Using Project-Based Learning in a Large Statics Course: Is it Worth It?

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Abstract

Project-based learning is a curriculum approach that is able to reinforce and use student content knowledge while also addressing some of the recommendations for engineering education reform such as including design early in the curriculum and developing other skills that students will need to successfully compete in the global pool of engineering talent. Our study considers the effectiveness of using projects in a large section of statics. Two sections of statics (roughly 100 students per section) were taught by the same instructor during the fall of 2012. One section was taught with a traditional lecture format and textbook based homework problems. The other section was taught in very similar way except students participated in three group design projects during the course of the semester. An existing concept inventory for statics was used to measure content knowledge gains in the two groups. Another affective instrument was developed to measure changes in student goals, engineering self-efficacy, and outcome expectations of becoming an engineer based on the hypothesis that students in the project section might have improved dispositions toward engineering and a greater intention to stay in the major.

Preliminary analysis of these quantitative assessments indicates that students in both groups had similar gains in content knowledge. The affective instrument also showed no main effects of treatment between the two groups. However, the impact of self-efficacy on outcome expectations was stronger for students in the treatment, which resulted in a larger indirect effect on intention to persist in engineering. For example, given two students with identical self-efficacy scores but one student is in the treatment and the other control, the student in the treatment group is more likely to intend to stay in engineering than the student in the control. Furthermore, student reflections were collected from the project assignments and these reflections suggest that students participating in projects were making gains in other skills such as working in groups. In fact, we hypothesize that students were benefiting from the project assignments, but the assessments we designed were not sensitive enough to capture some of these gains. Future research may involve developing tools to measure gains in these other critical skill areas.
A Case Study of an International Partnership to Increase Opportunities among Youth-at-Risk

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Abstract

This paper provides an overview of an international partnership between the Department of Construction Management at Colorado State University in Fort Collins, CO and the Department of Business Administration at Universidad Iberoamericana in Tijuana, Mexico. The Green Construction program is a partnership designed to provide workforce development and education to Tijuana, Mexico’s youth-at-risk in the area of sustainable construction. The partnership’s core elements address curriculum development, quality standards, management, private sector collaboration, and business administration as they apply to construction. The collaboration aspires to obtain educational excellence through mutually beneficial partnerships developed to increase human and institutional development capabilities.

The program uses an experiential learning approach that focuses on effectively managing people, materials, and resources, which is the foundation for any successful enterprise. Such skills are essential to starting and/or sustaining businesses on any scale and can provide opportunities that make the critical difference in the lives of youth-at-risk. This partnership is funded by the United States Agency for International Development (USAID) and supports the goals of Higher Education for Development (HED) by working with the people in Tijuana, Mexico to expand economic and educational opportunities for all people of the region.

The paper concludes with the lessons learned from this international collaboration, the short-term and long-term benefits to both institutions and program participants and suggestions for participants who are interested in establishing international partnerships.

Introduction

The Green Construction Program is a multi-institutional, (Colorado State University- Fort Collins (CSU), Universidad Iberoamericana, Tijuana, Mexico (UIA) and Mi Casa Resource Center (Mi Casa), multi-disciplinary (Departments of Construction Management, Business and Economics, Architecture, and Nutrition) educational partnership designed to provide workforce development and education to Tijuana, Mexico’s youth-at-risk in the area of green construction.

The program uses an experiential learning approach that focuses on effectively managing people, materials, and resources, which is the foundation for any successful enterprise. Such skills are essential to starting and/or sustaining businesses on any scale and can provide opportunities that make the critical difference in the lives of youth-at-risk. This partnership is funded by the United
States Agency for International Development (USAID) and supports the goals of Higher Education for Development (HED) by working with the people in Tijuana, Mexico to expand economic and educational opportunities for all people of the region.

A growing risk factor among Mexican youth and young adults is the rise of illicit drug trafficking and use. Over the past several decades Mexico has changed from being primarily a drug transportation hub to a drug trafficking and producing nation. Studies in Mexico have found that illicit drug use rates are highest in Mexican cities that border the U.S. such as Tijuana and Ciudad Juarez. In addition to drugs related problems, Tijuana, Mexico also has high rates of poverty. Half of new residents in Tijuana live in neighborhoods with inadequate infrastructure and limited clean water supplies, which increases the risk of transmission of infectious disease.

The partnership’s core elements addressed curriculum development, quality standards, management, private sector collaboration, and business administration as they apply to construction. The collaboration aspired to obtain educational excellence through mutually beneficial partnerships developed to increase human and institutional development capabilities. The Green Construction Human and Institutional Development Program also supports USAID’s goals of contributing to Mexico’s stability and economic prosperity by further developing the country’s market-based economy and enhancing Mexico’s global competitiveness.

**Program Overview**

The first phase of the program consisted of building relationships between CSU, UIA, Mi Casa and other stakeholders. Establishing and maintaining good working relationships among collaborators was essential to the success of the program. During the first phase the advisory board was formed with representatives from government agencies, non-governmental organizations, construction companies and the community. The first phase also focused on developing the Green Construction human development curriculum with input from the advisory board.

The second phase of the program consisted of training-the-trainers from UIA on successful implementation of the construction training curriculum. To accomplish this objective, a week-long training workshop (40 hours) was held in Tijuana in March 2012.

The third phase of the program consisted of the implementation of the Green Construction program for youth-at-risk. The program consisted of 360 hours of curriculum over the course of 9 weeks and a graduation ceremony. The curriculum consisted of the following topics:

<table>
<thead>
<tr>
<th>Week</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Life Skills</strong>: Students learn and practice the important soft skills necessary for maintaining entry-level employment including: conflict and time management, problem solving, goal setting, self-esteem, sexual harassment, work ethic, team work and communication.</td>
</tr>
</tbody>
</table>
Basic Green Building: Understand concepts innate in green building including reading prints or drawings and relate to real life layout of the building and systems, basic math and measurements.

Construction Safety: Construction jobsites are some of the most dangerous workplaces. Understanding the hazards in the construction industry and knowing safety practices reduces the risk of workers being involved in construction accidents.

Shed Construction Phase: Build two small sheds. The goal of the project is to teach students construction basics and technical skills, fostering within them a sense of self-satisfaction and pride in workmanship. One of the sheds will be donated to a non-profit organization while the other one will be deconstructed. Understanding the deconstruction process through a hands-on exercise is essential in the green construction industry.

Solar Energy: Students will receive training in solar photovoltaic (PV) installation. Solar panels are typically placed on the roofs of homes and buildings to convert the sun's rays into electricity.

Entrepreneurship Skills: Students will learn the basics of starting their own construction company.

Shed Deconstruction Phase: The shed will be deconstructed to emphasize sustainable construction practices including reduce-reuse-recycle. Construction workers often encounter jobsites where an existing building has to be demolished in order to build a new building. The deconstruction project will allow them to gain hands-on experience in salvaging materials to reuse them in another project. Reusing and recycling construction materials reduces the construction waste generated and lessens the impact of construction waste in our environment.

Career Readiness: Students learn and practice the job readiness skills needed to obtain employment including: resume and cover letter writing; transferable skills, obtaining references, interview skills including mock interviews, dressing for success, thank-you letters, how to network; creating a loose network, basic computer skills and responding to job offers.

Drug Resistance Strategies: Drug use in Mexican cities that border the U.S. are the highest in Mexico. Students will learn strategies to resist drug offers that have been demonstrated to be culturally appropriate and effective among individuals in Mexico.

Graduation Ceremony: At the end of the human development program, students will be awarded certificates at a graduation ceremony. This will give students the opportunity to share with their families their successful completion of the program and the start of their new life as part of the construction workforce. Family support and involvement is very important in the Hispanic culture; by involving the family in the ceremony the self-confidence and sense of pride of graduates will increase. The certificates will serve as proof of training and will give program graduates a competitive advantage over other prospective construction employees.

During a typical eight hour day, participants received lecture-based classroom training in the morning and participated in hands-on building activities in the afternoon. This model was particularly beneficial to our participants who are used to “learning by doing”. For example, one morning participants learned about foundation types, including verbal instruction of pouring concrete, etc. and in the afternoon on the same day they went to the jobsite and poured the concrete for the structure’s foundation.

Due to the demographics of participants, one full balanced meal was provided per day. During meal time participants and program faculty and staff had the opportunity to get to know each other. The meal time also allowed practitioners to discuss basic nutrition concepts. One of the program objectives was to provide the tools to allow participants to improve their quality of life by providing opportunities to continue their education or obtain employment. Participants received training in entrepreneurship to acquire the tools that would allow them to start their own...
businesses. During to program a group of four participants created the business plan for a green roof company and they are currently working on securing the funding to start-up.

**Conclusion**

The experience of international collaboration between different institutions has undoubtedly contributed to better knowledge transfer and understanding within, and between, both cultures. From the institutional level, both CSU and UIA have gained knowledge in ways of working together to develop educational models.

This partnership has fostered a deeper understanding about the issues faced by youth-at-risk and, through international collaboration, has created opportunities for youth-at-risk to improve their quality of life and resist the temptation to engage in criminal activities. Many young people decide to engage in criminal activities to solve their short-term financial needs because they have lost hope of a better future for themselves and their families. Criminal activities generate a false sense of belonging and a route of escape from reality for youth-at-risk, while legal and gainful employment provides true hope. Providing opportunities for youth-at-risk creates pathways for future development and economic integration that will allow for sustained employment and a pathway out of poverty.

Youth become at-risk not by choice but due to the lack of opportunities. Being deficient in employment skills is a significant barrier to being a productive member of society. We learned that not only poverty places youth at-risk, but an excess of free time due to different causes is a significant factor contributing to at-risk behaviors. Some participants had dropped out of school due to lack of family support, others were unemployed because of the current economic situation in the area. We believe that with their newly acquired green construction skills, our graduates will be placed in a construction sector with less competition and better prospects for both employment at construction companies and self-employment. In addition this partnership has contributed to our graduates by increasing their hope for the future are and their ability to network among individuals of different socio-economic status. Crossing social and economic barriers is often difficult in Mexico, however we believe our participants are better equipped to do so as a result of the training which will lead in greater opportunities for employment.

**References**

Learning by Competing: Challenges and Rewards for Construction Management Students

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Colorado State University, Fort Collins, Colorado

Abstract

This paper discusses the results of a study exploring the perceptions and attitudes of Construction Management students attending a student competition. These perceptions were captured in two surveys administered to a sample of students of the CM program at Colorado State University immediately before and after attending the ASC Regions 6 and 7 Annual Student Competition. The first survey was completed immediately before the start of a student competition. The second was administered immediately after the competition as a follow-up of the first one, and explored changes in views after the competition experience. It was found that while improving employability was the major drive for participation, other aspects such as the challenge to win the event were also of considerable importance. The student views and perceptions discussed here can be used for the academic leveraging of competitions as pedagogical tools, and the improvement of this and other similar competitions.

Introduction

Student competitions are increasingly popular as novel pedagogical tools for higher education and particularly to Construction Management programs. They offer a level of realism virtually impossible in a traditional classroom setting, and typically consist of the development in a very compressed time of a response to a project management challenge that was actually confronted by a team of specialists. Competing teams must solve issues that can include cost estimating, construction scheduling, work planning, contract analysis, time management and teamwork. Competitions can result in tangible benefits for Construction Management students, since companies hosting competition problems frequently use the event as a major differentiator for job interviewing. Moreover, the pedagogical value of learning by applying has been well established1. Competition stimulates many other professional attitudes enhancing participants’ education in general, and particularly for the requirements of the construction industry.

Research addressing student competitions has focused on seeking faculty opinions2 or writing the author’s own experiences3. Most of the literature addresses areas other than Construction Management4,5. Student expectations towards Construction Management competitions have not been adequately explored. Are students primarily motivated by the opportunity to showcase their
skills, and therefore enhancing their employability? Are the academic benefits valued at a similar level of importance? Are they pleasurable activities or just painful experiences undertaken for their career and academic benefits?

**Objectives**

The objective of this study was to explore the expectations and attitudes of a group of Construction Management students towards a student competition at two different points in time: immediately before participating in the competition and immediately after participating. A better insight of reasons driving student participation in competitions can result in the improvement of current and future competitions. A better understanding of these student expectations can also assist in the improvement of hands-on academic activities.

**Methods**

This study followed a qualitative research case study methodology. The two questionnaires used as main instruments included multiple-choice questions on a Likert scale and an open-ended question section. The before-competition questionnaire concentrated on student expectations about the competition, and also included questions about the respondent’s point in their studies at CSU and perceived mastery of key academic subjects. The after-competition questionnaire explored changes in perceived mastery of the same subjects and reactions to the competition experience.

The two questionnaires were administered to 40 students from a total of 61 participating in the competition. Responses were anonymous. Pairing responses was made possible by numbering the pre-competition questionnaire, and attaching to it a sticky note with the same number. Participants kept this note and then wrote this number on the post-competition questionnaire. Responses were analyzed by identifying and quantifying the frequency of recurring themes in the open questions.

**Context: The ASC Regions 6 and 7 Annual Student Competition**

Regions 6 and 7 of the Associated Schools of Construction (ASC) consist of Construction Management programs in the Rocky Mountain and the West Coast, respectively. They jointly host an annual student competition attended by over a thousand students and hundreds of faculty members and industry sponsors. It includes the 4 regional problem categories repeated for each of the 2 regions, and the 9 national problem categories shown in Figure 1. Competing teams of 6 students must develop a written response to the problem in a single day. Each response is orally presented and discussed the following day. The third day of the event consists of a career fair
followed by the announcement of the 3 top teams in each problem category. The competition takes place at Sparks, a suburb of Reno, Nevada, almost entirely occupying a large hotel in the area.

