2015. In this paper, we will discuss the course goals, teaching methods used, course outcomes, and provide some future directions that will strengthen the effectiveness of the course.

\textbf{Course Description and Goals}

As worded in the course catalog, this course is designed as a technical elective for students in Materials Science and Engineering, while also satisfying one of the six required courses for students seeking a Certificate in Entrepreneurship. Course content includes solving problems through the engineering design process, identifying the need for new materials in industry, designing a project to test for the “fastest route to failure” or develop a prototype, building a business plan, pitching new technology ideas to investors, and making team decisions about getting new technology into the market.

Furthermore, with respect to course outcomes and ABET criteria, this course was designed to introduce undergraduate students to the following:

- An ability to apply mathematical, scientific, and engineering knowledge to solve materials related problems
- An ability to design and conduct experiments, characterize materials, and properly interpret data in order to understand materials behavior
- An ability to select or design a materials based system, component or process to meet desired needs within realistic constraints, such as economic, environmental, social, political, ethical, health, and safety, manufacturability and sustainability
- An ability to function on teams whose members have interdependent and complimentary skills
- An ability to identify, formulate and solve materials-related problems
- An ability to communicate technical information effectively in oral and written form
- An ability to use the techniques, skills, and modern engineering tools necessary in materials engineering practices

Our goals for this course were to teach the students to think creatively, be leaders in innovation, solve problems, understand the broader context of research and engineering design, prepare for future careers in entrepreneurship and technology, and improve critical thinking skills. Goals and methods are outlined in Table 1.
Table 1. The goals and methods provided a framework for measuring the success of the Materials Innovation course.

<table>
<thead>
<tr>
<th>Goal</th>
<th>Method</th>
</tr>
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<tbody>
<tr>
<td>Think creatively</td>
<td>Students followed the design process where they identified problems, needs, design requirements, and design specifications before moving into the design space. Student projects then returned to the engineering design process iteratively with each new concept proposed. Students also researched products on the market and determined the limitations and negative feedback from customer reviews. Finally, they were encouraged to find creative solutions to the problems they identified.</td>
</tr>
<tr>
<td>Be leaders in innovation</td>
<td>Students learned about innovation by reading <em>The Four Lenses of Innovation</em> and through interactive experiences with users on campus.</td>
</tr>
<tr>
<td>Solve problems</td>
<td>Students were introduced to case studies in solving problems and the steps required to understand the problems completely. They walked across campus, looking for problems that could be solved with Materials Science and Engineering. Some semester-length projects came from these campus observations or from problems in other aspects of their lives. All problems addressed in the class were identified from things the students were interested in and had faced before.</td>
</tr>
<tr>
<td>Understand the broader context of research and engineering design</td>
<td>Recent graduates and members of our Industrial Advisory Board were asked to provide real-world problems that students could solve during the course of the semester. Some of these problems included: an alternative bicycle chain, a bicycle designed for use in non-traditional surfaces (snow, sand, and mud), cadmium plating replacement coating materials for fasteners, cadmium plating replacement coating materials for steel substrates, low temperature cure corrosion inhibiting paint systems for steel substrates, light-weight aggregate materials for kitty litter with high water absorption, temperature recycling and reliability of thermoelectric power generators, and the incorporation of nitrogen into TiN films as an effective resistance material. Problems from industry partners came from companies such as Mega Diamond, Northrup Grumman, Purr-fect Solutions, IM Flash, and Power Practical.</td>
</tr>
<tr>
<td>Prepare for future careers in entrepreneurship and technology</td>
<td>Students presented their projects before industry professionals from the companies that provided problems for them to work on, all of which were practicing Materials Engineers. In addition, students were introduced to negotiating skills and funding opportunities. Finally, they were encouraged to pursue their projects after the course ended by submitting their designs to student competitions.</td>
</tr>
<tr>
<td>Improve critical thinking skills</td>
<td>Students participated in the peer-review process in two ways. First, each project was reviewed in class multiple times (at each step in the design process) where feedback was provided. Second, student groups exchanged final papers with at least two other groups to gain feedback on their projects. Furthermore, students began their projects by reviewing current research and focusing on what had been done in research related to their chosen problem, defining the limitations of current products, identifying current products on the market, understanding user needs, and designing with the needs of the end user in mind. Students consulted with</td>
</tr>
</tbody>
</table>
Course goals were assessed based on course feedback, student assignments, and student comments. Course feedback addressed the following: objectives were clearly stated, objectives were met, course materials were helpful, assignments and exams covered what was taught in the course, the student learned a great deal, and whether this was an overall effective course. Furthermore, the course evaluation assessed some of the targeted ABET criteria, including applying mathematical scientific, and engineering knowledge to solve materials related problems; designing and conducting experiments, characterizing materials, and properly interpreting data, designing a materials based system, functioning on teams whose members have interdependent and complimentary skills; identifying, formulating, and solving problems; communicating technical information; and using techniques, skills, and modern engineering tools necessary in materials science and engineering.

Course evaluations provided the following options for students to choose from: strongly disagree, disagree, mildly disagree, mildly agree, agree, and strongly agree, where a numerical value was affixed to each response. In this case, a value of 1 was affixed to strongly disagree and a value of 6 was assigned to strongly agree. Therefore, results were collected and reported based on the numerical average.

Student comments were collected from course evaluations as well from conversations that took place after the course was completed. Not all students provided comments related to the class.

**Teaching Methods and Assignments**

In addition to teaching innovation in this course, we also explored alternative methods of instruction. We focused on increasing student engagement in the course. One way we did that was to introduce the students to a variety of experiential learning methods. For example, our course was taught at the same time as the on-campus farmers market, allowing us to use it as an on-campus learning laboratory. Patrons and vendors were used in mini focus groups as the students learned about the concepts of market research, user needs, design specifications, pitching technology, meaningful statistics in data collection, etc. During one class, the students went in their assigned groups with a device to ask people at the farmers market if they had heard of the device and if it was useful. They also asked for feedback regarding the problem that the device was likely intended to solve. After meeting with users at the market, the class met on the grass for lively discussion about what the students had discovered.

Other methods were used to increase student engagement in the course, including keeping some lecture dates empty so that students could select the topics we would discuss on those dates as well as class time where students could brainstorm ideas and gain feedback from their peers. Like many other classes, we also included presentations from experts in the field who spoke about innovation, entrepreneurship, and how they use problem solving techniques in their jobs. For example, one speaker was the university Patent Librarian who taught the students how to perform a thorough prior art search and determine patent classification codes, technology licensees, etc.
The course was broken into two main sections, design inputs and design outputs, where students had assignments that addressed the content of each section. Assignments due for the design inputs section included an assessment of user needs, a list of design requirements, a list of design specifications, and a midterm presentation where the students presented the information they had obtained and then proposed a technical solution to their selected problem. For the second half of the semester, the students presented their progress on their project, an assessment of the intellectual property related to their project, and then a final project where they presented on at least one critical issue related to their technical approach and provided a demonstration of their prototype. This final presentation was attended by industry experts who also helped in the grading of the quality of the projects. These experts also inadvertently provided excellent industry contacts for continued project development that extended beyond the course.

In addition, a critical component of the course involved a lab section where students met once a week to perform prototype development related to their proposed materials innovation. During the first half of the semester the students were still learning about the engineering design process and therefore did not yet have their semester design project ready for lab testing. Therefore, during this first half of the semester, we developed an extended lab assignment focused on general prototype development. For example, students learned about maker spaces on campus, SolidWorks design, machining resources, and also how to use and program Arduino devices to do specific tasks as indicated on the assignment. One such task was to use digital and analog power output to control sensors, motors, and simple servos. Once they were finished with the prescribed tasks, students were encouraged to explore other ways they could use their device to solve engineering problems.

Course Outcomes

Student projects were inventive. One group investigated the potential for building collapsible snowshoes, which included the addition of an anti-skid skin usually used in the ski industry. Another group wanted to increase awareness of smoking habits across campus by designing a device that counted the number of cigarettes that had been disposed in garbage receptacle across campus. A third project utilized an Arduino device in the development of a smartphone app and an electronic device that could be used as a hands-free signaling mechanism for cyclists. One of the most successful projects investigated the manufacturing of biodegradable clay pigeons, which would eliminate the need for hobbyists to clean up after shooting.

The outcomes of the course were assessed as indicated above, based on feedback from course evaluations, performance on course assignments, and on student conversations. Of the students enrolled in the course, 62% responded in the course evaluations. The results of select questions are provided in Table 2.