![Figure 1: Categories and Problems for the ASC Regions 6 and 7 Annual Student Competition](image)

Each problem is based on an actual project performed by its industry sponsor. In the weeks prior to the competition, each competing team of 6 students is provided with general information about the project. The number of teams competing in each category varies between 5 and 13. The bulk of the information is provided on the first morning of the competition. After the problem is handed out, teams must work without any contact with even their advisor or alternates and no internet access. Many administrative details are left to each problem’s industry sponsor, such as its starting time and deadline, written and oral presentation format, and judging rubric. At the end of the oral presentation sessions, the hosting company holds a debriefing of the approach that the company took to perform the project.

**Analysis of Results**

Figure 2 shows a summary of key issues identified in the responses to the question “What are the most important reasons that led you to join a competition team?” included in the survey administered before the competition. Most responses included more than one reason. The most common reasons were: experience, improved knowledge, and improved employability. If explicit comments about industry exposure are added to the similar concept of employability,
more than half of the sampled students singled out a job-seeking reason for participating in the competition. Other frequently mentioned reasons include the desire for networking and participation and challenging oneself. Additional reasons for joining a competing team were also pointed out, including the opportunity for improving skills on a given subject, enhancing their visibility to the hosting companies (“set myself apart from my peers”, “looks good on a resume”), or simply having fun.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experience</td>
<td>8</td>
</tr>
<tr>
<td>Learning / knowledge</td>
<td>8</td>
</tr>
<tr>
<td>Employability</td>
<td>7</td>
</tr>
<tr>
<td>Industry exposure</td>
<td>5</td>
</tr>
<tr>
<td>Challenge</td>
<td>4</td>
</tr>
<tr>
<td>Networking / participation</td>
<td>4</td>
</tr>
<tr>
<td>Specific skill</td>
<td>2</td>
</tr>
<tr>
<td>Setting oneself apart</td>
<td>2</td>
</tr>
<tr>
<td>Fun</td>
<td>2</td>
</tr>
<tr>
<td>Presentation</td>
<td>1</td>
</tr>
<tr>
<td>Career fair</td>
<td>1</td>
</tr>
</tbody>
</table>

*Figure 2. Responses to the question "What are the most important reasons that led you to join a competition team?"*

Figure 3 shows a summary of frequency for key issues to the question “Why would you participate or not participate in the competition again?” included in the after-competition survey. No response to this open-ended question was negative. Six comments mentioned that the respondent could not return because they would graduate in the coming year. Graduating participants had some of the most positive comments about the experience. A comment reflecting this enthusiasm was “I graduate in May, however, if I not graduating I would do the competition again for the experience, the industry exposure, and a chance to win.”

The most mentioned reasons on the before-competition questionnaire are also most frequently pointed out on the after-competition follow-up, namely the learning and knowledge acquired from the event, and the competition as experience. The prospect of having fun at the competition is barely included in the before survey, but it is among the most frequently mentioned motives for wanting to come again to the competition. The competitive challenge offered by the experience was also among the most frequently mentioned reasons for wanting to repeat the experience. Examples of student comments include “I would do it for the challenge”, “we can place in the top 3” and “I would do the competition again for the experience, the industry.
exposure and a chance to win”. The competition is described in several remarks as “stressful”, “very exhausting” and “grueling”. These terms are applied in a positive context, as part of the overall experience.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Employability</td>
<td>0</td>
</tr>
<tr>
<td>Real world experience</td>
<td>2</td>
</tr>
<tr>
<td>Presentation</td>
<td>2</td>
</tr>
<tr>
<td>Grueling / exhausting</td>
<td>3</td>
</tr>
<tr>
<td>Networking / participation</td>
<td>3</td>
</tr>
<tr>
<td>Industry exposure</td>
<td>4</td>
</tr>
<tr>
<td>Competing / challenge</td>
<td>5</td>
</tr>
<tr>
<td>Learning / knowledge</td>
<td>7</td>
</tr>
<tr>
<td>Fun</td>
<td>8</td>
</tr>
<tr>
<td>Good experience</td>
<td>9</td>
</tr>
<tr>
<td>(Graduating soon)</td>
<td>6</td>
</tr>
</tbody>
</table>

Figure 3. Responses to the question “Why would you participate or not participate in the competition again?”

Employability is not mentioned explicitly as a reason for repeating participation on the after-competition survey, but the roughly equivalent point of industry exposure is mentioned four times. Other issues addressed in the responses are the real-world experience of solving the problem, the willingness to participate “just for the experience and the [oral] presentation”, and the networking opportunities offered by the competition.

Conclusion

The results of the present survey show that the ASC Regions 6 and 7 Annual Student Competition brings to the fore some of the best qualities of over a thousand Construction Management students. There are important lessons applicable to the academic programs taking part in this event as well as to the development and administration of other current and potential competitions. Competitions can provide a path to the advancement of participating students’ professional career. In the case of the competition discussed here, it has established credibility among construction companies and its weight in the résumé is recognized by students. The competition’s history shows that this recognition was achieved after years of consistent promotion for both constituencies: host companies and academic programs. New or emerging competition events should pay as much attention to the self-interest of companies and students as to any academic objective.
Respondents showed remarkably positive reasons for participating in the event, and high expectations for its consequences. Significant reasons included the desire for learning and advancing professional knowledge, the importance given to peer and industry networking and the appeal of the competition as a challenge.

The limited size of the sample analyzed here constrains the reliability and generalizability of its results. This study will be followed by a wider survey among ASC programs, and more granular questions derived from these results.

Student comments revealed insight into the lessons learned, especially in valuing the experience independently of its importance as a career booster. The word “fun” was repeated on many of the after-event responses. The competition was sometimes described as exhausting and grueling, but responses mentioning this aspect also stated a desire for participating again. The competition as a challenge to overcome and the desire to win it were also very evident in the responses. All these issues should be pointers for the design and administration of student competitions in general.

References

Student Perceptions of the Importance and Achievement of Sustainable Engineering Outcomes

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Abstract

There are increasingly urgent global calls to train all engineers to incorporate sustainability principles into their designs. But how do engineering students perceive the need for sustainability? This research explores this issue using information from the University of Colorado Boulder (CU). CU’s fall 2012 incoming first-year students in engineering self-reported a good awareness of general climate and sustainability issues (average 4.2 on 1 to 6 Likert scale, 6 = very aware), higher than peers in the College of Arts & Sciences (average 4.0) and Business (average 4.1). Student interest in sustainability was similarly high among first year environmental and architectural engineering majors, and somewhat lower among civil engineering students. By the senior year, the perceived importance of sustainability learning outcomes was highest among environmental followed by architectural and civil engineering students. Some interest in sustainability was also evident among mechanical engineering majors, although these majors were not targeted for specific data collection. The results indicate that different engineering majors vary in the extent to which they embrace the ideals of sustainable engineering, and even within a single major these attitudes vary widely. Efforts to increase the emphasis on sustainability across a variety of courses may be the most effective in helping engineering students to realize the importance of sustainable engineering.

Background

There are national and international efforts to install knowledge of sustainability in all college students.\textsuperscript{1,2,3} This information will help all citizens to make informed choices that impact sustainable use of energy, water, and resources. Engineering as a profession has a key role to play in ensuring a sustainable future for the planet. Our engineered infrastructure, products, and other designs can have significant impacts on the efficient and socially appropriate use of our resources. Professional societies across an array of engineering disciplines are promoting the importance of sustainability (Table 1). This has taken a number of different forms. Societies have incorporated the need for considerations of sustainable development into their codes of ethics. Many societies have created committees to explore sustainability issues.
Although the calls from engineering societies implies widespread endorsement of the importance of sustainability, the extent to which engineering students across a diverse array of disciplines recognize the importance of sustainability and feel prepared to meet the challenges to engineer sustainably are somewhat uncertain. There has been studies on this issue, but many have been specific to particular institutions, rather than wide-ranging. Teaching about the importance of sustainability is expected to vary significantly between institutions. The new engineering program at James Madison University has a sustainability theme throughout the curriculum. A wide array of focus on sustainability was evident at different institutions in the benchmarking study and via the AASHE STARS ratings. Some examples of previous studies on the attitudes of engineering students toward sustainability are summarized below.

A survey to students at the University of Utah compared the sustainability attitudes of students in mechanical engineering (ME) versus civil & environmental engineering (CEE). Among freshman, 23% of CEE students (n=30) indicated they would consider sustainability or the environment in the design process compared to only 2% of ME freshmen (n=126). Among seniors, this increased to 33% of CE students (n=30) and 10% of ME students (n=58). Despite these results, a number of other surveys were conducted and the authors concluded “The results indicate that there is not a discernible difference between the knowledge and interest between the two disciplines... there is no indication that civil and environmental engineering students are more committed to sustainability than mechanical engineering students.”

National data from a 2011 student survey by ASME and Autodesk found that ~27% of mechanical engineering students (number of responses = 1882) indicated that they were “not at all involved” with sustainability or sustainable technologies, while ~53% were somewhat involved and ~19% were extremely involved. The two most important categories of activities that related to sustainability were rated as products that use less packaging (~45%) and designs that use less energy or reduce emissions (~43%). But only ~28% of the students indicated that sustainability was included in the standard curriculum.
In a survey of senior civil (n=121) and environmental (n=32) engineering students at Georgia Institute of Technology (GIT), 73.7% of the students indicated strong interest in sustainable infrastructure (rated 6 or 7 on Likert scale). In addition, 77.8% indicated that it was very important for engineers to be able to discuss sustainable development (rated 6 or 7 on Likert scale), but only 49% indicated a similar level of confidence in this outcome. This is despite the fact that the curriculum already includes one sustainability-focused course required for both civil and environmental engineering students, Civil Engineering Systems. In addition, instructors rated 49% of 37 courses in the curricula as having “high” sustainability content. So the curriculum at GIT has quite a bit of sustainability integration.

In a 2012 study with 47 chemical engineering students at Singapore Polytechnic University, 49% strongly agreed that it was important for chemical engineering students to learn sustainable development; 38% agreed, and 13% were neutral; none disagreed. To the question “do you agree that chemical reaction engineering plays an important role in promoting sustainable development in the chemical industry”, the majority (47%) of the students answered neutral. Thus commitment to sustainable engineering was not clear. In a study by Azapagic, where 75% of the 3134 respondents were chemical engineering students, the average rating of the “importance of sustainable development to you as an engineer” was 3.2 out of 4 (where 3=important; 4=very important); this was more important than the average rating to the students’ personally (avg. 3.0) but less important than to future generations (avg. 3.7).

To provide further information on the attitudes and knowledge of sustainability among engineering students, this study combines together quantitative data from an array of survey methods and qualitative information from student homework assignments and survey responses. The data was collected from engineering students at the University of Colorado Boulder (CU). Where appropriate, comparisons to other published studies are made.

Results

First-Year Orientation

In fall 2012, sessions on sustainability were held at the CU orientation for new students. At the end of the orientation session, the student participants were administered a survey. Key results are summarized in Table 2. CU enrolled about 5470 new students in fall 2012, so the number of survey respondents represents about 11% of the incoming class. The students on average indicated a good awareness of general sustainability issues; less than 5% of any of the majors rated this question 1. Engineering majors had the highest average self-rated level of awareness compared to majors from the College of Arts & Sciences or Business. About two-thirds of the students indicated that living a sustainable lifestyle was important. But only about a third to a half of the students indicated that the sustainability reputation of CU factored into their decision to attend CU. These results indicate that many of the incoming engineering students at CU are fairly aware of and interested in sustainability.
First-Year Student Coursework

At CU, engineering students take a one- or two-credit introductory course to their major and/or engineering. The author of this paper has included a module on sustainability when she teaches this course to architectural engineering (AREN), civil engineering (CVEN), environmental engineering (EVEN), or open-option (OPEN) engineering students in the civil engineering module. Table 3 summarizes the courses where she has included a sustainability module.

### Table 3. CU First Year Introductory Engineering Courses with Sustainability Module

<table>
<thead>
<tr>
<th>Major</th>
<th>Years</th>
<th>Activities and Assessments</th>
</tr>
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<tbody>
<tr>
<td>AREN</td>
<td>2012</td>
<td>Two lectures, in-class clicker questions, homework assignment focused on LEED worth 11% of course grade</td>
</tr>
<tr>
<td>CVEN</td>
<td>2009-2012</td>
<td>Two lectures, in-class clicker questions, homework assignment worth 11% of course grade</td>
</tr>
<tr>
<td>EVEN</td>
<td>2009-2010</td>
<td>Lecture, in-class clicker questions, homework assignment worth 11% of course grade^12</td>
</tr>
</tbody>
</table>
| OPEN  | 2011-2012| 2011: lecture, in-class clicker questions; may include in Grand Challenge poster  
2012: lecture, homework assignment focused on ENVISION^13 |

Student performance on the sustainability homework assignment cannot be used to directly indicate interest about sustainability. Different assignments were used for each course. Within the OPEN course, the average score (out of 10) on the fall 2012 sustainability assignment was determined for different majors of students. The results were: EVEN 9.2 (n=2), aerospace 9.1 (n=31), CVEN 9.0 (n=2), mechanical 9.0 (n=28), OPEN (undeclared engineering major) 8.8 (n=43), electrical 8.4 (n=3), and chemical 7.8 (n=3). Only the grades for students who completed the assignment were included in the average; so not included were zero scores from 4 mechanical, 4 OPEN, and 1 aerospace majors. The better performance of some majors may be due to more interest and therefore more effort invested in the assignment. However, only three
majors had high numbers of students in the course, so the results from the other majors should be interpreted with care.

As the final homework of the semester, the students were asked to reflect on what they had learned about the AREN, CVEN, or EVEN discipline. This included a definition; whether they did/did not want to continue in the major and why; what they had learned during the semester that impacted this decision; what aspects of the discipline did/did not appeal to them; and what areas of the American Society of Civil Engineers (ASCE) Body of Knowledge (BOK2) were strengths, weaknesses, areas of interest or not interested. Note that sustainability is one of the 24 learning outcomes in the BOK2. The students also summarized an outside professional society meeting or guest speaker that they had attended and what they had learned. An analysis of the final reflective essays from 2010 (CVEN, EVEN) and 2012 (AREN, CVEN) was conducted. First, a simple word search was conducted to identify essays that used the term “sustainab*” (to include sustainability and sustainable). Then, the context of the use of the term was categorized. Results are summarized in Table 4. Over seventy percent of the students discussed sustainability in their final essay, even though they were not explicitly prompted to. Over one-third of the students included sustainability in their definition of their engineering discipline. Civil engineering students were most likely to discuss learning about sustainability in the course, perhaps indicating less initial familiarity with the concept. A much higher percentage of the students indicated that sustainability was a topic that they enjoyed and/or considered a strength, in comparison to a small percentage of students who indicated that they disliked sustainability or considered it a weakness in their knowledge areas. Thus the results indicate that the majority of architectural, civil, and environmental engineering students have begun to consider sustainability in the context of their engineering profession.
Sustainability through the Curricula

Within the CU civil engineering major, sustainability topics are taught in a number of courses. There is potentially high similarity between CVEN and AREN or EVEN, with more than 50% of the courses in common. Some of the courses with sustainability elements are highlighted below:

CVEN 1317 is required for all CVEN students. There has been a module and homework assignment on sustainability since 2009, as described above.

CVEN 3414 Fundamentals of Environmental Engineering is required for all CVEN and EVEN students. It is a sophomore or junior level course. One of the 19 topics covered is “Resource Sustainability”. However, there were not explicit questions in problem sets or exams that seemed to test knowledge of sustainability. The textbook used for the course does not really place an emphasis on sustainability. There are alternative textbooks that weave sustainability themes throughout all of the chapters rather than a single focused covered.

CVEN 3246 Introduction to Construction is a required junior-level course for all AREN and CVEN majors. One of the stated course objectives on the syllabus is: “Special attention will be paid to ethics, emerging technologies, and sustainability as applied to construction engineering and management practices.”

CVEN 3602 Transportation Systems is required for all CVEN students, and one of the topics is how transportation relates to environment and sustainability. This statement was found on the syllabus, but again no supporting direct evidence of student learning related to sustainability was
found in the homework or exams.

Sustainability-focused learning activities were developed for AREN 2110 Thermodynamics by Professor JoAnn Silverstein. Although this sophomore-level course is required for AREN, CVEN, and EVEN students, Prof. Silverstein teaches the course once per year and so the sustainability focus may not be consistent across the other professors who teach the course in the other semester each academic year.

A sustainability lecture and assignment were added to the Hazardous & Industrial Waste Management course taught by Bielefeldt in Fall 2011. The course is a junior/senior level elective for CVEN and EVEN students. The students execute calculations related to the carbon emissions, energy consumption, toxic chemical releases, costs, and worker safety of various site remediation technologies using a spreadsheet-based tool developed by the U.S. Air Force (the Sustainable Remediation Tool, SRT). A homework problem indicates basic familiarity with the software, and the students are also encouraged to consider sustainability implications during their group term projects.

**Capstone Design Senior Survey Data**

Information on sustainability attitudes has been collected from seniors. In 2011, a survey on the ASCE’s Civil Engineering Body of Knowledge (BOK2)\(^{14}\) was administered in the capstone design courses for AREN, CVEN, and EVEN majors. Students were presented with a large table that showed each of the 24 outcomes and a statement on the level of achievement (LOA) that is expected for these outcomes at the Bachelor’s degree. These outcomes generally map to the ABET criterion C “A to K” outcomes and additional program-specific criteria.\(^{15}\) Students were asked to rank the importance of these outcomes, from 1 (most important) to 24 (least important). Surveys were returned anonymously, without names. Sustainability is outcome 10, with an expected LOA of: “Apply the principles of sustainability to the design of traditional and emergent engineering systems.” The capstone design students first ranked the relative importance of the 24 outcomes. On average, sustainability was ranked third, 6\(^{th}\), and 16\(^{th}\) by EVEN, AREN, and CVEN students, respectively. Other data are summarized in Table 4. Due to variability in student responses, even the top rated outcome had a seemingly low average rank score; i.e. civil engineering students indicated “problem recognition and solving” was the most important with an average rank of 4.9. The huge range of students’ rankings is remarkable. Interestingly, students in all three majors strongly indicated that more sustainability was needed in the curriculum, even CVEN students who rated its importance rather low. The students were asked to rate three items that should receive more attention in their curriculum at CU. About 30 to 40% of the students included sustainability in this top 3 rating.
Graduating Senior Survey Data

All undergraduate engineering students graduating from CU are encouraged to take an online exit survey. Some questions are common to all majors, while questions on learning outcomes are specified by each major. For the first time in fall 2011, a question related to sustainability was added to the list of outcomes for AREN and CVEN students. The question was: “Ability to apply the principles of sustainability to the design of traditional and emergent engineering systems.” Students used a 5-point Likert scale from 1 = not at all, 2= not very, 3 = moderately, 4 = very; 5 = extremely. In fall 2011/spring 2012, AREN students rated the importance and achievement of sustainability higher than their CVEN peers (Table 6). AREN students’ average importance 4.30 and ability 3.98 (n=43). CVEN students’ average importance 3.76 and ability 3.23 (n=56).

Table 5. Ratings from Senior Capstone Design Students on the BOK2 Survey

<table>
<thead>
<tr>
<th></th>
<th>AREN Spring 2011</th>
<th>CVEN Fall 2011</th>
<th>CVEN Spring 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of responses</td>
<td>37</td>
<td>55</td>
<td>23</td>
</tr>
<tr>
<td>response rate (# responses / # students in class)</td>
<td>73%</td>
<td>70%</td>
<td>79%</td>
</tr>
<tr>
<td>Average rank of sustainability importance (1= highest, 24 = lowest)</td>
<td>9.3 ± 5.8</td>
<td>13.4 ± 5.8</td>
<td>7.3 ± 5.3</td>
</tr>
<tr>
<td>Range of rank of sustainability importance</td>
<td>1 – 24</td>
<td>2 – 24</td>
<td>1 – 20</td>
</tr>
<tr>
<td>Median rank of sustainability importance</td>
<td>9</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>% of students rated sustainability importance in the top 5</td>
<td>29.7</td>
<td>16</td>
<td>43.5</td>
</tr>
<tr>
<td>Average rank of sustainability in “more needed in curriculum at CU”</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Percentage of students who said more sustainability was needed</td>
<td>42%</td>
<td>29%</td>
<td>39%</td>
</tr>
</tbody>
</table>

Table 6. Graduating Senior Survey Results for Importance and Achievement of Sustainability Outcome (Likert scale; 1 = not at all important; 5 = extremely important)

<table>
<thead>
<tr>
<th>Major</th>
<th>Importance Average ± stddev</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>AREN</td>
<td>4.30 ± 0.60</td>
<td>0</td>
<td>0</td>
<td>7.0</td>
<td>55.8</td>
<td>37.2</td>
</tr>
<tr>
<td>CVEN</td>
<td>3.76 ± 0.98</td>
<td>1.8</td>
<td>9.1</td>
<td>23.6</td>
<td>41.8</td>
<td>23.6</td>
</tr>
<tr>
<td>Ability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AREN</td>
<td>3.98 ± 0.86</td>
<td>0</td>
<td>4.7</td>
<td>23.3</td>
<td>41.9</td>
<td>30.2</td>
</tr>
<tr>
<td>CVEN</td>
<td>3.23 ± 0.85</td>
<td>3.6</td>
<td>10.7</td>
<td>50.0</td>
<td>30.4</td>
<td>5.4</td>
</tr>
</tbody>
</table>

Among the 19 outcomes rated by AREN students, this ranked the importance and achievement 9th. Among the 22 outcomes rated by CVEN students, this ranked sustainability 21st among 22 outcomes for both importance and achievement.

On this same fall 2011/spring 2012 senior survey, a few AREN, CVEN, EVEN, and mechanical
engineering (ME) students also wrote open responses appealing for more sustainability in the curriculum.

CE student: “I believe that there should be more classes on sustainability and it should be integrated into the currently taught classes.” CE student: “sustainability needs to be included as its a growing practice and hugely important to CVEN careers, or at least should be.”

CE student: “You should require a Life Cycle Engineering or Sustainable Design course because this is becoming a more and more pressing issue recently.”

AREN: two students referred to “Sustainable Building Design” as most useful AREN courses;AREN student: “a class related to sustainability/ LEED should be required.”

EVEN student: “I really enjoyed learning about sustainable and renewable energy and more classes like that should be offered.”

ME student: “A course that talks about sustainability, aesthetics, and all aspects of design would be refreshing from the purely technical course load and would provide the future developers of the world a more rounded perspective when designing.”

Summary and Conclusions

This study explored sustainability interest and attitudes among architectural, civil, and environmental engineering majors at the University of Colorado Boulder. Among first year students, architectural and environmental engineering majors seemed to share similar interest and enthusiasm for sustainability, which was somewhat higher than their civil engineering peers.

The extent to which curriculum content will influence students’ opinions is unclear, but in general it can be assumed that topics which receive little attention may be perceived as less important by students. Further research is needed to determine if student attitudes about sustainable engineering are influenced more by their discipline, by institutional culture in general, or by the institutional culture for the specific discipline.

References

3. Association for the Advancement of Sustainability in Higher Education (AASHE). http://www.aashe.org/about/aashe-mission-vision-goals
Learning from High Potential, Next Tier Students: Evaluating a Noncognitive Questionnaire for Use in Admission Practices

Beth A Myers, Jeffrey T Luftig, Daniel W Knight, Jacquelyn F Sullivan

Abstract

Undergraduate admission to college has historically been strongly tied to a students’ past performance in school and their cognitive abilities as assessed by standardized tests. These metrics of merit may or may not accurately predict a students’ long-term potential to succeed in higher education. Evidence suggests that, beyond aptitude and ability to perform well on tests, noncognitive factors significantly impact student success in education.

The University of Colorado Boulder’s College of Engineering and Applied Science investigated the implementation of an existing Noncognitive Questionnaire (NCQ) to assess incoming first-year undergraduate applicants via eight variables. The NCQ was given to a small group of prospective students when they interviewed for admission to the engineering program. While the results from the NCQ were not used in subsequent admission decisions, the plan was to query whether prediction of success in an engineering program could be inferred from the noncognitive results. If yes, consideration would be given to using the NCQ in future admission practices.

The NCQ is comprised of qualitative questions that require subjective ratings of participant responses. To consider data generated by any such instrument to be reliable, it must be assumed that knowledgeable raters, using the same responses generated for the same subjects, would generate concordant ratings even if assigning those ratings independently.

As a first step in assessing the reliability of the NCQ instrument, a study was executed to measure inter-rater agreement. Unfortunately, the results of this study demonstrated that the raters were unable to employ the NCQ instrument to yield statistically concordant results. The methodology employed for the study, the comprehensive statistical analysis executed and the implications for use of this sort of non-cognitive instrument will be discussed.

Background

The historical and recent precedent for how students are admitted to college is heavily based on their high school performance via grade point averages and standardized test scores. The common standardized tests used to determine college readiness are the ACT test\(^1\) administered by ACT, Inc.\(^2\) (formerly known as the American College Testing Program Assessment) and SAT\(^3\) test administered by The College Board\(^4\). While there are structural differences, these are both cognitive assessments of aptitude.

As a result of the limitations of standardized testing, a recent focus has emerged on using other noncognitive factors to assess student readiness for college and potential success in college.\(^5,6\)
Our own university and engineering college claim a holistic review of applicants; however, standardized test scores weigh heavily in current admission decisions. We are interested in investigating if there are reliable noncognitive tools that will help predict success in an engineering college.

**Purpose**

The University of Colorado Boulder’s College of Engineering and Applied Science investigated the implementation of the Noncognitive Questionnaire (NCQ) created by William Sedlacek. This questionnaire assesses survey takers via eight variables: positive self-concept, realistic self-appraisal, understands and knows how to handle racism; navigates the system, long-range goals, strong support person, leadership, and community and nontraditional knowledge acquired. The NCQ was given to a small group of prospective students when they interviewed for admission to a small, performance-enhancing first year engineering program. While the results from the NCQ were not used in subsequent admission decisions, the plan was to query whether prediction of success in an engineering program could be inferred from the noncognitive results. If yes, consideration would be given to using the NCQ in future admission practices.

**Design/Methods**

The NCQ is comprised of twenty-nine questions, both likert-scale type questions and qualitative questions that require subjective ratings of participant responses. The original survey asked six demographic questions at the beginning of the survey. Based on our knowledge of stereotype threat, we removed the question that asked for the student social security number and moved the other five demographic questions to the end of the survey. Other than that, the survey was given as published by the author. The remainder of the survey includes eighteen likert-scale responses (questions 11-28), two multiple-choice (questions 7 and 9) and three open-ended questions that asked students to list three answers (questions 8, 10, and 29).

A prescribed scoring key is provided by the author. This key was given to three different raters, who were asked to score the results of the open-ended listing questions for 49 students. To consider data generated by any such instrument to be reliable, it must be assumed that knowledgeable raters, using the same responses generated for the same subjects, would generate concordant ratings even if assigning those ratings independently.