<table>
<thead>
<tr>
<th>Course Questions</th>
<th>Numerical Average (1 strongly disagree, 6 strongly agree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objectives clearly stated</td>
<td>4.9</td>
</tr>
<tr>
<td>Objective met</td>
<td>4.9</td>
</tr>
<tr>
<td>Course materials helpful</td>
<td>4.5</td>
</tr>
</tbody>
</table>
In addition to the questions with preset responses, students were also given the opportunity to provide comments on overall effectiveness. Favorable comments include “guest speakers were brought in, additional books and materials were available, and I felt like the homework assignments were helpful in meeting the goal of this class,” “the way you’re forced to think in this class is completely different to a typical engineering class...it [forced] you to think of things beyond just the math and science behind it...I liked all of the project presentations we were assigned and think that guest lectures [were] extremely useful,” “[I liked] the numerous group presentations.” There were also some negative comments: “the structure of the class was a little rough around the edges for getting started and understanding the desired outcome of class...final presentations needed to probably be over a course of two days so more time could be given to each group to present” and “I believe that this course needs a great deal of work.”

Fall 2015 was the first semester when the course was taught. Therefore, negative comments were expected and will be used as opportunities for growth and improvement, therefore making the course better in future semesters.

Results for course assessments and student comments are compiled into the data presented in Table 3. Table 3 shows each course goal and the outcome after teaching the course for the first time.

<table>
<thead>
<tr>
<th>Goal</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Think creatively</td>
<td>The grades received on the first assignments were much lower than expected. Therefore, we made some modifications to the way we presented our expectations for each assignment. We did not decrease our expectations. We only changed the way we presented them so that students knew what we were looking for. As a result, student performance increased and their learning was reflected in their assignments. The final projects were very creative and student...</td>
</tr>
</tbody>
</table>

Table 3. An assessment of the goals based on course feedback, student comments, and performance in the class demonstrated that the students learned about innovation.
groups chose to focus on problems within their life experiences, rather than those presented by people from industry.

**Be leaders in innovation**

Students struggled with not coming up with an immediate solution to the problems they identified. One group had been working on a senior design project and had hoped that their project could apply to this course. However, after struggling through trying to fit their project into a problem, they chose to abandon that idea and solve a new problem. Their final result was much better than it would have been had they kept going in the other direction.

**Solve problems**

All student groups focused on problems related to things in their lives. Many groups read through Amazon reviews or performed focus groups, trying to determine the limitations of current products.

**Understand the broader context of research and engineering design**

Comments from the panel of experts at the end of the class stated that they were surprised at the amount of work the students accomplished in only one semester, that they were impressed with the level of understanding the students expressed, and that they would actually hire some of the students based on the quality of their projects.

**Prepare for future high-tech careers**

Two of the groups chose to pursue the commercialization of their projects. Both have submitted invention disclosures to the University of Utah, and one is actively pursuing funding to continue their project.

**Improve critical thinking skills**

One of the most important components of the class was the ability for students to provide feedback during the semester and on the written portions of their final projects. Not only did the quality of the project increase after each iteration, but the students also thought more deeply and explored additional ways they could improve their projects.

While the course is not without a need for improvement, the first attempt at teaching materials for innovation was successful in that the students gained a new way of looking at the world around them, identifying problems, approaching the way they solve problems, and applying what they learn in their undergraduate coursework to solving real world problems and innovate solutions that have commercial potential. In addition, some students casually remarked that they felt like they did not learn much in the class. Follow up questions addressed whether the students knew how to identify problems, identify the correct end user, and define user needs. Upon further reflection, all students acknowledged that they learned a great deal in the course.

**Future Directions**

Based on both our experiences teaching the course and student feedback, we plan to change the Arduino lab at the beginning of the semester by giving more specific engineering challenges and having the students learn even more about the prototyping process including a module on 3D printing. We hope that students will learn more about the value of failure and reassessment iteratively during the prototyping phase so that they will be more adept at stepping back from their designs and performing a failure analysis in a lean processing approach. As such, we will also incorporate more course content on failure analysis and risk assessment.

Students did not appreciate the value in allowing them to choose some of the course topics, and the content on many of those weeks was weaker because it was either outside our realm of
expertise or the students had decided what the course topic would be with little time to prepare. In the future, we will allow time for students to ask questions in a discussion forum on Canvas, but we will also schedule the topic for each class meeting. Furthermore, time will be spent during the semester to highlight what the students learned. Because we did not include exams, the students did not understand what they had learned or the value of it.

Finally, the course textbook was not heavy on technical content, and we have therefore decided that we will try a combination of textbooks, including *The Lean Startup* and *Zero to One* that relate to solving problems in engineering, thinking innovatively, and even taking their ideas to the next level by reading about creating startup companies. We hope that this combination will provide them with resources to consider in their future endeavors.

**Conclusions**

In direct response to feedback gained from our recent graduates and from our Industrial Advisory Board, we created a course that teaches students in Materials Science and Engineering about innovation, entrepreneurship, and creativity. To do this, we had them solve a problem that could be solved with materials-related solutions and by following the engineering design process. We made sure that they followed the process from the beginning so that their final solutions would effectively address the needs of the end user. The goals for the class were to teach the students to think creatively, be leaders in innovation, solve problems, understand the broader context of research and engineering design, prepare for future careers in entrepreneurship and technology, and improve critical thinking skills. These were assessed based on course evaluations, performance on course assignments, and student comments. As a result of this course, students felt that they had the skills they needed to be innovative as they solved real-world problems. In addition, people from industry were impressed with the quality of the projects. As we teach the course over the next few years, we hope to make it more successful by including additional resources that will be helpful for students as they graduate and transition into careers that require them to think creatively to solve materials-related problems.

**References**


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Jeffrey Bates received a PhD in Materials Science and Engineering from the University of Utah in 2013, and is an Assistant Professor (Lecturer) in the Department of Materials Science and Engineering at the University of Utah. As a graduate student, he developed and taught a first year course for engineering, which explores all of the engineering majors at the University of Utah and helps students choose a major.

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Engaging Students in Circuit Theory Laboratory Course by Incorporating Advanced Techniques in Directed Metallization and Student-Based Component Design

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Abstract

Student learning and knowledge is directly related to the engagement and active participation in the classroom. Moreover, retention has been shown to increase for students who practically use their theory studies. This creates a need for students to have more practical applications of materials learned and knowledge of tools used in engineering fields. This paper explains the application of the advanced fine image printing in the Circuit Theory laboratory experiments to fabricate components and circuits. In a sequence of laboratory experiments students practice to fabricate resistors, inductors, and capacitors. In each lab they exercise their own fabricated component and compare it with the similar available commercial component. Laboratory practices end with fabrication of resonator circuits and inductive/capacitive sensors by finishing this state of the art laboratory work, participants not only can learn the fundamentals of Circuit Theory Laboratory but also improve their knowledge of current technologies in their field.

Keywords

Circuit Printing, Nano Particles, Sensors, Conductive Ink, Capacitors.

Introduction

Interdigitales capacitores (IDC) can be made using the Dimatix DMP 2800 ink-jet printer. The capacitor is designed using CAD software such as Adobe Microsoft and is printed on to paper substrate. The factors that have effect on capacitance of an IDC are the finger length, finger width, gap between fingers, end gap, number of fingers and dielectric constant. These parameters will be varied through several different IDCs, students will record and analyze the data. The dielectric constant depends on the environment of the IDC by exposing the IDC to different environments students can measure the change and learn the basics of capacitance sensing.

Each component design, fabrication, and test considered as a practice. Every practice is easy and fast enough to be done in the standard laboratory time. Fine Image Printing is environmentally safe technology and currently in use for fabrication of flexible electronics\textsuperscript{1,2}. Developing this practice helps to achieve all academic goals of the course as well as improving engagement and retention.
This paper explains practical experiences in designing, developing and fabricating components for testing. This course will go over design, fundamentals of CAD software currently in use, by user made designs to prepare for fabrication, learning the fabrication process, and further analysis and testing of components created. This will give students practical knowledge, encourage student enthusiasm, and give opportunity for them to participate in the development of new technologies available. Assessment of the course includes students grade and their survey of the study.

Background

Paper based electronics have been attracting attention because they are low cost and environmentally friendly\(^3,4\). Compared with the conventional printed circuit board (PCB) process, which uses a subtractive method of etching away metal foil. With Drop on Demand (DoD) Fine Image Printing, droplets of conductive ink are placed only where desired, this eliminates extra costs and waste, and requires fewer steps than traditional PCB manufacturing techniques\(^5\). Another great advantage of ink-jet printing is the ability to print onto organic substrates. Hence ink-jet printing is an environmentally friendly process.