As a first step in assessing the reliability of the NCQ instrument, a study was executed to measure inter-rater agreement. Cohen’s kappa values were calculated using MVPstats software since the data produced from the scoring procedure of the open-ended, list-three-type questions of the NCQ results in essentially categorical data at three levels. Cohen’s kappa values were assessed for each item individually.
Results

Unfortunately, the results of this study revealed that the raters were unable to employ the NCQ instrument to yield statistically concordant results for individual items on the survey. In Table 1 below, the Cohen’s kappa values for the three raters’ scoring of the open-ended questions are listed. Where “missing data” is listed, one or two of the raters scored that particular item, but one or two of the raters did not score that item; this could happen because the rater used their own judgment to decide what to score in the open-ended questions.

The author also suggests pooling some questions together to create rounded average scores for particular variables. As we did not believe this was an appropriate approach for categorical data, we ran Cohen’s kappa on some of these values and found even lower estimated agreement indices. Looking closely at the data we found that there were situations where one rater would score a response with the highest rating of 3 while another rater scored it the lowest rating of 1. This discrepancy in the scores which represents the maximum discrepancy possible, results in the very low Cohen’s kappa indices found across almost all questions in the survey for three raters.

For a Cohen’s kappa to be considered a substantial level of agreement we would have expected values greater than 0.6010.

The inability of the three raters to yield statistically concordant results for this particular NCQ has implications for future use. If we wanted to continue to use this survey, one option would be

<table>
<thead>
<tr>
<th>Survey question</th>
<th>Individual Items</th>
<th>Cohen’s k</th>
</tr>
</thead>
<tbody>
<tr>
<td>8a1</td>
<td></td>
<td>0.339</td>
</tr>
<tr>
<td>8a2</td>
<td></td>
<td>0.488</td>
</tr>
<tr>
<td>8a3</td>
<td></td>
<td>0.463</td>
</tr>
<tr>
<td>8b1</td>
<td></td>
<td>0.394</td>
</tr>
<tr>
<td>8b2</td>
<td></td>
<td>0.496</td>
</tr>
<tr>
<td>8b3</td>
<td></td>
<td>0.397</td>
</tr>
<tr>
<td>9</td>
<td>Multiple-choice question</td>
<td></td>
</tr>
<tr>
<td>10a1</td>
<td></td>
<td>0.419</td>
</tr>
<tr>
<td>10a2</td>
<td></td>
<td>0.489</td>
</tr>
<tr>
<td>10a3</td>
<td></td>
<td>0.338</td>
</tr>
<tr>
<td>11-28</td>
<td>Likert-scale questions</td>
<td></td>
</tr>
<tr>
<td>29a1</td>
<td></td>
<td>0.735</td>
</tr>
<tr>
<td>29a2</td>
<td></td>
<td>0.583</td>
</tr>
<tr>
<td>29a3</td>
<td></td>
<td>0.566</td>
</tr>
<tr>
<td>29a4</td>
<td></td>
<td>0.534</td>
</tr>
<tr>
<td>29a5</td>
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<td></td>
</tr>
<tr>
<td>29a6</td>
<td></td>
<td>0.079</td>
</tr>
<tr>
<td>29b1</td>
<td></td>
<td>0.516</td>
</tr>
<tr>
<td>29b2</td>
<td></td>
<td>0.103</td>
</tr>
<tr>
<td>29b3</td>
<td></td>
<td>0.047</td>
</tr>
<tr>
<td>29b4</td>
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<td></td>
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<td>29b6</td>
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<td></td>
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<tr>
<td>29e1</td>
<td></td>
<td>0.366</td>
</tr>
<tr>
<td>29e2</td>
<td></td>
<td>0.211</td>
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<tr>
<td>29e3</td>
<td></td>
<td>0.120</td>
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<td>29e4</td>
<td></td>
<td>0.104</td>
</tr>
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<td>29e5</td>
<td></td>
<td>0.115</td>
</tr>
<tr>
<td>29e6</td>
<td>missing data</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Inter-rater agreement for open-ended questions, Cohen’s kappa values

Conclusions

The inability of the three raters to yield statistically concordant results for this particular NCQ has implications for future use. If we wanted to continue to use this survey, one option would be
to create a more detailed scoring rubric and train the raters so that there is less ambiguity in the scoring procedure. If the scoring were more clearly defined we would expect to see more concordance after the training. We would also need to reproduce the Cohen’s kappa values after the training to confirm the agreement indices were indeed at an acceptable level.

Another option would be to have all the raters sit down together to discuss the ratings as a panel. Lastly, we could have used only the median value for scores produced from the raters. However, we did not feel that any of these options would be feasible in our application because it creates more work in an already-cumbersome admission process. Thus, we have decided to investigate other potentially more automated and less time-consuming ways to incorporate noncognitive factors into our engineering admission decision process. Stay tuned!

References

Status and the Roles of Students in Engineering: A Justification for Studying the Creation of Status Assignment in Freshman and Sophomore Year

J.Y. Tsai and D.A. Kotys-Schwartz

Abstract

As young engineers leave high school and enter the system of undergraduate engineering education, they are forced to navigate the experience of becoming a little fish in a big pond of well-prepared, high-achieving engineering students. So, who is the fastest swimmer in this pond, rising to the top of the hierarchical system established by 1st and 2nd year engineers? The authors hypothesize that these young engineers, trained in the habits of algorithmic plug-and-chug learning through high school math and science courses, are primarily focused on grades and GPAs, creating respect and privilege for the students who can answer questions the fastest and are seen as “smart,” as defined by their peers. At the University of Colorado Boulder (CU-Boulder), it is not uncommon to hear 1st and 2nd year students bragging about “being able to do all of the math and get the right answer even though I don’t understand what’s really going on in the problem.” This begs the questions—how is status being created between engineering undergraduates? What are the implications? Why should we care?

In this presentation we will introduce the concepts of status and roles, based on the theoretical roots in sociology. Additionally, we will present a hypothesis regarding the construction of status among young engineering students. We posit that status and the differential assignment of it to novice undergraduates is one critical element of the structure, culture, and system of engineering, which works to keep some people in and push other students out. The purpose and promise of this work is the potential identification of cultural productions and structures that explain why some interventions or programs are successful while others fail at supporting diverse undergraduates to persist in engineering degree programs.
A Project-structured Approach to a Graduate-level Advanced Thermodynamics Class

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University of Colorado at Colorado Springs

Abstract

While project-based and project-oriented classes are common in undergraduate instruction, particularly in lower division, introductory courses, these approaches are utilized less often in upper division, graduate, and specialized technical classes. This paper describes the structure and approach of a graduate-level advanced thermodynamics class based largely around the development of a software model of an internal combustion engine. The background and topical areas are presented and the structure of the class is outlined. In this class, the project starts with a very simple software model and progresses week-by-week adding features of increasing complexity (and accuracy) to reach the final product. Examples of assignments are presented and the step-by-step approach to the model development is described. Student feedback for the approach was generally positive for this relatively small class of eleven students. Sample student comments are included in the paper. Potential drawbacks of this approach are discussed including lack of student interest in the project, difficulty with programming separate from the technical material, limitations on topics, and others. A comparison with traditional project-based courses along with the potential for generalizing this structure to experimental projects, undergraduate course, and an entire curriculum is discussed.

Introduction

Problem-based and project-based classes are gaining traction internationally in engineering curricula. While the terms are not exact, they generally refer to courses in which the structure is based on presenting students with engineering problems or projects, and they generally involve students taking a more active role in acquiring the targeted engineering science concepts as they work on the assigned projects or problems. There are a number of attractive features with such an approach, as well as some potential pitfalls and drawbacks.

Schachterle and Vinther\(^1\) describe a variety of benefits of project-based education. They describe challenges of a technological society including the pace of technological change, changing landscape of the practice of engineering, and globalization, and propose that a project-based education helps provide a meaningful response to these challenges. They list many
specific attributes/ benefits including the integrative nature of project-based education, increased student motivation, participation in experiential and active learning that enhances the capacity for students to be lifelong learners.

Heitmann\textsuperscript{2} reviews the history and various approaches to project-based education and indicates that there is a rapid trend toward increasing elements of project-based learning in engineering education driven by the needs of industry. Furthermore, it is proposed that the continued improvement of engineering educations lies with the expansion of project orientation and the promotion of active learning.

Kolmos\textsuperscript{3} distinguishes between project-organized learning and problem-based learning and points out that international rising trends in education are observed for both. Project work is described as ‘assignment project’, ‘subject project’, and ‘problem project’ with increasingly general levels of direction by the instructor. Roles for all three types of project work are described. The project described in the current paper would tend to fall under the most narrowly specified category of ‘assignment project’.

Perrenet\textsuperscript{4} describes problem-based learning and examines its implementation in medical and mechanical engineering programs. In this context, problem-based learning describes a three phase process in which students first encounter problems rather than information, which then motivates individual self-directed study followed by application of the knowledge to the problem. Unfortunately for engineering education, problem-based learning may not lead to locating correct knowledge to apply to the problem. While the learning skills are important, problem-based learning has limitations for engineering education, and must be applied in a limited way emphasizing integration rather than acquisition of knowledge. It is suggested that project work may be more appropriate than a pure problem-based learning approach. The narrowly defined project with specific and directed assignments that is the subject of the current paper would seem to avoid the pitfalls described.

Hadim and Esche\textsuperscript{5} describe the application of “project-based learning” to a freshman-level solid mechanics course and a junior-level machine design course. The project-based learning that they describe for the freshman course coincides closely to the project-oriented approach in the current paper. A single, semester-long project became the framework to which the course material was related. It was observed that motivation and interest improved as a result of this format and a measureable performance improvement was noted.

Mills and Treagust\textsuperscript{6} explore the application of problem-based and project-based approaches to engineering education in a variety of settings. They identify communication and teamwork skills, perspective on social, environmental and economic issues, and practical application of
engineering science as areas that are not well served by the current engineering educational system. They use a definition of problem-based learning similar to that described by Perrenet, and used extensively in medical education. Noting that project-based learning is defined in various ways, they provide concrete examples of implementation in various engineering programs. Ultimately, they conclude that project-based learning is more likely to be adopted and used in engineering programs than a problem-based learning approach.

Frank, et al.\(^7\) provide a qualitative evaluation of student perceptions, attitudes and performance in an introductory freshman engineering course that implemented a project-based learning approach. They used interviews with students and instructors and classroom observations to collect their data. It should be noted that in this freshman introductory course, the primary role of the instructor was seen as arousing interest and motivation rather than conveying information. Within that context, the project-based learning approach provided a number of clear benefits.

Lehmann, et al.\(^8\) examine project-based learning in the context of teaching sustainable development concepts at Aalborg University (Denmark). They find that the broad and diverse mixture of skills necessary for education in sustainable development are well-suited to a project-based educational approach.

From this partial review of some of the relevant literature, it is apparent that for engineering education, project-based learning appears to be more widely useful than the less-constrained problem-based learning approach that leaves students to discover quantitative technical information on their own. It also appears that even project-based learning, with a variety of definitions, has mostly been applied to introductory and lower division courses where the transmittal of engineering science is combined with, or is even subservient to, qualitative aspects of engineering solutions such as societal impact, teamwork, and motivation for learning.

This paper describes the implementation of a project-oriented class structure in a graduate class which is engineering science intensive.

**Course Description**

Unlike the relatively well-defined scope of subject matter in a first undergraduate course in thermodynamics, a graduate-level course in the subject might explore any one of a wide variety of topics, or it might cover several topics more broadly. Specialties might include compressible flow, statistical thermodynamics, thermodynamics of materials, thermodynamic properties, exergy and availability, and many others. One challenge of a graduate course in the subject is maintaining student engagement in areas which might not be a primary source of research focus or personal interest.
For this course, a project-oriented structure was sought that would lend itself to an incremental, building block approach as well as to a wide variety of specific thermodynamic topics. The development of a software model of an internal combustion spark ignition engine was selected. Thermodynamic sub-topics inherent in the project include: gas power cycles, combustion, compressible flow, temperature dependent properties, thermodynamic property relationships, and others. The course was laid out as shown in figure 1:

<table>
<thead>
<tr>
<th>assg #</th>
<th>due date</th>
<th>project topic</th>
<th>associated lecture topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25-Jan</td>
<td>Otto cycle</td>
<td>Otto, Diesel, and Brayton cycles</td>
</tr>
<tr>
<td>2</td>
<td>1-Feb</td>
<td>Diesel and Brayton cycles</td>
<td>ideal gas properties, mixtures of gases, fuels</td>
</tr>
<tr>
<td>3</td>
<td>8-Feb</td>
<td>Matlab for an Otto cycle, include plots, properties of air mixtures</td>
<td>combustion, enthalpy of formation, heating value, adiabatic flame temperature</td>
</tr>
<tr>
<td>4</td>
<td>15-Feb</td>
<td>step-by-step (1 degree calculations) match with Otto cycle, explore effect of temperature changes on properties, balancing combustion equations, adiabatic flame temperature</td>
<td>compressible flow, speed of sound, regressions</td>
</tr>
<tr>
<td>5</td>
<td>22-Feb</td>
<td>subroutines to calculate properties based on temperature, compare to constant temperature calculations using an average value for specific heats</td>
<td>compressible flow, Wiebe function, first law analysis of combustion</td>
</tr>
<tr>
<td>6</td>
<td>29-Feb</td>
<td>develop a phenomenological combustion model, explore sensitivity to model parameters</td>
<td>converging nozzles, converging-diverging nozzles</td>
</tr>
<tr>
<td>7</td>
<td>14-Mar</td>
<td>development of heat of combustion model for octane as a function of theoretical air</td>
<td>compr./incompr. flow calc for draining a tank, normal shock equations</td>
</tr>
<tr>
<td>8</td>
<td>21-Mar</td>
<td>re-set to get everybody to the same point</td>
<td>normal shock, oblique shock, valve operation</td>
</tr>
<tr>
<td>9</td>
<td>4-Apr</td>
<td>develop valve opening and closing profiles, compressible and incompressible flow through valves</td>
<td>expansion waves, property relations, exhaust stroke</td>
</tr>
<tr>
<td>10</td>
<td>11-Apr</td>
<td>flow through exhaust valve implemented into model, explore effect of exhaust valve operation on engine output</td>
<td>property relations, Mayer relation, intake stroke</td>
</tr>
<tr>
<td>11</td>
<td>18-Apr</td>
<td>flow through intake valve implemented into model, iterative model convergence implemented</td>
<td>Mayer relation, Calpeyron equation, heat transfer approach</td>
</tr>
<tr>
<td>12</td>
<td>25-Apr</td>
<td>heat transfer from cylinder walls included in model</td>
<td>Joule-Thomson coefficient, isentropic volume change, pressure drops across valves</td>
</tr>
<tr>
<td>13</td>
<td>2-May</td>
<td>implement elevation dependent operation, exercise model parametrically for different operating conditions, speed, elevation, richness of mixture</td>
<td>isothermal volume change, semester review</td>
</tr>
</tbody>
</table>

**Figure 4. Assignment and Topic Outline**

For each week, the homework assignment due the next week was introduced, along with all of the necessary background material to complete the assignment. This normally included some technical thermodynamic subject material and some pragmatic material germane to the
programming approach, or to the program structure. Once the assignment had been introduced, the remainder of the lecture time for that week was used on current thermodynamic technical subjects. These were sometimes closely tied to the homework assignment, sometimes loosely related, and sometimes relatively far afield.

The software model was developed in a MATLAB programming environment. All students in the class had had some exposure to MATLAB programming prior to the class. However, expertise varied widely. Some students initially struggled with structured programming using subroutines and loops, however, by partway through the semester all students has gained sufficient competency that the programming was no longer a significant barrier to completing an assignment.

The approach of the course was to start with the simplest possible model of a spark ignition, internal combustion engine: a simple air standard Otto cycle. The air standard Otto cycle is traditionally taught in undergraduate thermodynamics courses because it approximately represents the processes of the spark ignition engine. Attractive attributes include consisting of only four simple processes making analysis very accessible, and accurately representing some general trends of a real engine such as increasing efficiency with peak temperature, and increasing efficiency with increasing compression ratio. The air standard Otto cycle consists of these four steps:

1-2 isentropic compression (representing the compression stroke)
2-3 constant volume heat addition (representing the air-fuel mixture combustion)
3-4 isentropic expansion (representing the expansion stroke)
4-1 constant volume heat rejection (representing blowdown, exhaust, and intake)

Figures 2 shows the first homework assignment for the engine model development project (this was the third assignment of the semester) and figures 3 and 4 show the outputs for parts B and D-E, respectively. At this point, the computer model simply automates the same calculations done in undergraduate thermodynamics classes, and the analytical and computer model outputs for the net work and efficiency should agree exactly because they are just two different routes to the same calculation. This provides student the opportunity to check their programming and program structure thoroughly by hand. Thus, they can easily make sure that the structure is working properly before entering into more complex parts of the program.
MAE 5301—Spring 2012

Homework #3
assigned 2/1, due 2/8

MATLAB protocol
*Every line should have an explanatory comment including at least a label, and units for the number
being calculated, and explanation, if necessary. (everything after “%” is treated as comment)
*Every section should be preceded by a commented explanation.
*Every plot should be labeled with axis titles and units.
*An example is attached

Assignment, Problem #1
A) Write a MATLAB program that will determine the following for an ideal air standard Otto cycle:
temperature, pressure and entropy – after each process of the cycle
specific work and specific heat flow – over each process of the cycle
cycle thermal efficiency, net work for one cycle, power output
given the inlet temperature, inlet pressure, compression ratio, cylinder displacement, engine speed and
heat input.

Compare the thermal efficiency calculated from the compression ratio with that calculated from the net
work and heat input.

Checkpoint:
for: $T_1=211.1^\circ C$, $P_1=1$ atm, $r=12$, $V_0=0.7$ liters, $Q_m=1.173$ kJ/cycle, speed=500 rpm, $s_1=6.696$ kJ/kgK
check is: $\eta=0.63$, $T_{max}=2579K$, $p_{max}=105.26$ atm (same as hw#1)

Turn in your program and output as specified above for the case of $T_1=40^\circ C$, $P_1=0.8$ atm, $r=9$, $V_0=0.8$
liters, $Q_m=1.5$ kJ/cycle, speed =600 rpm, $s_1=6.696$ kJ/kgK

B) Add T-s and P-V plots to your program. Turn in those plots for the case in part (A).

C) Assume a peak allowable cycle temperature of 2700K. Calculate the optimum compression ratio for
that case to give maximum next work.

D) Modify your program so that a peak temperature is specified instead of a compression ratio. For a
peak temperature of 2700 K, run it for 7 values of compression ratio, 3 on either side of the optimum,
and plot the net work as a function of compression ratio.

E) Plot the cycle efficiencies for the 7 points from part (D) as a function of compression ratio along with
the analytic expression for cycle efficiency.

Figure 5. First Project Assignment
Using the framework of the rudimentary Otto cycle calculation, the next assignment changed the model to do all calculations one degree of crankshaft rotation at a time. To ensure that there were no programming errors, this model could be run with constant specific heats to yield identical output to the simple Otto cycle case. Once that was working correctly, a subroutine for calculating specific heats as a function of temperature was assigned and implemented into the model. This gave the model the capacity to accurately reflect variable specific heats throughout the cycle. Then, a phenomenological combustion model was introduced and implemented.

A model for the heat of combustion of octane was developed and included in the overall engine model, followed by the development and inclusion of valve opening and closing profiles along with an accurate flow model (supersonic and subsonic) for flow through the valves. This necessitated the inclusion of an iterative approach for the model to converge to a consistent operating loop. Finally, a rudimentary inclusion of heat transfer from cylinder walls was included. The engine model was essentially complete at that point, and the last assignment was used to embed the engine model into an operational framework that would allow the students to
exercise the model for various operating conditions including speed, elevation, and air-fuel mixture.

Figure 5 shows the last assignment of the semester, and figure 6 shows a single P-V diagram from the completed engine model. The effects of compressible and incompressible flow through the valves can clearly be seen in the intake and exhaust strokes. Less visible effects of cylinder heat transfer are also present.

Figure 5. Final Project Assignment
While the development of the engine model proved to be a compelling and successful vehicle for teaching a wide variety of advanced thermodynamic topics, there were a number of drawbacks to this approach. First, an interest in internal combustion engine operation is assumed but may not be present for all of the students in a given class. In that case, the domination of the class by the engine model would surely be an irritant. Second, computer programming constituted an overwhelming majority of the homework for the class. While it appeared that anyone conversant with general programming concepts could easily adapt to doing programming in a MATLAB environment, some students were quite weak in programming background coming into the class, and struggled to master that capability. Since this was a graduate-level class, and some computer programming capacity should be a tool available to all graduate students, the struggle may have been for the best. Finally, the structure of the class—covering both broad thermodynamics topics as well as going into some depth into spark ignition engine operation made selection of a suitable textbook problematical. There are excellent textbooks in both areas, but no single text was obviously well suited to this exact presentation of the material.

Conclusion

The approaches outlined in this paper—proceeding step-by-step from a very simple model to a very capable simulation, and using a single core idea as a framework to present a broad variety of subjects—could be generalized in a variety of ways. Clearly, an experimental project or a
computer model of a different system could be used instead. By adjusting expectations and
depth of development, undergraduate courses, and even lower division courses could be built
around a similar approach. Indeed, some years ago the author explored with a colleague, in a
purely hypothetical way, the potential to build a whole engineering curriculum around a single
system such as a motorcycle. Undergraduate mechanics, strength of materials, heat transfer,
fluids, thermodynamics, advanced dynamics, systems modeling, design, measurements, machine
design, electronics, and much more would all be represented in a complex machine.

Compared to the full range of engineering courses using problem-based and project-based
structures, this course was definitely at the far end of the spectrum for narrow focus and tight
constraint. Each assignment was narrowly defined and executed. As indicated by Perrenet⁴, this
is probably appropriate for a course with significant technical content. Less constrained
approaches might be more appropriate for introductory and lower division courses.
Nevertheless, this graduate thermodynamics course reaped significant benefits from many
aspects of the project-based structure.

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Undergraduate Research: Proof of Concept Projects

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Abstract
Companies are taking the advantage of University undergraduate research programs by providing projects for students to work on. Some of the projects may be about improvement on current products, development of new products, and/or just some ideas. A production company may not have the extra engineering power to work on some of those projects or the results of such research may not be implemented immediately. Most of the projects may not require a fully working engineering product as result. We call this type projects proof of concept projects.

In 2008, when we started incorporating undergraduate student research into our mechanical engineering technology curriculum, there was only one company in Denver working with us, while in 2011 there are three different companies working with us and in 2012 our students are working on six different projects from five different companies.

This article will present and discuss the aspects of those projects, including phases of the projects, the involvement and the responsibilities of the mentoring engineers from the companies, the faculty members and other related parties, and the assessments of this type projects.

Introduction
The Metropolitan State University of Denver (MSU) is a primarily undergraduate institution. Students of the Mechanical Engineering Technology (MET) program at MSU students are required to participate in a two-semester project in their senior years. At this time, this requirement is part of machine design and senior capstone classes. These two classes are designed as two plus two classes, that is half of the meeting time are scheduled for lectures while the other half for students project work. The total credit hours for each course is three semester hours. Over the past fifteen years, the lecture and laboratory ratio of the courses does not change much, while the content of the project portion has changed dramatically in the past five years.

MSU Denver started to encourage involving undergraduate students in research programs several years ago. In summer of 2008, Swisslog Company re-started its college relation program. The MET program of department of engineering technology (ETS) decided to undertake the challenges in the area of mechanical design and manufacturing using the class layout then, and became the point of contact in making this college and industry connection. So far, there have been more than one hundred MET, forty industry design (IND), and a few other disciplinary students participated this program.
Swisslog is a Denver based design and manufacturing company whose main product is translogic material handling system. The company's product dominates the world and the US markets, about 70% of the world and 90% of the US. Costumers of the system are usually hospitals and medical laboratories, who use the system to transport testing specimen of and medicine for patients. Although its products are widely employed over the world, the company consistently improves its products to meet the needs of its costumers’ and to keep up-to-date with current technology. As many private companies, the engineering group are fairly busy with current design and implementations. There is little to spare for many other research activities. Having undergraduate students to work on some of the possible improvement becomes a good idea. One other reason is that the students might be able to offer the company with some out of the box ideas.

The nature of these projects is basically to demonstrate to the company some possible ways to improve current system, some possible alternatives of design, or some ideas that appear to be good but may not work at all in real life. We call this type of projects proof of concept projects.

The following discussions are mainly based upon the experience working with Swisslog Company, while some comments are added based upon current work.

**How it works**

The projects are decided to be two semester long projects. The two classes selected to accommodate the projects are Machine Design in the fall semester and Senior Capstone in the following spring. The workloads will be finishing design in the first semester and completing a physical ‘proof of concept’ model before the end of the second semester.

Activities in the first semester, so far it has been the fall semester, include:

1. Project creation: In the summer, the MET instructor works with the engineering manager of the company to discuss and create a few broad ideas, which may be possible improvements or additions to the current systems. The descriptions of those are handed out to students before the end of the first meeting so that the students will a chance to discuss and exchange interests amongst themselves, and to form groups before the next phase of the projects. A sample of such project description would look like:

   **Objective:** These projects are intended to provide the students with the opportunity to design and develop a product relevant to a customer, in this case Swisslog. The projects may affect (1) an end-use, paying customer with the purpose to develop new products or markets, (2) an internal process-intensive customer with the purpose of developing or improving new manufacturing processes or (3) an internal or external customer with the purpose of improving cost, quality or delivery performance.

   **Scope:** The projects are intentionally specified generally. The students will be required to work with their internal mentor/engineer and develop the relevant technical and commercial data packages to accomplish the objective of each project. Elements of the technical package will include a specification, technical approach, drawings, calculations, virtual and physical models and data as appropriate for the particular project. Elements of the commercial package include proposed budgets,
schedules, and presentations necessary to communicate progress and provide project and product management awareness of the projects’ status and challenges.

**Purpose:** Learn, Interact, Work on Something Useful and Meaningful, Have Fun!

**Project Opportunities:** The following are the project titles and brief description of the goals and opportunities within it. Detailed project descriptions are omitted here.

2. Projects kickoff: A project kickoff meeting is usually hosted by the company during the second week of the semester. The students will learn more about the company and its products, and meet their engineer mentors. Students will tour the company facilities, including the manufacturing area and company testing laboratory.

Last year the kickoff meeting was hosted in classroom at the University, because it is impossible for students to tour five different companies during the first couple of weeks of the semester. The students will visit the companies as groups interested in the project(s) proposed by the company. The instructor will follow up with the groups and companies.

Engineer mentors play very important role in the projects. They are the points of contacts for the students and provide on-the-fly help to students. They will gather the information and materials, such as current drawings, required by the students and arrange laboratory facilities and schedule date and time for the students’ activities. They are also responsible for checking purchase orders and forwarding the orders to appropriate department.