Methodology

The Dimatix Drop Manager software requires a monochromatic bitmap image. Patterns can be designed using any computer aided design (CAD) software that can produce a bitmap image. Microsoft Paint or Adobe Photoshop are examples of such CAD software tools. Each pixel will represent where a drop may be placed. To calculate the size of the printed image it is necessary to take into account the drop diameter of an ink droplet.

In order to accurately print the IDC designs it is necessary to find the drop diameter\(^6,7\). For this project we used Diamond Jet Silver Nano Ink printed on to Epson paper. Using the DMP-2800 fiducial camera the drop diameter was measured to be 30 μm. If the drop spacing is too close, then the ink tends to pool up causing inconsistent print quality. If the drop spacing is too large then the ink may not be continuous. We found that using a drop spacing of 25 μm provided sufficient overlap and avoided pooling up of the ink. In one of the samples it was observed that the resistivity was not uniform on the x and y axis. In the x direction the resistivity measures about 0.5 Ω/cm, however in the y direction it measured 100 KΩ. This is due to drop spacing being too large and the tendency of the ink to flow in the direction of the printing head movement. It was found that with a drop diameter of 30 μm, 25 μm produced a uniform conductivity in both the x and y directions with 0.5 Ω/cm.
In this study we included the Circuit Theory class. We had the students design IDCs of varying parameters. The specific parameters we left open for the students to choose. We used a DMM to measure the capacitance of the various capacitors. Electing the IDC with the best capacitance, we then varied the gap size between the fingers and the number of fingers to observe the change and optimize the capacitance of the IDC.

Figure 2. a) Right when decreased the gap size from 200 µm to 75 µm increased the capacitance form 3pF to 12.4 pF. b) Right: Varying number of fingers.
An IDC can be used as a sensor by changing the Dielectric constant and then measuring the change in the capacitance. Figure 3 illustrates the application of an IDC as a liquid level sensor by immersing the IDC in a liquid and measuring the change in capacitance.

![Figure 3](image)

Figure 3. Change in capacitance verse liquid level.

Each environment that an IDC is exposed to has a unique dielectric constant, by measuring the capacitance it is possible to identify or speculate what types of materials are present. To help the students build intuition of this principle, students exposed their IDC to various materials and noted the unique capacitance due to the dielectric constant of each material.

![Figure 4](image)

Figure 4. Top Left: Exposed to air. Bottom Left: Exposed to tap water. Top Right: IDC with a droplet of water. Bottom Right: exposed to dish soap.
Conclusion

In this study inkjet printing has been performed as a method of metallization. It can be performed on different substrates with different textures, with the proper surface treatment to ensure good conductivity. Compared to the traditional electrolytic method (subtractive) for PCB manufacturing, the additive process water-based process greatly reduces the number of manufacturing steps, eliminates the need for toxic solvents, and greatly reduces metallic and chemical waste. Circuit patterns made using this technology have broad application and can be applied to many future PCB demands of the marketplace such as medical circuits, flexible material, and sustainable electronics. Using this technology student of Circuit Theory Laboratory course, designed fabricated and tested their own capacitors and sensors. It was fast and reliable experiment and engaged students in laboratory works.

References

Abstract

A Faculty Learning Community (FLC) in any university provides an excellent way for faculty to both innovate and improve teaching methods and styles. When our FLC, consisting of seven faculty members and two staff members, convened, it became apparent across academic disciplines that undergraduate research warranted emphasis. Undergraduate research integration into curriculum promises benefits: student engagement and development of employer-desired skills such as communication, teamwork, analytical reasoning, and the application of knowledge to real-world settings. This paper details the FLC’s efforts to incorporate more research into seven undergraduate classes by using discovery learning pedagogies and to begin compiling a list of best practices to share with others. The fact that these efforts span different undergraduate grade levels and disciplines offers key insights for any undergraduate program. Further, discussions about the formation and collaboration of the FLC at this university presents a guide to others for starting one of their own.

Keywords

Faculty learning community, discovery learning, undergraduate research

1. Introduction

Industry expects students to conduct research, think abstractly, and work in teams. Incorporating research into undergraduate classes can enhance student learning and performance in all those areas, but incorporating it bears two inherent challenges. Course content in most cases must give way to introducing or incorporating research. An even larger hurdle, faculty accustomed to certain teaching methods and pedagogies have to change their approach and take the risk of incorporating research into their classes. This paper presents an initial effort by an innovative Faculty Learning Community during the 2015-2016 academic year to find the best ways to overcome the challenges associated with incorporating research into undergraduate classes.

This paper presents a series of course-specific approaches with comments about their effect on student learning. Diverse experiences from six courses in five STEM disciplines and one in global security and intelligence provide ideas from previously tested methods for incorporating research. The total of seven classes included in this study had a total of 341 students ranging from the second to the fourth year. Admittedly, the small size of the university and correspondingly small class sizes (less than 30) made it easier to maintain contact with students, improving monitoring and feedback.
For those thinking about incorporating research, this paper offers insights, some course-specific and some generic, about the associated challenges and how to improve the initial experience for both professors and students. At the end of the project’s first year, the FLC felt that the outcomes of incorporating research warrant the costs. By offering insights and lessons learned from this particular experience, this paper will help other faculty avoid surprises, lower initial costs, and enrich the experience of their students.

2. The Basics & Benefits of Faculty Learning Communities

A Faculty Learning Community (FLC) is a group of trans-disciplinary faculty working together in groups of 8 to 12.1 Each FLC engages in an active, collaborative, year long program with the goal of enhancing teaching and learning. Participants in FLCs may select projects that allow for experimenting with teaching innovations and assessing resultant student learning. FLCs increase faculty interest in teaching and learning, and provide safety and support for faculty to investigate, attempt, assess, and adopt new (to them) teaching and learning methods. After participation in an FLC, faculty report using new pedagogies, while also seeing improvements in students’ critical thinking and ability to synthesize and integrate information and ideas, often in an holistic manner.1 Additionally, FLC participants in one study reported improved teaching effectiveness, confidence, and an increase in knowledge about how students learn.2 Faculty participation in FLCs also has been shown to improve scholarly productivity, create stronger connections with colleagues and students, and foster greater collegiality across the institution.3-5 More recent research showed by participating in an FLC, faculty development is enhanced through opportunities for professional learning and growth.6

As a topic-based learning community, which designs a curriculum to address a special campus or divisional teaching and learning need, issue, or opportunity, faculty from the Embry-Riddle Aeronautical University Prescott Campus’ Colleges of Engineering, Global Security and Intelligence, and Aviation formed a topic-based learning community during the 2015-2016 academic year. The topic of interest and study focused on ways of integrating aspects of research into the undergraduate curriculum, which is one approach for discovery learning and is also a current university initiative. As such, each faculty member implemented one or more types of discovery learning in one or more of their courses during the 2015-2016 academic year.

3. Discovery Learning

Discovery learning is a specific type of active learning strategy that allows students to have hands-on learning opportunities, focusing on the process of learning through inquiry and the exploration of concepts. Failure and feedback are both important and necessary for learning to occur. Discovery learning is constructivist in nature; it is grounded in inquiry-based instruction where learners build new knowledge from prior knowledge and active experience. Further, discovery learning focuses on the process of learning rather than the product. Discovery learning takes the form of a variety of pedagogies, including, but not limited to: problem-based learning, case-based learning, simulation-based learning, and project-based learning. As a result, methods of discovery learning result in a greater and deeper understanding of course content.
Discovery learning is characterized by three main attributes, as cited by Castronova, all of which prove integral to the teaching and conduction of research:

1. Using exploration and problem-solving to create, integrate, and generalize knowledge.
2. Using student-driven, interest-based activities where students determine the sequence and frequency.
3. Involving activities to encourage the integration of new knowledge into the learner’s existing knowledge structure.

3.1. How Research Impacts and Improves Learning
Nationwide, undergraduate research and scholarship is recognized as a high impact practice that increases student engagement and success. In addition, undergraduate research has been shown to provide the skills employers are looking for: Communication, teamwork, analytical reasoning, and applying knowledge to real-world settings. The traditional model for involving undergraduates in research is an apprenticeship model with either one-on-one interaction between a mentor and student or mentorship of a team. However, as defined in the PCAST report, National Academies of Sciences, Engineering, and Medicine, and recently highlighted by Elgin, et. al., this often limits the total number of students who are involved in undergraduate research and primarily targets students during their junior and senior years. Therefore, an increasing number of institutions and individual faculty are identifying ways to integrate research into their courses and program curricula, which results in greater involvement of the student population as a whole. This relatively new approach for learning how to conduct research at the undergraduate level provides for scaffolding of research skills across a curriculum.

Given the mission of Embry-Riddle Aeronautical University, “...to teach the science, practice, and business of aviation and aerospace, preparing students for productive careers and leadership roles in service around the world.”, it is not surprising that undergraduate research is already an important part of the university culture. The current Quality Enhancement Plan, part of the Southern Association of Colleges and Schools Commission on Colleges accrediting requirements, focuses on engagement of students in research and scholarship through both curricular and co-curricular activities.

Between the importance of this university initiative and innate interest of all FLC members to teach skills and knowledge relevant for conducting research, each FLC member selected a form of discovery learning most applicable to their discipline that fostered the development of such skills pertinent for conducting research at the undergraduate level.

In the next section, we discuss the resulting seven course-specific approaches with comments about the inherent challenges, opportunities, and effects on student learning.
4. Implementations of Discovery Learning

4.1. Engineering Fundamentals Course

In order to implement problem-based learning in an introductory engineering programming course, groups of first and second-year undergraduate students were required to design an automated mechanism for sorting Lego robot parts based on their shapes or colors. Additionally, students presented their preliminary design review and wrote a technical report. Students were asked to complete a self-report survey adapted from the rubrics of AACU Value Assessment of Learning in Undergraduate Education (https://www.aacu.org/value-rubrics), for which they evaluated their creative thinking, oral and written communication, and teamwork skills once before the project started and once at the project’s completion. Pre/post tests were administered to check for significant improvement in all four skills. Students were also asked to respond to an additional questionnaire designed by the instructor to acquire further information specific to the project; see Table I. Here, blue and red cells for each row refer to the sub-skills with the smallest and the largest average differences between pre and post project data.

While the overall objectives of the design were given, selecting among alternative design solutions and details as well as the level of difficulty for the final product was left for the students to decide. Students had to apply the material taught in class to a real-life mini-industrial project and learn about software-hardware communications. Furthermore, to fulfill the requirements for one of the tasks, they had to study an advanced topic of MATLAB programming, i.e., creating Graphical User Interfaces on their own; hence, engaging in a form of self-directed learning. Lastly, the students had to learn how to effectively work in teams outside of the classroom in order to deliver a final oral presentation and written report about the project.

In this project, the students were given an opportunity to enjoy a hands-on experience in programming and learn about hardware-software communication. This is typically not included in the syllabus of a first-year introductory programming course. They could learn how to design a mini-industrial robotic project and add value to their resumes. They could also reinforce what they learned in this course as well as the material from a pre-requisite engineering fundamentals course where they worked with Lego Mindstorm robots. Finally, the students understood the benefits of active learning as opposed to traditional lectures, including self-directed learning, and obtain improvement in critical thinking, oral and written communication, and teamwork skills.

One-tailed paired t-test with a significance level of 0.05 tested for differences between responses on the AACU rubrics completed before the project started and after the project was done, for critical thinking, oral and written communication, and teamwork skills. It was hypothesized that conducting this project would lead to a significant increase in each measured skill, meaning that the averages of sub-skills for each skill after the project completion will be significantly bigger than what they were before the project started, i.e., probability of pre- and post-averages for each sub-skill belonging to the same population is less than 0.05. Results for each item on each of the rubrics are in Table II in Appendix A. Furthermore, the questionnaire using a response scale of 1 (Strongly Disagree), 2 (Disagree), 3 (Neutral), 4 (Agree), and 5 (Strongly Agree) showed significant results for a variety of items. Table I shows the results for the questionnaire.
4.2. Digital Circuit Design Course

Faculty in the electrical engineering program investigated the impact of research, when introduced across both class and lab sections of the same course. Students in a freshman-level digital circuits design class, which was historically biased to electrical and computer engineering (EE/CE) majors, served as study participants. Since over 85% of the students enrolled in the course were aerospace and mechanical engineers (AE/ME), we wanted to observe whether the students connected disparate EE/CE laboratory topics to real-world AE/ME applications (problem-based learning) after writing a substantial research paper on a topic of their choosing, within the broad category of aircraft control systems and design.

Table I – Average of the Responses to the Extra Questionnaire in the Introduction to Engineering Course.
Scales of 1 to 5 refer to Strongly Disagree, Disagree, Neutral, Agree, and Strongly Agree, respectively.

<table>
<thead>
<tr>
<th>Question</th>
<th>Average Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Because of having hands-on experience and learning about hardware-software communications in this course, I think I am knowledgeable to apply what I learned in the future robotics and controls courses, which require running robots, such as Lego EV3 with MATLAB.</td>
<td>4.04</td>
</tr>
<tr>
<td>Because of having hands-on experience and learning about hardware-software communications in this course, I think I am knowledgeable to apply what I learned in the future real-life industrial problems, which require communication between hardware and software.</td>
<td>4.12</td>
</tr>
<tr>
<td>I think that fulfilling this project, which is a modified version of a graduate automation project, during a semester, might count as a worthwhile item in my resume for future employment opportunities.</td>
<td>4.36</td>
</tr>
<tr>
<td>I learned more from this project by working outside the class rather than inside the class.</td>
<td>3.32</td>
</tr>
<tr>
<td>I learned more from this project by working in a group rather than individually.</td>
<td>4.08</td>
</tr>
<tr>
<td>Because of working with Lego robots and webcams and having hands-on experience in this course, I enjoyed this class more than a purely-programming course.</td>
<td>3.84</td>
</tr>
<tr>
<td>I think the need to use programming for the final project reinforced what I learned in class about MATLAB coding.</td>
<td>.96</td>
</tr>
<tr>
<td>I think the need to build two different robots using the Lego EV3 kits and work with these robots for the final project reinforced what I learned in the &quot;introduction to engineering (EGR 101)&quot; course about the Lego robots.</td>
<td>3.92</td>
</tr>
<tr>
<td>Through this self-directed learning process of studying about GUI development in MATLAB on my own, I could achieve sufficient understanding of how to make a GUI in MATLAB.</td>
<td>3.44</td>
</tr>
<tr>
<td>I might learn more about developing standalone apps from MATLAB GUI's to earn money in the future.</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Several challenges emerged in this exercise. One of the most challenging aspects was gaining student compliance. While a majority of the students were interested in the topics they were researching, several students expressed discontent at the volume of work that needed to be done for a freshman-level class. Of the 90 students enrolled, 9 failed to complete the research
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assignment altogether, despite it being worth 10% of the final grade in the class. Of the 81 submissions received, 11 adhered to the standard set by the assignment requirements, while the remaining 70 submissions had major omissions in terms of content, formatting, or citations.

Another challenge is in student research techniques. Despite receiving a large number of acceptable research papers, most students could not use academic journals to support their research to the extent required by the assignment. After conducting one-on-one debriefing sessions, many students expressed either that academic journals have information irrelevant to the concepts of interest to students, or that these journals are specialized and examine scenarios that seldom happen in the real world. A large number of students could not extract meaningful information from articles to support their research even when these articles were well-written.

Yet another challenge was in laboratory implementation. The last lab of the sequence was to build a joystick-controlled model of a supersonic aircraft, designed to use all of the concepts learned in the course. Students had to apply their knowledge of how the aircraft control surfaces should react to inputs from the joystick and how the aircraft should automatically correct its orientation when faced with external forces based on an accelerometer’s readings. From the instructor's standpoint, the implementation of the laboratory experiments that tie together theoretical concepts into real-world applications required a great deal of effort. As most of the concepts used in the final laboratory experiment were at the advanced level, the entire lab sequence had to be overhauled to include a scaffolded approach. Students learned the pieces to a more complex puzzle one at a time. These “stepping stone” labs introduced students to state-of-the-art technologies and industry tools.

When completed in tandem, the research paper assignment gave greater relevancy to the laboratory exercises and tied disconnected topics to real-world applications. Students were more receptive to the concepts introduced during their laboratory sequence and could envision potential applications of these concepts when designing aircraft. An end of project survey was administered to evaluate student motivation, applicability of concepts, and the relevance of digital circuits in aeronautics and avionics. Results from this survey are presented in Figure 1.