A very unique experience for the students at the kickoff meetings is that they must sign off a non-disclosure agreement form. The students will be treated as independent contractors who will work on the company’s projects. Of course, as independent contractors, their first job is to convince the company that they will have a great product that fits the company’s needs.

3. Initial proposal: Each group is required to submit an initial proposal based upon their sponsor’s description and what they learned during their first visit to the company. The requirement of the first draft includes: 1) team and individual identification, a team leader must be identified; 2) the project description or problem statement, which should be partially from the sponsor’s description but usually not the entire statement; 3) preliminary design, usually some general ideas at this stage; and 4) references, the is the part shows students initial research on their selected topic. There are usually no more than four students per group.

The initial proposals from each group are made available to the entire class by the instructor. Each individual in the class is required to review all of the proposals and prepare their comments and questions for the coming critique sessions. This becomes a requirement of the class based upon the instructor’s observation that the students are usually very much involved in their own project while paying very little attention to the others.

4. Critique sessions and final proposal: There will be at least two critique sessions before the proposals are finalized. Two different types of critique session have been employed during the past: internal and external critique session.
Internal critique session is the session with only the students and the instructor, while external session will involve personnel from sponsoring companies. In the past, students, instructor, and the Chair of the Engineering Technology department will visit sponsoring company for the external critique sessions. Last year, the managers and mentor engineers from the supporting companies were invited to the campus for the external critique session. The purpose of the critique sessions includes clarifying design ideas, re-scoping the projects to a doable scale, and incorporating suggestions from the sponsoring companies.

After each critique session, groups are required to improve their proposals for next iteration, till the final proposal presentation. The proposals become more and more specific and detailed in design through this process.

The last critique session is usually an internal one. The main purpose of this session is for students to try out their final presentations before standing in front of a larger audience.

5. Final proposal presentation: This usually takes place a week before the end of the first semester. The required elements in the final proposal include all that is required in the initial proposal plus 1) all the appropriate calculations; 2) three dimensional models of parts and assemblies; 3) two dimensional detailed drawing if any manufacturing is anticipated; 4) any engineering, such as fluid or thermal, analysis involved; and 5) project schedule and milestones for the next phase of the project.

6. Assessment: Students are evaluated by groups and as individuals starting from initial participation to final presentation for the first semester. Their efforts on building and testing phases of the projects will be evaluated in the second semester. During the years, we learned that students are usually very positive in working with and contributing to their project groups, while not as active in participation in the question and discussion of the critique sessions and each presentation. To encourage students paying more attention to other groups, participation in the discussions and assessments becomes a required element.

After the projects are finalized, some students may work through the winter break in order to finish their project. However, most of the group activities will be in the second semester. The second semester is the time for students to build their models for proof of concept. The activities include:

1. Material approval and purchase: Based upon approved project proposals from the previous semester, students will create bill of materials (BOM) and submit to sponsoring company for approval of purchasing. They will fill out purchase order forms from the company and submit the forms to the purchasing department of the company just like any other business contractors. When small materials are needed, students may purchase from local hardware store based upon approval and then get reimbursed by the company.

2. Lab and equipment usage: The MET program at MSU Denver has a manufacturing laboratory for teaching and for students to work on their projects. The tests are usually conducted at the company’s testing lab. Now, the group leaders will need to schedule with engineer mentors to test their design or use the company’s equipment to obtain data needed for the projects. This takes a lot of coordination between the group of students and their
mentors. We have learned it is easier for the group of students to commit a common available time by scheduling the class on Friday with four hour sessions. The students also learned that a schedule should be made available ahead with careful planning in order to avoid the inconvenience of their mentors and group members.

3. Redesign and reengineering: Working on industrial projects gives the students opportunities to learn the concept of redesign and reengineering at first hand. As future engineers, the students learned even with all the considerations, there will be compromises to be made as the projects progress.

4. Presenting final products: The final presentation of the projects will take place at the sponsoring company, since this usually involves demonstration of the product in connection with appropriate facilities in the company’s laboratory or testing facilities. As more and more companies get involved, we require that students video tape their assembling, testing and demonstration as part of the final presentation. Now the final presentations are held in classroom with all parties invited.

Assessment

Usually, three parties will be involved in the project final assessments; students in the class, engineering mentors from the companies, and some faculty members from the department.

Students are required from the beginning of the projects to assess their team members and other team’s work. This requirement has become an element for most other project involved classes offered by MET program, as we learned that the students are most likely to be heavily involved in their own projects, while paying little or no attention to what is happening with the other teams and other projects. With the requirement, not only do the students pay attentions to other project, but also make very positive contributions from design ideas to making of the products.

Engineering mentors form the companies have been very much involved in the projects from the beginning. They are part of the external critique sessions and provide guidance to their teams from start to finish. They make it possible for students to utilize company facilities and obtain materials in a timely fashion.

Faculty members of the engineering technology department and other academic areas are invited to the final presentations. Some of them may have been involved in the projects along the side of the instructor, especially for the projects involving multi-disciplinary efforts. During the years, we have students from electrical engineering program and industrial design department working with MET students on projects.

One other academic unit at MSU Denver has been great help in making the connections between University and the industry is the office of cooperative education/internships. A designated person has been assigned as internship coordinator to coordinate engineering student internships. At the final presentation, the internship coordinator serves as an evaluator as well.
Beneficial to all

As some of our graduate said, I got the job because I have the project listed in my resume, and my boss is very much impressed by what I did in my senior year. Some of the Denver area companies keep hiring our as interns then turning them into full time employees and most of them like the students senior experiences with real companies.

The program has been successful not only in beneficial to students, but also to the faculty, engineering team of the companies, and the office of cooperative education at the University. Through the projects, the involved faculty members are able to learn the current industry development in using technology and incorporate in future classroom teaching. The office of the cooperative education at the University will have the opportunity to develop more internship or job placement for the students. The engineers and managers from become more effective and efficient dealing with students and the University.

Besides having the opportunity to apply their knowledge to real world project in qualitative, quantitative analysis, and design, the students will be able to learn firsthand in the following areas suggested by the ABET:

*Teamwork.* Students are required to work in groups. Some may have team members from different academic disciplines such as electrical engineering technology and industrial design. They learn from each other and collaborate to move project forward. Sometimes, compromises will have to be made in order for the project to be successful.

*Communication.* Through the project, not only do students have to communicate amongst themselves, but also they will have to convey their ideas with the engineers and manager to verify and defend their design, to order materials, and to demonstrate their ideas using engineering graphics. Since the critique of other groups became a required element, students learned to make suggestions, comments, and assessments on other projects. Finally, the students will present the results to an audience of managers, engineers, faculty members, and other personnel. In their technical communication, three dimensional models and two dimensional drawings are required elements.

*Life-Long Learning.* In fact, working on the projects, students realize what knowledge is needed in solving the problems. They will come to the instructor for special sessions on design of certain machine elements and explore internet and/or library for needed information. From communication with the industrial personnel and observation of engineers at work, students learn to appreciate the fact that there will be a lot more of learning after college.

*Contextual Awareness.* MSU Denver has a diversified student body, department of engineering technology reflects that image. At this time, the underserved group composes about fifteen percent of MET student population, which is about double of the percentage a decade ago. Students working on the projects must also learn to deal with the engineers and other personnel in a professional manner. The signing of non-disclosure agreement form has been indeed a unique experience for most, if not all, of participating student.
Diagnosis. As stated earlier, the project description given at beginning of the class was purposely made very broad. Our students will have to pick and define their own problem. As the projects progress, they must make their assumptions to simplify design or implementation without compromising the output of the project and they will have design and conduct experiments accordingly.

Personal Development. This is also a topic best learned in practice. Besides in contact with their sponsoring company, many students also visited with the end users of their product to gain the understanding of the importance of diversity and the global and societal impacts of technology.

Conclusion

The past five years has proven to be a great learning period for the MET program to gain and develop working experience with company supported projects. We defined the proof of concept project as a research project for industry as the final product may not be a fully functional engineering product and have been successfully running the projects with our industrial partners.

MET program will update its curriculum to better accommodate senior experience element. A proposed change is to create two courses concentrate on the project aspect of senior experience, with the first one designed as one semester credit hour for the project design and proposal phase, the second designed as two semester credit hours for the building and finishing projects.

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Lagrangian Projects in Sophomore Dynamics

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Abstract

This paper describes experiences in implementing a project into a sophomore-level dynamics course involving basic Lagrangian mechanics. One of the challenges that students face in dynamics is reconciling their notion of the way that mechanisms move over time with the “snapshot” nature of the questions, e.g., sophomore dynamics asks what is the speed of the pendulum at the bottom of its swing, not what is the speed of the pendulum over time. Similarly, in the follow-on dynamics systems course, students seem to have difficulty in extending the notions of sophomore dynamics into differential equations. This paper describes efforts at bridging the gap between sophomore dynamics and dynamic systems via a dynamics project in Lagrangian mechanics for a conservative system. Example projects are discussed along with student experiences, with particular emphasis on how the projects bridge the gap between energy methods and Newton’s 2nd Law.

Introduction

Sophomore dynamics looks at motion at specific instances in time. Questions typically involve finding the force, acceleration, or speed of an object in a given configuration. Students entering a junior dynamic systems course are expected to extend their calculus-based understanding of dynamics into a differential equations framework; some of them have difficulty in letting go of the “snapshot” nature of sophomore dynamics to understand systems’ evolution over time.

This separation of dynamics into calculus-based and differential equations-based formulations is a result of the mathematical maturity level expected of sophomore and junior engineering students respectively. At the South Dakota School of Mines and Technology (SDSMT), the prerequisites for sophomore dynamics include calculus II, physics I, and statics, whereas the prerequisites for junior dynamic systems include sophomore dynamics and differential equations. In keeping with this separation in the study of dynamics, most introductory dynamics texts (e.g. Hibbeler\textsuperscript{1}) do not cover the differential equations interpretations until the very end of the text, although there are some exceptions (e.g. Gray\textsuperscript{2}). With that said, the expression that students are
taught for Newton’s 2nd law in polar coordinates is easily identified as a differential equation by students who are ahead in the math sequence.

The author feels that the students can gain a better appreciation for the study of dynamics by a brief introduction to the equations of motion. Both mechanical and civil engineering students (the SDSMT course has a mix) can benefit from this approach, since the mechanical engineers will be moving on to a dynamic systems course and the civil engineers, should they continue along a structural route, will be moving on to a vibrations course. The challenge for the dynamics instructor is to introduce the meaning of the equations of motion without requiring a course in differential equations.

**Introduction to Lagrangian Mechanics**

The introduction that the author has settled on incorporates both Newtonian and basic Lagrangian mechanics into a class project. Lagrangian mechanics are incorporated to see the equivalence between the energy-based approaches and Newton’s 2nd law, and the author has found that most students wind up preferring the Lagrangian approach to the Newtonian despite the fact that the Lagrangian approach is “magic” to them. For simplicity, projects are restricted in the following ways.

- The mechanical systems are conservative. For conservative systems the notion of generalized force is not required; in fact, the students need only to be able to calculate the kinetic and potential energy of the systems, which is covered in great detail in the course.
- The appropriate coordinates are given to the students. This avoids the discussion of generalized coordinates.
- The concept of the Lagrangian is not introduced. Lagrange’s equations are presented in terms of kinetic and potential energies only.

The students are given, without any justification or proof, the equation

\[ \text{[Equation]} \]

and asked to solve for the equations of motion for a mechanical system. As discussed in the second bullet, they are also explicitly instructed on what to substitute for the \( q_i \)’s.

There is some danger that students will attempt to apply the conservative form of Lagrange’s equations to problems with external forces and torques. The author explicitly states the limitations of the conservative form during the lecture to limit this possibility, but it cannot be completely mitigated. In general the author feels that the benefit outweighs the risk in this case;
even the conservative form of Lagrange’s equation can solve a great number of dynamics problems, often with far less effort than the Newtonian approach.

Filling in the Blanks

Given that neither calculus III nor differential equations is required to take sophomore dynamics, some basic concepts must be introduced before the project will make sense to students. In particular, the author has had to introduce

- Differential equations. The notion that an equation is the answer to a dynamics problem is foreign to many students. In addition, some are largely unaware of what a differential equation is. The author introduces this concept by considering Newton’s 2nd law for a simple mass-spring system, and noting that the acceleration can be replaced by the 2nd derivative of position.
- Partial derivatives. This concept is briefly introduced with examples and the assurance that partial derivatives are strictly easier than standard derivatives. Most students in sophomore dynamics at SDSMT have already taken or are concurrently taking calculus III, so this affects very few students in the class.

In addition to these mathematics concepts, the author typically does a few basic examples comparing the Newtonian and Lagrangian approaches, including finding the equations of motion for a simple pendulum. In general the author has not fielded many complaints about the level of the material or its “newness”; the procedure is easy for them to follow even if they don’t understand the purpose of each individual step.

Example Problems and Student Feedback

The first project problem that the author posed to the students is shown in Figure 8. This is a simplified model of the popular Segway transportation system, with the rider represented as a point mass and the problem restricted to straight line motion. The students were told to model the Segway wheel as a thin disk and to assume that the Segway rolls without slip. This project requires students to understand both rigid body dynamics from a Newtonian perspective and how to calculate the kinetic energy of a rigid body. While much of the student feedback on this initial assignment was positive, there were concerns that this problem was too difficult. In retrospect, the author agrees with this criticism, in particular for the Newtonian portion of the dynamics. Subsequent problems have lessened the difficulty level while retaining the philosophy behind the project.
The classical system shown in Figure 9 proved to be at a more appropriate level of difficulty for students. The Newtonian mechanics are substantially easier, with a simple polar coordinate formulation needed to derive the equations of motion. The Lagrangian mechanics are also simpler. One of the benefits of projects such as this one is that the project does not require knowledge of rigid body mechanics. This allows the project to run earlier in the semester; however, it loses the comprehensive nature of the problem shown in Figure 8. Subsequent projects have featured a standard cart-pendulum system and a simple vibrational model of a two-story building under base excitation.