![Figure 1](image-url)  

**Figure 1.** Student responses to survey questions in the test and control groups. The test group consists of students, which underwent the new laboratory/class implementation.
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The most frequent complaint from students concerned the narrowness of the research assignment topic because it focused solely on aircraft control systems. From one-on-one student interviews, it became apparent that there were a large number of students in the space and astronautics track within AE, for whom aircraft were not a topic of interest. As an alternative to consider when moving forward, students proposed introducing additional topics, such as flight termination systems for spacecraft, rocket gimbaling (gimbaled thrust), and spacecraft attitude dynamics.

Moreover, since this is a freshman-level course, it would be beneficial to have an overview of proper research techniques and formatting guidelines early in the course. Plus, introducing the research assignment as a staggered set of assignments (i.e., scaffolding), where the instructor provides comments at each stage of the research process throughout the semester, is recommended for future implementation. In retrospect, if scaffolding for the research assignment had been used this time around, compliance may have increased, and the students would achieve greater accuracy in citing and paper formatting. It is believed that scaffolding would have allowed students to better understand and use information from journal articles more effectively.

4.3. Experimental Space Systems Engineering Course

A junior-level experimental space systems course for students in aerospace engineering implemented discovery learning through integration of new knowledge and exploration: students discovered a peer-reviewed paper about a satellite subsystem of their choice; and, students created their own lab for which another section completed a few weeks later.

A major challenge was that some of the students would collaborate on the same paper or fail to read the paper beyond the abstract. They also struggled to choose papers that were peer-reviewed and to follow citation guidelines. Furthermore, students had difficulty creating enough tasks for the entire lab section. Students were also challenged by creating the lab in one 150-minute session. Furthermore, students did not have the opportunity to test their lab before handing it off to the other section. Thus, the resulting labs produced mediocre results.

Both these exercises gave students a choice about course content. Peer-reviewed papers gave students a chance to learn about cutting-edge research, albeit engrossed in difficult terminology. Yet, by creating their own lab, students learned to create a method to test a hypothesis, which was especially challenging when the hypothesis itself was not well understood by the students.

In general, students reported that summarizing peer-reviewed articles benefited them. One section of 17 students was asked, “How do you feel about including peer reviewed articles in the discussion section? Why?” Of the 14 students who responded, 71% felt the peer reviews were useful and 29% felt they were not useful. While students disliked reading the whole article, they found value in learning about new technology. When implementing the reading of peer-reviewed papers in the future, it is important to provide enough information as to where to find acceptable articles and how to correctly cite them. Students who provided informal feedback expressed enjoying the opportunity to create their own lab but wished they had another week to test it before implementation. Alas, students who performed the labs thought that the labs were too simplistic and not worth repeating. In the future, an additional week will be added to this project.
so that students have time to create a more in-depth lab and can conduct a pilot test of the lab before the other section is asked to complete it.

4.4. Object-Oriented Programming Language Course

Faculty investigated project-based learning in a sophomore-level programming language course. Students researched a software security issue of their choosing. This was a 5% extra-credit opportunity which resulted in over 80% of the class participating in the project. As part of this project, students researched C/C++ security issues: finding vulnerability, discovering how the vulnerability is exploited, and identifying how the attack can be mitigated. They orally presented their findings during class in a 10-mins. presentation and wrote a two-page research report; report template was given by the instructor and resembled a standard research publication.

A major challenge when attempting to integrate research into the course revolved around achieving a 100% student participation. Factors hindering student motivation for project engagement may be because it was made optional, timing of when the assignments were issued, cyber security topic not being of interest to some engineering students, and the heavy workload of the senior-level students in the course. Furthermore, 3 lecture periods on advanced programming language features in the week 14 of the semester had to be traded for student research presentations; on the other hand, students learned C/C++ security topics.

A majority of the students in the programming language course were cyber security majors. By integrating a software security research opportunity in the programming course helped them gain much needed insight that they can leverage to enhance their knowledge from past and future cyber security courses. They were exposed to relevant software issues that are emerging in cyber security research. Students presented their research in a rather comfortable fashion. Some students even demonstrated example code execution as part of their presentation. PowerPoint slides varied in quality from medium-to-high (80% to 100% score), but the quality of the research reports disappointedly varied from low-to-medium (60% to 80% score).

4.5. Programming Language Organization Course

We used project-based learning in a junior-level course on the comparative study of different computer programming paradigms. The majority of undergraduate software and computer engineering students learn the imperative style of programming alone. But, these students are challenged by alternate programming language designs, including functional and logic programming that have application in many interesting areas such as game theory, natural language processing, artificial intelligence. Hence, generating student interest in learning these additional types of programming and thinking more critically about fundamental computing theories, even when student experience is limited to imperative procedural programming, was the primary goal of this exercise.

Immediate student objections towards learning these additional programming languages included statements like: “I can solve any problem I care about with MATLAB or C, or FORTRAN, so why should I learn something new?” The course introduced programming languages such as
Lisp, Scheme, Haskell, Caml, Swift, and Racket, all of which focus on alternative methods of functional programming as well as Prolog, which focuses on the alternative of logic programming methods compared to procedural programming. Along with historical single paradigm alternate programming languages like Lisp and Prolog, multi-paradigm languages such as Python and C# are reviewed and may be selected by students for further study. Because the very latest multi-paradigm (imperative and functional) programming language are being more rapidly adopted in engineering programming courses along with high-level interpreted programming languages for teaching, we decided to introduce it to our students as part of this FLC endeavor.

Each student researched why an alternative programming language was created, its associated strengths and weaknesses, and then chose an algorithm to demonstrate said advantages and disadvantages by picking an algorithm and application to build of their own interest. Examples included game playing programs, optimization, numerical methods, biological classification, and test automation. Before doing so, they were asked to hypothesize which programming language would be best suited. Students devised metrics and the analysis to demonstrate value and research history as to why others use alternative programming languages and features today. This was an individual research project. The previous year the same individual projects were assigned, but without the related research aspect. The hypothesis was still assigned, but students were not asked to consider what prior researchers had determined related to their algorithm and application of interest. In the previous year only 33% of the projects had a positive hypothesis outcome (Prolog hypothesized to have advantage and shown to in fact have advantages for scheduling logic), 33% had a neutral outcome (Lisp was shown to have some advantage), and 33% had no outcome (incomplete). So in the prior year, 66% completed the project satisfactory or better overall.

This year, the majority of students hypothesized that the alternate programming language would provide some advantages (29% hypothesized the alternative would be worse than the primary). In 14% of the cases, the presentations simply failed to design a good experiment and/or to identify objective metrics. The majority of the presentations (57%) proposed objective, unbiased arguments and concluded the alternate programming language was worth more of their time to learn and use in scenarios similar to what they investigated. Overall, it appeared as if students ultimately convinced themselves that an alternate programming language, or multi-paradigm programming language, is worthy of further investigation and study for specific classes of algorithms and problems, especially those that are semi-numerical, logical and symbolic in nature. So, while the majority of students again completed the assignment satisfactory or better, they also formed a hypothesis supported by research and experimentation and convinced themselves of the value of alternative programming methods.

4.6. Electromagnetic Fields Course

In this junior-level electrical engineering course, students were tasked with an open-ended problem involving electromagnetic waves and antennas. The problem statement asked for a design of an antenna that would work for an 802.11n router. Working in groups of 2 or 3, decided by the type of antenna they would be designing, students were charged with producing
an antenna similar to the type expected of them upon employment post-graduation. Students kept a record of their meetings and meeting minutes, just as would be expected of them in industry. Meeting journals also included generated ideas, discoveries, and questions about assignments given. Instructor feedback was provided for the type of research performed prior to the agreed upon antenna design. This process was repeated throughout the course. Group members were each responsible for completing tasks regarding a very specific part of the antenna’s design. Each group shared their designs with the entire class at the end of the semester.

Three specific challenges emerged throughout the course of the project. First, students’ prior knowledge about antennas was limited, causing much confusion when the first assignment was issued. Second, students’ experience working with and solving open-ended problems was lacking. Third, time demands for the instructor were high. Spending time during class explaining the properties of antennas prior to when they are typically covered, plus extensive time spent grading and providing student feedback on a regular basis, made this type of assignment unexpectedly challenging for the instructor.

Students were given many opportunities to work together on an open ended assignment much like they will do in their careers. Moreover, they were tasked with making their own meeting times, keeping adequate notes, and with the division of tasks as needed. Many individual assignments were given as necessary. One such assignment asked students to find an article related to electromagnetics and give a 3 minutes presentation on it. Each student had to research and cite a peer reviewed article for the presentation. Students also received feedback in the form of questions related to their design proposals. Such feedback allowed them to research and critique their own designs while coming to conclusions about what was good, better, or best. This is the basis of a “trade off design,” where making one minor change causes something else to change.

This problem-based learning approach provided unique insight for the instructor and students. As part of the design and learning process, students were able to assess one another on their presentation skills and the feedback received allowed for self-reflection and assessment. Overall, student feedback about the assignment was positive. In general, students reported that they thought the subject was well designed for the course, but additional information at the beginning of the term about the assignment’s overall goal and end-product would have been helpful.

4.7. Global Security and Intelligence Course

In this junior-level social science course with 29 students, the research process was fully scaffolded. The course design paralleled that of the three phases of the research process: finding literature, writing a review of the literature that compares alternative explanations, and then taking a position and defending it using logic and evidence based on the literature. In order to understand the research process, students were given a broad question to answer—Why will Russia stay in Syria? Proposing this particular question gave the students a problem to solve (problem-based learning approach): how do I explain this predicted phenomenon? Eight classes were specifically devoted to introducing, teaching, and developing the skills needed to accomplish assigned tasks assigned in each phase; five of which forced students to bring ideas or
The intent of using a scaffolded research process in a social science course (Introduction to International Relations) was to increase each student’s ability to examine a situation, frame an associated problem, consider potential causes for a particular behavior, and then analyze and evaluate the possibility and plausibility of different causes. Providing students experience with the research process was an effort to give them an opportunity to engage in discovery for themselves—from taking an unstructured question and guiding them through framing the problem to posing potential explanations or causes. Additionally, students were encouraged to embrace the idea of imperfect information and find ways to use research to argue for potential causality knowing they did not have all the facts.

Four primary challenges emerged during the completion of the research project. First, was time or the lack of. Incorporating this fully scaffolded research process into an undergraduate class reduced the opportunity to present new course topics due to time spent otherwise. Plus, asking students to conduct research outside of class led them spending less time preparing for class. In addition, the time required to provide adequate feedback for each assignment was exorbitant and very time consuming for the instructor. Second, all four skills introduced in this class (annotated bibliography, literature review, position paper outline, and position paper) were new for the students. Only about 25 percent of the students were able to incorporate the skills presented in the class fully into most of their assignments. Roughly 50 percent of the students were able to incorporate some of the skills, and the remaining 25 percent incorporated only a few. Third, the students struggled to incorporate instructor’s timely feedback into their revised and future assignments. For example, detailed comments provided in one assignment rarely manifested into the next. Fourth, students struggled with citing and formatting credible sources—a challenge noted by many FLC members. Only five of the 29 submitted outlines were acceptable without further revisions; the sources provided for the arguments were poorly sourced.

Students, nevertheless, had the opportunity to learn and practice basic research skills. Students learned some of the benefits of collaboration, such as the value of presenting their work to each other in every phase and how discussing other’s work and ideas improve self-understanding. Across the board, students grew in their knowledge and capacity. Despite the general lack of mastery for sourcing, the final position paper showed a connection (in varying degrees of proficiency) between theory and evidence—one of the main objectives of the course.

The overall results of the scaffolded approach to teaching research in this course suggest four conclusions. First, the feedback from the students overwhelmingly indicated that peer-group work contributed significantly to their ability to understand the purpose of the different phases and exercises. Second, the course required students to learn and apply too many new skills at one time—students generally understood the purpose of each phase, but could not adequately perform the desired skill. Third, students need additional exposure and practice with sourcing; the final position paper showed significant improvement in terms of finding relevant sources to make a particular claim compared to previous students, but students as a whole still struggled with finding appropriate and credible sources that provide substantive support for a particular point or...
claim. Fourth, the only exercise that required two iterations (submission-feedback-revise and resubmit) showed the greatest and most consistent improvement. Thus, it is suggested that classes incorporating the teaching and learning of research skills provide students with at least two opportunities to perform the targeted skill.

5. Conclusions

Seven faculty from different disciplines and two staff members came together to form a Faculty Learning Community (FLC). The FLC spent two months debating several topics of interest to its members and settled on the integration of undergraduate research into courses. Another two months were used by each FLC instructor to develop a suitable plan for one of their upcoming courses and meeting the Institutional Review Board (IRB) requirements. The individually developed plans were shared with the FLC for feedback and common discovery learning pedagogies for the development of student skills and knowledge pertinent to conducting research were also identified. The first year focus of the FLC project was on lessons learned, leaving the collection of data on the impact on student skills and course outcomes to future work.

The FLC instructors adopted their chosen discovery learning technique into their courses in the following semester. A total of seven courses were impacted, incorporating new activities that gave students opportunities to use exploration and problem-solving to create, integrate, and generalize knowledge, develop their own interest-based course exercises, and, integrate new knowledge into existing knowledge structures. By using active learning, students honed their critical thinking, oral and written communication skills, and teamwork skills.

Overall, despite the demands placed on instructors and students as a result of the chosen strategies employed to integrate research organically into the course content, students, on the whole, greatly benefited. In most cases, hands-on experience coupled with active learning was positively received by students. Projects requiring the finding of solutions to real-life inspired problems, the creation of laboratory exercises, and programming with fringe languages, provided students with opportunities to engage in novel topics on their own.

In spite of the successes noted above, challenges were still present. One such challenge for instructors involved the open-ended structure of the activities. If other instructors plan to adopt the strategies discussed herein, note that an adequate amount of lead time needs to be allocated to design the majority of the learning activities prior to the course’s beginning. In addition, instructors must prepare for logistical matters in advance of implementation, such as purchasing and checking out equipment to students, reserving 24/7 labs with necessary software and hardware support packages, providing more frequent timely feedback to students, and understanding IRB training and compliance needs. And, as with most active learning implementations, especially when lecture had previously served as the primary delivery method, instructors faced student complaints about the course, and students were initially disinterested in actively participating in learning.

Like instructors, students faced their own challenges. When structuring a course using discovery learning methods, students typically learn the course material at a greater depth, but in order to
do so, they need to dedicate out-of-class time and apply material to real-world problems. Plus, if students had not had much prior experience working in teams or presenting work orally, these two additional expectations may have proved challenging for them as well. Finally, students also appeared to struggle reading journal articles in their entirety and providing feedback for their peers.

6. Next Steps

Taking what was learned from this FLC project, we believe we can improve the effectiveness of the FLC and more easily integrate research into our upcoming engineering and social science courses. One improvement is to identify end goals for the FLC, set realistic milestones for the group, establish individual member responsibilities based on these end goals, and better communication of logistical requirements such as IRB compliance and data collection rules. In our future courses we plan to make enhancements, such as scaffolding the learning of research components throughout the semester to make students show greater learning for searching, citing, and summarizing research articles. Understanding the most basic components for conducting research, i.e., searching, citing, and summarizing peer reviewed journal articles, will be our collective primary focus for future work when it comes to teaching and learning undergraduates about the importance and process of conducting research.

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Appendix A:
Results of paired t-test on the data collected using the rubrics of AACU Value Assessment of Learning in Undergraduate Education from before and after the project.

Table II – Results of Paired t-test for Sub-skills of Critical Thinking, Oral and Written Communications, and Teamwork between the “before the project started” and “after the project was done” Data. Blue and red cells for each row refer to the sub-skills with the smallest and the largest average differences between pre and post project data.

| tstat for Critical Thinking Sub-Skills, df=22, tcritical = 1.717144 |
|---|---|---|---|---|---|
| Acquiring Competencies | Taking Risks | Solving Problems | Embracing Contradictions | Innovative Thinking | Connecting, Synthesizing, Transforming |
| 0.000177 | 0.001166 | 0.000101 | 0.00054 | **0.0000397** | 0.00054 |

| tstat for Oral Communications Sub-Skills, df=22, tcritical = 1.717144 |
|---|---|---|---|---|---|
| Organization | Language | Delivery | Supporting Material | Central Message |
| 0.000228 | **0.000417** | 0.000064 | 0.000228 | 0.000177 |

| tstat for Written Communications Sub-Skills, df=22, tcritical = 1.717144 |
|---|---|---|---|---|---|
| Context and Purpose of Writing | Content Development | Genre and Disciplinary Conventions | Sources and Evidence | Control of Syntax and Mechanics |
| 0.000241 | **0.000034** | 0.00054 | 0.000929 | 0.00121 |

| tstat for Teamwork Sub-Skills, df=22, tcritical = 1.717144 |
|---|---|---|---|---|
| Contributes to Team Meeting | Facilitates the Contributions of Team Meetings | Individual Contributions Outside of Team Meetings | Fosters Constructive Team Climate | Responds to Conflict |
| 0.001977 | **0.000101** | 0.002379 | 0.001977 | 0.000177 |
To Flip or Not to Flip, that is the Question