Student opinions have been generally positive for the course project. This is likely due to two factors: the initial project was mandatory whereas the follow-on projects have been optional.
(replacing the lowest test grade), and the follow-on projects have been easier than the original. Some comments from students are:

- “I felt this project was very beneficial and eye-opening.”
- “This project was a good way to relate different methods of solving a problem.”
- “I found the Lagrangian approach to be difficult but FAR easier than the Newtonian approach.”

**Visualizing Motion – SolidWorks Motion**

Students have two options for completing the project. Individuals are required to submit the equations of motion derived via both Newtonian and Lagrangian approaches, whereas teams of two are required in addition to submit a SolidWorks motion study model including graphs of the system response. Students at the sophomore level do not have the necessary tools to numerically solve differential equations, and there is not sufficient time to teach them this skill in sophomore dynamics. To develop a basic simulation SolidWorks motion is used; mechanical engineering students have significant training in SolidWorks assemblies in their introductory mechanical engineering course. Example student models for the cart / pendulum system are shown in Figure 10 and a student’s result plot for the linear velocity of the seat is shown in Figure 11.

![Figure 10: Student-Generated Cart-Pendulum Systems](image-url)
Conclusions and Future Work

This paper has presented an approach for introducing basic Lagrangian mechanics into a sophomore dynamics class. The projects are limited to conservative mechanical systems and are designed to serve two purposes: introducing the concept of equations of motion, and linking Newton’s 2\textsuperscript{nd} law and energy approaches. The Lagrangian approach is difficult to derive, but is relatively simple to use for the systems studied in sophomore dynamics. Given the students’ positive response to the projects thus far the author intends to continue their use in sophomore dynamics at SDSMT.

References

SolidWorks Examples for Dynamics Instruction

Mark Bedillion and Raymond Raisanen
South Dakota School of Mines and Technology

Abstract

Dynamics of Mechanisms is a required course both for sophomore mechanical engineering students and for senior civil engineers at the South Dakota School of Mines and Technology. It is also widely considered to be one of the most difficult courses in the curriculum for students and routinely has a high failure/dropout rate. One of the major difficulties for students seems to be developing the visualization and intuition skills that help to make sense of the mathematics in the course. In addition, students have expressed frustration with the “snapshot” nature of sophomore dynamics and are curious how these “snapshots” relate to the overall motion of the system over time. This paper describes an effort to incorporate a software component (SolidWorks Motion Simulation) to the class to aid in visualization and problem solving for in-class examples. Mechanical engineering students have extensive training in SolidWorks during their freshman Introduction to Mechanical Engineering course, and the choice of SolidWorks over Adams or other competing software was made for continuity in the curriculum. Several SolidWorks examples are presented and future work on improving the examples and assessment strategies are discussed.

Introduction

Dynamics of Mechanisms (ME-221) is a particularly difficult class for students at the South Dakota School of Mines and Technology. The class teaches predominately sophomore mechanical engineering students and senior civil engineering students the basic concepts of dynamics through two-dimensional rigid body motion. Students from both of these populations (mechanical and civil engineering) have difficulty in the class, but some of the issues seem to come from different sources. The sophomore mechanical engineering students seem to be challenged by the mixture of calculus and physics and the expectation that they can recall material from those classes. The senior civil engineering students demonstrate more maturity as students but have more difficulty recalling basic concepts from freshman physics, such as Coulomb friction and Hooke’s law. Both populations suffer from the following:

- A lack of understanding of basic physics. The Dynamics Concept Inventory\(^1\) is administered at the beginning and the end of the semester, and the class has scored at near 27% on the exam on the first take for the last four semesters. While the students
should not be expected to know all of the concepts on the exam going into the class, they should understand Newton’s 3rd law, which a full 60% of the class routinely misses.

- Difficulty with the chain rule. Despite presumably being drilled extensively on the chain rule in calculus and a review in ME-221, nearly 50% of the class misses chain rule related questions on the first exam in the class, even when they are explicitly told that the chain rule will be tested.

- Trouble with visualization. Dynamics inherently involves the study of motion, whereas most teaching methods use a static chalkboard environment. Particularly from the perspective of interconnected rigid bodies, students have difficulty visualizing the motion of mechanisms. This lack of visualization capability makes it difficult for students to assess the validity of their velocity and acceleration answers at a snapshot in time.

In an effort to resolve the third issue above, the authors have generated a set of SolidWorks motion study solutions to problems from Engineering Mechanics: Dynamics by Hibbeler that are solved as examples during lectures. The course notes are made available to students via Powerpoint slides that incorporate the animations from these motion studies along with graphs from the motion study that indicate the actual results. In addition, all files for the motion studies are made available to students so that they can modify the simulations and generate additional results.

The approach of this paper is similar to the approach by Fisher, but uses SolidWorks for the dynamics simulation tool. The reason that this work uses SolidWorks instead of alternatives such as Adams is that SolidWorks is extensively covered in ME-110: Introduction to Mechanical Engineering. Use of a common tool across the curriculum has two advantages: the instructor does not need to teach a new software package in ME-221, and the students’ SolidWorks skills are reinforced in the sophomore year, which helps to improve retention for more involved work in senior design classes.

**SolidWorks Examples**

The authors have generated various SolidWorks examples for use in the class, a subset of which are presented here. From a visualization perspective students seem to have particular difficulty understanding roll without slip, which is one of the primary topics covered in general plane motion. Figure 12 shows an image from a video showing a tire rolling without slip between two conveyors that move in opposing directions at different speeds. Markers are used to show the overall translation of the wheel in the direction of the higher conveyor speed. This example is used to demonstrate general plane motion kinematics, e.g., finding the velocity of the center of the wheel given the two conveyor speeds. The authors have found that this example helps students to understand the distinction between fixed axis rotation and general plane motion. A
similar example is shown in Figure 13 in which a wheel rolls without slip on a single conveyor belt. The walls on the sides hide the finite nature of the moving conveyor in the animation.

![Figure 12: Rolling Wheel Between Conveyors](image12)

![Figure 13: Wheel Rolling Relative to Conveyor](image13)

![Figure 14: Kinematics in Rotating Frames](image14)

Another example that demonstrates rigid body kinematics is shown in Figure 14. This is an example of motion for which an analysis in rotating frames is required; the authors use this
example to emphasize the breakdown in assumptions behind the standard Cartesian formulation of general plane motion kinematics and demonstrate the relationship between polar coordinates particle kinematics and rigid body kinematics in rotating frames.

As a final kinematics example, Figure 15 shows a simple mechanism that students seem to have trouble visualizing. In particular, students deem this example to be “impossible” because the values of the instantaneous angular velocities calculated in the position shown cannot be constants; given the geometry of the problem none of the links can rotate through a full 360°. The authors added a block to the top of the problem to show the oscillatory motion of the mechanism. The hope is that students will be better able to understand the distinction between instantaneous values of motion parameters and the evolution of those parameters over time.

![A Simple Mechanism](image)

**Figure 15: A Simple Mechanism**

From a kinetics perspective examples cover problems on Newton’s second law, the principle of work and energy, and the principle of impulse and momentum. An example that covers both work and energy and impulse and momentum is shown in Figure 16, with the simulation results shown in Figure 17. The various stages of the motion shown in Figure 17 help to demonstrate the various analysis techniques to be used. As the pendulum falls, conservation of energy may be used to find the velocity at impact; the velocities are “instantaneously” changed by the impact, after which the block gradually slows to a stop under friction while the pendulum swings freely without damping.
Finally, Figure 18 shows two examples that demonstrate the use of either normal and tangential or cylindrical coordinate systems.

![Figure 16: A Simple Impact Problem](image16)

![Figure 17: SolidWorks Results from the Simulation of Figure 16](image17)

![Figure 18: Examples in Particle Kinetics](image18)
The system to the left of Figure 18 demonstrates the motion of a tetherball with an elastic cord, whereas the system to the right demonstrates the motion of a simple carnival ride. In both cases, students are able to clearly see the relationship between rotation speed and vertical motion and can easily extract the forces in the cables and the spring.

Conclusions and Future Work

This paper has presented several examples that demonstrate the use of SolidWorks in improving students’ visualization of motion. The first full implementation of these examples into the course is occurring in the current semester, and so no formal evaluation results are available at this time. Informally, students have said that they find the examples useful and like the incorporation of the videos into the online notes. The authors will be assessing the current implementation via a student survey to be issued at the end of the semester as well as results on the post-course take of the Dynamics Concept Inventory\(^1\).

While the authors were able to model many common dynamics examples in SolidWorks, there remain several examples in the class that the authors were unable to model. A large class of examples that have proven difficult to model are “yo-yo” problems, which involve cords wrapped around drums (this class also includes problems with pulley systems). Such “yo-yo” problems are covered extensively in ME-221 to demonstrate the kinetics of rolling motion and the transition to slipping; they are also among the most difficult problems for students to properly visualize. Future work will seek solutions to this class of problems and attempt to expand the approach into follow-on classes such as Introduction to Dynamic Systems and Intermediate Dynamics, where the students can take an active role in simulating the dynamics.

References

Developing an Educational Agenda in a Research Intense College of Engineering
Dr. Tom Siller and Dr. Steve Abt

The College of Engineering at Colorado State University in Fort Collins is a research intense college where the faculty currently average over $600K in extramural funding on an annual basis. In this paper we discuss how the college has developed an educational agenda in parallel to this research agenda that has resulted in several innovative programs and added to the overall college focus.

This educational agenda addresses several important emerging trends in engineering education. First, the type of student entering college today is very different from the student population when most faculty members were undergraduates; often referred to as the millennial generation, their needs and their approach to education require new ideas to support their endeavors. Second, engineering is a changing profession and requires a rethinking of how we educate future engineers. Third, the role of engineering in society is changing as the calls for greater involvement in outreach and K12 education continue to get louder.

In response to these motivators, our college has embarked on a series of innovative education projects that are now a part of our culture. These efforts include: new recruiting efforts, the building of a new residence hall to house a living-learning engineering community of undergraduates, a Professional Learning Institute aimed at developing students professional skills, a first of its kind teacher education program to produce K12 technology and engineering teachers for middle to high school level education, and a first semester pass-fail option for incoming first year engineering students.

Each of these projects will be briefly described in this paper and associated presentation. We shall discuss how and why each project came to fruition, and discuss some of the impacts they have had on our students and college.
Creating a Space for Engineering in the Science Curriculum in K-12 Schools

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1College of Engineering, University of Utah

Abstract

In the State of Utah engineering is considered a part of career and technology education, or CTE. These courses are not rigorous and do not adhere to the same curriculum standards as math and science classes. Furthermore, these classes are not taken by most students who enter the College of Engineering at the University of Utah because CTE coursework is in direct competition with the high levels of math and science courses that are recommended to begin an engineering major at the University of Utah. To bypass barriers in the K-12 system, we met with K-12 teachers and administrators to determine the need for incorporating hands-on application activities. Based on their input, we designed lesson plans and materials aligned with the state core curriculum and provided a resource for teachers to answer questions related to the real-world applications of content taught in science courses. Teachers are able to download our lesson plans from our website and also check out lesson plan kits from the College of Engineering for use in their classrooms. Our lesson plans are geared toward the engineering design process and help students understand not only the differences between the scientific method and the design process, but also how science is used in engineering design. These materials provide a resource to augment a given curriculum, rather than compete with it. After three years of sustained growth and encouraging feedback from teachers in our community, we believe this program helps introduce students to engineering as a potential career.

Introduction

High school graduation requirements in Utah do not leave significant room for students to explore a variety of electives. Often students must choose between the arts, technology and rigorous, college preparation courses. The high school graduation requirements are as follows: 4 units of English, 3 units of math, 3 units of social studies, 3 units of science, 2 units of physical education and health, 1.5 units of arts, 1.5 units of career and technical education (CTE) and computer technology and 6 required units of electives1. Students must complete 27 units to graduate from high school.

Early in their high school years, students must choose to pursue the arts, follow a CTE pathway or become college ready. The lack of wiggle room forces students into an unofficial track at a young age, without the proper knowledge of the implications of each track. Students who wish
to study visual or performing arts fill the majority of available elective credits with courses that fall into their interests. Students who enjoy the hands-on nature of CTE coursework may choose the pathways of Project Lead the Way as a way of exploring engineering as a future career. During their time in the Pathways Program, educators encourage students to maintain the momentum they gain by taking additional coursework. The CTE Pathways Program in Utah includes the following pathways: agriculture, business, family and consumer science, health science, information technology, marketing, etc\(^2\). These pathways do not compete with high school graduation requirements, but they inhibit the pathway to college preparation by directly competing with the coursework that will prepare students for the rigors of college.

Students who wish to pursue a pathway to the University of Utah must complete two years of math beyond Elementary Algebra, as well as two consecutive years of the same foreign language. Furthermore, Utah high school graduation requirements do not require students to take science or math during their senior year, which poses a threat to their success in higher education. Students who take courses with less rigor during their senior year in high school have more barriers to overcome when they enroll in college because they fall behind in their studies\(^3\)-\(^{16}\). In order for students to overcome this, students are advised to take math and science throughout their high school degree program. Ideally a student who wishes to study engineering will not only continue with math and science, but will take AP Physics and AP Calculus BC in high school. Taking these courses in high school will best prepare “engineering ready” college students as they enroll in engineering majors at the University of Utah.