Abstract
Engineering is a field focused on problem solving, and hence engineering courses focus on students solving various problems related to course material. This type of course lends itself well to being taught in a ‘flipped’ format where a significant portion of class time is devoted to working homework problems, facilitating student/instructor interaction with an emphasis on the students’ problem-solving methods and techniques. This paper examines a sophomore level statics course taught in two formats, a conventional lecture style and a partially flipped format. The ‘partially-flipped’ terminology is used because the course was formatted such that class time was divided between lectures on course topics and homework solving sessions (alternating between each). In comparing the two formats, the difference is essentially a trade between more in-depth lectures (and worked examples) and individual interaction between the instructor and students while the students solve problems. There is little doubt in the author’s mind that this benefits some students greatly. However, the question that is hopefully addressed is, “Does this focus towards individual students benefit the class as a whole in some measureable manner?” To gain insights toward answering this question, the two courses are compared in several areas. The comparison between the formats is made using qualitative and quantitative data. Qualitative aspects of the comparison include course development and implementation as viewed by the instructor, student perceptions of the effectiveness of the format in learning the material (via student surveys, comments, and evaluations). While quantitative data are admittedly limited, an attempt is made to quantify student performance relative to the learning objectives in both course formats. This is accomplished by comparing student scores on common exam problems given during the course.

Introduction
A significant portion of an engineering career is focused on problem solving. As such, engineering courses often focus on problem solving. Additionally, in lower level courses, it is important to train the students in proper problem solving techniques, even to the level of format and organization. Many teaching methods have been and are used to emphasize these important aspects. In particular, the flipped-classroom is one method that one could see being very effective since the instructor and students have significant interaction while the students are working problems. Thus, not only can the instructor assist students in problem solving, but the instructor can help younger students develop appropriate problem solving techniques during this interaction.

The statics course at Southern Utah University presents an excellent opportunity to leverage a flipped class format. The statics course, ENGR-2010, is typically the first engineering course with problem solving and therefore students could benefit from significant interaction with the instructor while solving problems. The course is normally taught once a year, however during the 2015-2016 academic year it was taught both semesters by the same instructor. In the fall semester the course was taught in a more conventional lecture-style format. Based on instructor
observations, other faculty observations and student comments, converting the course to a flipped format seemed appropriate. Unfortunately, due to the short amount of time between semesters there was not time to entirely convert the course format. However, there was an opportunity to begin to the process and teach the course in a partly-flipped format. The format was largely based on an existing course format used by another instructor for a statics class at another university.

The back-to-back semesters of the same course with the same instructor provided the opportunity to compare the two course formats. During the two semesters several of the same exam problems were used to be able to compare student performance as directly as possible (including exactly the same problem with different numbers, or only changed slightly such as moving a force on the structure). Additionally, the students were given a survey at the end of the course to attempt to understand the students’ opinions as to whether or not they like the format and their perceptions of how their performance was affected by the course format.

**Course Format**

ENGR-2010 is the statics course for the engineering program. The course is normally taken in the first semester of the sophomore year. In the past, the course has been taught as a conventional lecture-style course with little in-class work. In the fall of 2015, students expressed interest in solving problems in-class and working homework during class time. Additionally, faculty that observed a lecture suggested exploring the flipped format. Due to the short amount of time between the fall and spring semesters, completely flipping the format was not practical. However, one of the faculty in the department was aware of a statics class taught at another university where a large portion of class time was devoted to students completing homework. Details on this class format can be found in reference [1].

In this example the class time was divided between lectures and homework roughly equally. A short lecture was provided for each topic on one day and the next class was devoted to solving homework related to the previous day’s lecture. While it was not completely flipped, a significant portion of the flipped format is incorporated in that half the class is devoted to students completing homework problems.

Obviously, lecture time is now reduced, which presents potential issues. In a more conventional lecture-style course, there is plenty of time to cover material and detail and work several examples. Now with only half the time devoted to lecture, the challenge for the instructor is to cover material and complete examples in one class time sufficiently so students can complete homework based on that lecture. In some cases this is not an issue, but for more detailed topics this poses a significant challenge.

Following the example class\(^1\), ‘pre-lecture’ assignments were created for students to complete prior to each lecture. The intent was for students to take the initiative to familiarize themselves with the material prior to the class lecture. The assignments included reading sections of the book and simple fundamental problems based on the reading. In the example class, these assignments were collected and graded at exams as part of a course notebook. In the current case, similar assignments were generated and available to the students but not graded.
As an example, in the fall semester, 9 pages of notes and 2 - 3 class days were spent on 3-D particle equilibrium, divided between theory and example problems worked on the board. In the spring semester, this material was covered as 1 topic. The students were expected to read the book material such that they could answer simple questions, such as defining and using unit vectors and drawing 3-D free-body diagrams. The lecture was reduced to 1 day (still 6 pages of notes but focused on worked examples) and another day was dedicated to students working homework problems in class (individually and in groups). The pre-lecture assignment and course notes can be found in Appendix A. A similar structure was put forth for all of the course topics.

Results

Student Performance

The partially-flipped course was evaluated in two ways. First, student performance on exam problems was compared to the previous semester. While entire exams were not exactly the same, each exam had similar questions or problems where numbers were changed but the problems were the same. The other method of evaluation was through student surveys. At the end of the course, students were given a survey asking their opinions about the format and questions about the course material.

For the assessment comparison, only engineering students in the courses were compared. The statics class was also required for engineering technology majors during the fall semester. However, the engineering technology curriculum is transitioning those students to another statics course. In the fall 2015 class 16 students were engineering majors and there were 20 engineering students in the spring class (18 of which responded to the voluntary survey).
Figure 1 shows average and low scores for several exam questions for the two classes. The labels for the questions (1 – 9) increase with time into the semester. Questions 1 and 2 are scores from the first exam, questions 3 – 5 are from the second and third exams while the last four questions (6 – 9) are from the final.

There does not appear to be any significant difference between the two classes if one examines the average scores (bars), and therefore does not support some studies where flipped classrooms have improved overall grades.\(^2\) However, the lowest score on each question, denoted by the diamonds and triangles, shows a consistent trend for the second half of the semester (problem 4 and higher). The low score for the spring semester is on the order of 8% higher or more than the fall semester low score. This trend is perhaps explained by other research where higher performing students tend to not improve with the flipped format but lower performing students feel the course helped them improve their performance\(^3\). While this certainly is not conclusive it does seem to indicate that the lower performing students are helped by the flipped format as other research has shown. One might also draw the conclusion that the higher performing students are hurt by the format since the averages are similar but the low scores have improved. However, this is most likely not the case since the averages are relatively high and common errors for a near-perfect score are minor math errors, sign errors and the like and typically not concept related. Thus, it is unlikely that the higher performing students are comprehending less in the flipped format but suffering from careless mistakes.

![Figure 1: Comparison of exam problem scores. Exam 1 (problems 1 - 2), Exam 2 (problems 3 - 5) and Final (problems 6 - 9), n = 16 (fall) and n = 20 (spring).](image-url)
This trend is not the same for the problems from the first exam. While there is no conclusive data to support a theory, this is potentially due to a switch in the pre-requisites for the course between the semesters. Physics was a required pre-requisite for statics for the fall statics class but this requirement was removed for the spring semester. Several students commented that they struggled with vectors in the first few weeks of the course because they had not covered them in other courses. However, these same students commented that they learned vectors so well in statics that it helped them in their physics course. This might explain the lower performance in the spring semester on the first exam.

Student Surveys

In addition to examining the assessments in the course the students were surveyed at the end of the semester. The survey asked the students whether they enjoyed the format of the class, whether or not they did the homework, and whether they felt the course format helped them learn the material. Figure 2 shows the student responses to the first question, whether or not they liked the format of the course. The majority of the students enjoyed the course format as others have found. While survey data was not directly correlated with student grades, these survey results do not indicate a trend where mediocre students did not enjoy the flipped class. Only 2 students indicated they did not enjoy the format. One of these students commented that he felt intimidated when other students could complete the in-class problems more quickly. One might
conclude that this student was one of the lower performing students in the class, but again, the survey data was not correlated with grades in this effort.

Figure 3 shows the response data as to whether the students felt the course format helped them understand the material better. As can be expected, since most of the students enjoyed the course format, a similar number felt the course helped them understand the material. As can be seen from the data, not all students enjoyed the format. Some of these students provided additional comments which associated with their concerns. These comments indicated that some students did not enjoy working in groups or were intimidated when other students completed a problem before they did.

![Figure 3: Response to: “I feel that the class format of having homework sessions during class time helped me better understand the material compared to a more traditional format.” (n = 18)](image)

Questions three and four pertained to the assignments in the course. Question 3 ask whether the students completed the ‘pre-lecture’ assignments. As can be seen from Figure 4 most of the students did not complete these assignments. Other studies have shown similar trends. As one might expect, since the assignments were not graded most students did not complete the assignments. Conversely, nearly all of the students completed the homework on time (Figure 5)
Figure 4: Responses to "I completed the ‘pre-lecture’ assignments most or all of the time." (n = 18)

Figure 5: Responses to “I completed most or all of the homework on time.” (n = 18)
Since one of the primary changes in the class format was reduced lecture time, the students were asked whether or not they felt the reduced lecture time made the material more difficult to understand. Figure 6 shows the responses. Nearly 40% of the students felt that the shortened lectures made the material more difficult to understand. Comments relative to this question mostly indicated that some lectures appeared rushed and that more examples were desired.

![Figure 6: Responses to “The reduced time for lectures made the material more difficult to comprehend.” (n = 18)](image)

Given that several students felt they had difficulty understanding the material, one cannot help but wonder if there is any correlation between these responses and whether or not the students did the assignments. As was noted earlier, the majority of the students completed the homework, but most of the students did not complete the pre-lecture assignments. Figure 7 shows the student responses for both of these survey questions. Interestingly, the majority of the students that indicated the material was more difficult to understand given the short lectures also responded that they did not complete the pre-lecture assignments. This is indicated by a high response (5 or 5) for the solid blue column and a low response for the red patterned column (1 or 2). While the instructor readily admits that some of the lectures felt rushed when covering more complex material, it begs the question as to how much the students’ difficulties could have been alleviated by completing the pre-lecture assignments.
Question 6 on the survey asked whether students would prefer a flipped-format class in the future. As can be seen in figure 8 that most of the students would prefer this type of class. While students seem to prefer this type of format, student perceptions as to whether this type of course improves their grade is less clear. Figure 9 shows the student responses to the last question in the survey (note that a negative response (1 or 2) indicates that the student feels a flipped class would improve his or her understanding of the material). While more students responded that they feel the flipped format would improve their understanding, it was not overwhelming (similar to question 6 in figure 9). While ten students felt that the format would improve their understanding, 7 did not feel that the format would help their understanding. Several of these responses came from students that performed well in the class and likely would perform well in any class format. However, it is interesting to note that students appear to enjoy and prefer the format but do not necessarily link it to their success in the class.
Figure 8: Response to question 6; "I would prefer this type of format over the more conventional format in similar classes I have to take in the future." (n = 18)

Figure 9: Student response to question 7; "I do not feel that the flipped class format helped me have an increased understanding of the material, I would have had a similar grade in a conventional lecture style class."

Note: a negative response (1 or 2) indicates that a flipped class will increase student understanding of the material.
Instructor Notes

Having taught the course in both formats back-to-back semester, there are some observations worth mentioning. As the students indicated, some of the lectures did seem rushed. While anyone attempting to keep a schedule for a semester may find times when the lesson is rushed. However, this format tends to amplify the problem since each topic must be covered sufficiently for students to complete homework problems in the next session. Obviously, if the course were completely flipped this problem would be alleviated since the students could watch the lectures any time and as often as desired. Some of this can be worked as the course is taught more. Lectures can be refined but this will not completely solve the problem. This problem may also be reduced if the students complete the pre-lecture assignments. If the students come into class with a basic level of understanding, the lectures may flow more easily for them and questions during class may be reduced or focused on the finer points of the material rather than the main concepts (which typically require more explanation).

Another important aspect of the partially flipped class was the opportunity to see the students completing homework. Since this is the first real engineering analysis class the students take, effort is placed on formatting homework and problem solving methods in addition to concepts of statics. Watching students actually doing homework provides opportunities to correct bad homework habits earlier. Rather than simply grading turned-in homework and making notes, the student(s) can be stopped and shown the appropriate way to proceed. Based on observations, this seems to have more impact on the students as homework solutions were much improved over the previous semester regarding format and clear problem-solving technique.

Finally, one of the most valuable results of the partially-flipped format was the interaction with the students. The early homework classes essentially provided an ice-breaker where the instructor could interact with each of the students. Compared with the previous semester, as the class progressed many more students felt comfortable asking questions, coming to office hours and participating in class. This instructor feels this is in large part due to the fact that in the first couple of homework classes an intentional effort was made to interact with each student. This effort created a rapport which seemed effective in increasing communication.

Additionally, the previous homework was handed back during each homework class. This provided an opportunity to discuss the graded homework with the students (individually). Again, direct feedback individually can be given before the student has completed another homework, thus aiding in improving understanding, format, and problem solving techniques. This extra level of feedback seemed to have more impact than simply writing notes on the homework.

Lessons Learned

As mentioned, one of the most valuable lessons learned in this effort was that the homework sessions provided an avenue to develop a rapport with the students. This improved interaction between the students and instructor and had several positive effects. Most importantly, when students took advantage of the homework class they did not fall behind as questions did not have to wait until office hours or some other time outside class where the student could meet with the
instructor. Additionally, the homework format and problem solving techniques were much improved over the previous semester. Specifically, seeing students do homework real-time and correcting issues as the students were initially working on the problem seemed to have more impact than through feedback while grading homework. Graded homework could also be examined in the homework classes, providing reinforcement to that type of feedback.

Lastly, while there are many improvements that could be made to the course, the most important change must be relative to the pre-lecture assignments in this case. It is clear that without tying these assignments to the student’s grade they will not be taken seriously. Additionally, since most of the students that had difficulty understanding material in the shortened lectures also did not do the pre-lecture assignments, the data seem to indicate that student success could be improved further if the students completed these assignments. This issue will be addressed for the upcoming semester. There are several options, but the intent is to increase student completion of these assignments without creating an extra burden of grading on the instructor. One method being examined is using online textbook material. In this case, the students will have reading assignments in the online material and be quizzed on these assignments. The questions are concept questions or simple problems and can quickly be answered. The completion and success of the student can be automatically tracked and fed into online grading. Thus, the only burden on the instructor is minimal set-up in creating the reading assignments and coordinating the logistics to have the online material automatically fed into the grading system. Additionally, the software tracks the questions answered correctly and incorrectly, giving the instructor valuable data regarding areas where students have difficulty.

Conclusions
The ENGR 2010 class at Southern Utah University was partially-flipped between the fall and spring semesters of the 2015-2016 academic year. The resulting course appears to be a course format that most students enjoy and prefer. It is not clear that top performing students see any additional benefit compared to conventional course formats. However, it does seem that lower performing students do benefit from the format (both based on assessments in the course and student perceptions). Based on this experience it is critical that the instructor tie independent student learning to the student’s grade (in this case pre-lecture assignments).

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References


Appendix A

Pre-lecture assignment for 3-D particle equilibrium

Lesson Topic (L-4): Forces in space, equilibrium of particles in space

Objectives:
1. Compute components of forces in 3-D space
2. Addition of concurrent forces in space
3. Solve problems involving equilibrium of a point in space

Reading Assignment: Beer, Johnston and Mazurek: Chapter 2.4, 2.5

Notes from reading:

Define the rectangular components of a force w.r.t. the direction cosines.

Define unit vector.

Write down the equations for the unit vector of a force in terms of the direction cosines, and in terms of the force components.

Draw a FBD for the point C for the loading shown.
Find:
(a) Tension in wire if $P = 391 \text{ N}$ and $y = 165 \text{ mm}$
(b) $Q$ required for Equil

a) Assume equal & A

\[ \lambda u = \frac{200 \text{ mm}}{y + 165 \text{ mm}} \]

\[ \Sigma F_y = 0 = P + F_e \left( \frac{200}{526} \right) \]

\[ \text{This is negative, so found in Part a.} \]

b) \[ \Sigma F_x = 0 = Q - F_e \left( \frac{200}{526} \right) \]

Don't know $P$ or $Q$...

\[ P^2 - 526^2 = (200)^2 \]

Can find $P$, then $Q$

Know $y = 165 \text{ mm}$

\[ F_e = 872 \text{ N} \]

\[ F_0 = 197 \text{ N} \]

\[ F_0 = 417 \text{ N} \]