**Methods and Results**

*Engineering Ready Coursework*

To best advise students into engineering majors, we met with administrators in both the high school classrooms and the Utah State Office of Education. The focus of the meetings was to determine barriers students face as they choose their high school coursework and to outline ways high school students could overcome those barriers without changing the K-12 system. The coursework outlined in Table1 demonstrates pathways in which a student in the state of Utah could become engineering ready.
Table 1. Suggested High School Coursework

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<th>7th Grade</th>
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<th>10th Grade</th>
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<td>Math III 2</td>
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</tbody>
</table>

1 Optional, but highly recommended
2 Students may qualify for an honors level Math class. With the new common core, honors level Secondary III Math is required for entrance into calculus in 12th grade.
3 Required for Admission to the University of Utah

The coursework outlined creates a clear track for students to follow; however, it leaves very little room for elective exploration in other subject areas.

Science Core Curriculum

The science curriculum standards in Utah are subject to the knowledge of the educator in the classroom. Broad statements outlined in the science core curriculum include: students will understand the structure of matter,” “students will understand the relationships among energy, force and motion” and “students will understand transfer and conservation of energy.” These broad statements are accompanied by learning objectives that are equally generalized. The open-ended nature of the standards of the core curriculum creates freedom for educators to include enrichment activities that not only compliment scientific discovery, but also principles of engineering design.

A series of lesson plans was developed to help teachers who are not familiar with engineering and the design process to incorporate hands-on engineering activities into their science classes. Each lesson plan highlights a standard and objective of the science core curriculum, which allows a teacher to fit the lesson plans into their teaching. These lesson plans are meant to augment and enrich the standards outlined in the science curriculum.

Hands-On Engineering Lesson Plans

Build Something That Moves
This lesson helps students learn about potential energy through rolling, torque, pressure and springs. Students learn how to create movement through potential and kinetic energy. This lesson supports both the 8th Grade science and high school physics standards: students will understand the relationships among energy, force and motion; and objectives: investigate the application of forces that act on objects, and the resulting motion. The plan suggests that teachers explain what potential and kinetic energy are. Demonstration instructions include: place a textbook on a desk and ask the students if there is any energy in the desk; let the textbook fall to the ground and explain the difference between kinetic and potential energy; ask the students how they would create more energy with the textbook (raise it higher and higher); and demonstrate the energy with each height change.

Teachers are further instructed to teach the students that roller coasters use the concepts of kinetic and potential energy: ask the students when they have the most potential energy (at the crest of the first hill); explain to the students that mechanical engineers build up the energy at the beginning of the ride by raising them to a high point and illustrate that the rest of the roller coaster uses kinetic energy—energy in motion. Furthermore, the remainder of the ride is only expending the potential energy gained at the initial height. This demonstrates an example of energy through rolling.

The activity has the students break into groups of three, create potential energy by building something that moves, assign a different type of movement to each of the different groups, and then have them present their project and type of movement to the class. The goal is to show that potential energy can be demonstrated in a variety of types of movement.

Artificial Heart Valve

The purpose of this lesson plan is to introduce students to biomedical engineering by demonstrating practical applications of biology, anatomy, and physics. This lesson supports both 7th Grade and high school biology standards: students will understand that the organs in an organism are made of cells that have structures and perform specific life functions; and objectives: identify and describe the function and interdependence of various organs and tissues. Teachers are encouraged to reiterate the following concepts to the students prior to the activity: heart valves are located in the heart; the heart contains four heart valves that ensure unidirectional blood flow through the heart; if a heart valve leaks, then blood can flow in the wrong direction and decrease circulatory efficiency; symptoms of a leaking heart valve include fatigue, dizziness, swollen feet or ankles, and shortness of breath; leaking heart valves can restrict a person’s ability to be active and move around and replacing leaking heart valves can give the patient a higher quality of life.
Teachers then introduce the field of biomedical engineering: biomedical engineers create artificial heart valves that can replace leaking human heart valves; must create a heart valve that can open and close with the pumping of the recipient’s heart; artificial heart valves must maintain unidirectional flow; engineers have created a variety of different types of heart valves which resemble human heart valves, or some engineers have designed artificial heart valves to work like some water valves that regulate flow.

For the activity with this lesson plan, students are divided into groups and then work with various materials to design a heart valve that allows fluid to flow in only one direction. Materials include wire, PVC tubing, aluminum foil, electrical tape, tarp material and any other material available to the teachers. Students should have time to create a prototype for testing with fluids of similar viscosity to blood. Devices should be tested from both directions. Students should be able to identify failures in the prototype and encouraged to follow an iterative process to create a device that closely meets the design specifications.

Solar Powered Bird House

In this lesson plan, students are introduced to photovoltaic technology from a variety of perspectives including materials science and engineering as well as electrical engineering. Students are taught how solar panels work and how they are fabricated. They also learn how they can be used to generate power for residential and commercial use. This lesson plan is suggested for use with standards in both chemistry and physics: students will understand the relationship between energy changes in the atom specific to the movements of electrons between energy levels in an atom resulting in the emission or absorption of quantum energy, and students will understand transfer and conservation of energy. Students are taught how a solar cell works:

The solar panels used in this lab are made of amorphous silicon. That means that the silicon atoms are randomly placed on the wafer. When you see an atom, there are different bands where the electrons orbit the nucleus. The outer layer is referred to as the valence band. There is an additional band in silicon and other photovoltaic and electronic materials referred to as the conductance band. When light hits the silicon atoms, electrons move from the valence band to the conductance band for a brief second. Additional materials are used to capture the electrons at that point and hold them long enough to move them to the leads.

Students are also taught how solar cells can be used in homes:
The solar panels on the roof of a house generate electricity that will be used by that house. We all know that there is no light at night, so how do we get electricity to light up the lights in our house when we actually need them? The sunlight hits the solar cells throughout the day, and the electricity is stored in a capacitor (battery). Then when the homeowners need the electricity, it is available to them.

Students are introduced to Ohm’s Law: current, voltage, resistance, as well as capacitance, and both series and parallel circuits.

Four activities are described: students assemble the solar circuit and use light to charge a power source; students use Ohm’s Law to calculate the resistance in the system; students connect the circuits in both series and parallel as they attempt to light multiple lights in the bird house; and students explore what else they can do with the solar powered circuits.

Analysis of Lesson Plan Usage

The lesson plans were piloted in a course taught by the College of Engineering in a local charter school, the Salt Lake Center for Science Education. The focus of the course was to create lesson plans that were based on science concepts and introduced engineering design rather than the approach of CTE coursework. After the initial development of the lesson plans, a lesson plan book was created and distributed to teachers in Utah. The books were distributed individually through teacher contacts, at the district level through curriculum training days and at the state level through both the science and math curriculum specialists. The lesson plans are available to teachers both in print and online. To date, the College of Engineering has distributed 637 teacher lesson plan books.

In addition to lesson plans, the College of Engineering created a library of equipment needed for the lesson plans. This library is available to teachers via the internet. In 2009, there were 5 teachers who checked out materials. The number of materials checked out in 2010 grew to 8; in 2011 there were 24 teachers who utilized the online library; and thus far in 2012, there have been 38 kits checked out for use in the K-12 classrooms in Utah.

Discussion and Conclusions

In Utah there are many barriers that prevent students from becoming “engineering ready.” These barriers range from a lack of information regarding suggested high school coursework to the direct competition of personal interests with the rigorous coursework needed to adequately prepare not only for college admission, but also for entering an engineering major at the University of Utah. To mitigate these barriers, we have outlined the suggested high school coursework that will best prepare students to meet the demands of an engineering major.
Furthermore, due to the high demands on student coursework, we created a method for teachers to implement engineering design concepts into the science curriculum rather than create new courses that would also compete with the demands on student time in class. The lesson plans developed have direct ties to the science curriculum. This tie to the curriculum has benefits to both teachers and students. Teachers now have access to a new set of hands-on activities and enrichment activities that adds to the state science core curriculum. Furthermore, teachers do not have to justify spending time away from the core curriculum. Students benefit because they are not only introduced to the scientific processes described in the core curriculum, but they can also be introduced to real-world applications of the science concepts taught by applying pieces of the engineering design process.

By making these lesson plans available to teachers, we have seen an increase in the number of requests received for the teacher resource library we have created. In addition, we hope to continue to expand the hands-on resources available to teachers. As the teacher resource library has been made available to more teachers, they have continued to comment on the value of making real-world connections to some of the less intuitive concepts taught in the science curriculum. We hope to continue to serve as a resource for teachers by providing quality lesson plans and materials that can be used in the K-12 science classrooms that highlight science concepts used in engineering.

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Learning from Failure: Understanding Unintended Barriers to Math Success in Engineering

Beverly Louie

Abstract

A sound math background is an important cornerstone of an engineering education. This notion is well understood, permeating the high school advising culture such that self-identified engineering-bound students are guided to take high level calculus courses. However, an inadvertent mismatch may exist between high school mathematics advising and university expectations. And, well-intentioned university processes may be creating unintended barriers to success in engineering through the requirement of undergraduate mathematic courses for which students may not be prepared.

The University of Colorado Boulder’s College of Engineering and Applied Science is implementing a new approach to guide first year engineering student placement in math courses. New in 2012, the ALEKS math assessment was piloted as a pre-college evaluation of trigonometric and pre-calculus preparedness for all first-year students. In-person advising procedures, as well as a generalized online advising recommendation, assist in placing students in their first math class. Our history in first year engineering student success in calculus is dubious at best; a five-year retrospective analysis showed that 28% of students failed (grade of C- or lower) Calculus I and 29% failed Calculus II. These results suggest a broken system, and beg the question: what is not working?

This paper focuses on statistically evaluating the effectiveness of the ALEKS mathematics assessment in placing engineering students to optimize their performance in pre-calculus and calculus courses. We will also discuss the messaging that surrounds the math placement test administration and how messaging may negatively impact student performance outcomes. Another salient factor to be discussed is the role that informal and formal advising plays in the selection of math classes by engineering students. Last, we will make evidence-based recommendations for improved processes to place engineering students in mathematic courses that will promote their long term success in the engineering curriculum.
Design Center Colorado: Fostering Meaningful Partnerships between Students, Industry and Government Agencies

Daria Kotys-Schwartz

Abstract

In recent decades, industry-university partnerships have driven innovation and economic growth. For the U.S. to maintain its global positioning, unique industry/university partnerships need to be developed that broaden the traditional funding of discrete research projects. One mechanism is the implementation of yearlong sponsored engineering design projects. These projects provide a structure where long-term, beneficial relationships between colleges of engineering, industry, government agencies, as well as non-profits can be built. For universities, these partnerships provide an authentic learning experience for budding engineers. For sponsors, the benefit is access to a pool of talented engineers that can accelerate their competitiveness. Yet, establishing multiple collaborations between university and sponsors requires strategic preparation and open communication. What are some of the best practices used to successfully establish partnerships between universities and external entities?

The Design Center (DC) Colorado is an industry/government/organization-education partnership within the Department of Mechanical Engineering at the University of Colorado Boulder. For the last 12 years, the center has immersed teams of graduate and undergraduate students in sponsored design projects throughout the academic year. The organization coordinates the Industrial Advisory Council bi-annual meeting and sponsors a distinguished lecture series. Last, the center coordinates the project laboratories that support the design-based courses at the graduate and undergraduate levels. The center has tackled some of the educational shortcomings in the mechanical engineering department, specifically focusing on the development of professional skills and the translation of technical skills into the design context.

This presentation introduces the DC Colorado model and details the approaches we use to maintain 27 sponsored engineering design projects on a yearly basis. Key strategies for building a center will be delineated and barriers to growth will be described. Assessment results from center stakeholders will be shared including feedback from center students, faculty team advisors and industry partners.
Inclusive Excellence to Bolster Diversity: A System of Capacity-Building Pathways to and Through Engineering

Daria Kotys-Schwartz

Abstract

By 2050 it is expected that the U.S. minority population, currently at 30%, will grow to 50% of the overall population\(^1\). This demographic shift gives urgency to the rationale for increasing diversity in the engineering workforce to remain globally competitive, a critical objective emphasized by leaders in industry, government, and academia\(^1\). Discussion on broadening participation has increasingly permeated STEM discourse and engineering education agendas for two decades\(^2\)-\(^4\). Yet, results remain stagnant; only about 10% of BS engineering graduates are underrepresented minorities – effectively unchanged over the past 15 years,\(^5\),\(^6\) while the national average for women engineering graduates peaked at ~21% in 2002\(^7\),\(^8\). Clearly, a need exists to identify better models to bolster engineering diversity; we expect these models will be multidimensional and complex.

The *Inclusive Excellence* research project is an NSF-funded investigation at the University of Colorado Boulder that takes a *system approach* to promoting academic excellence through inclusion. This research explores the development of varied components of a holistic model that weaves recognized and emerging identity factors with successful practices to broaden the pathways into engineering college for the next-tier\(^*\) of potential students, and cultivates early development of professional engineering identity as a way to scaffold academic persistence and excellence. The result of the *Inclusive Excellence* project will be dissemination of practices that other institutions can adapt to create their own *inclusive excellence system* to counter the shortfall of more diverse students in U.S. engineering schools.

This paper introduces the *Inclusive Excellence* project, describes the research design and highlights the potential outcomes for the engineering education community.

References


* Next-tier students are those just below “making the cut” for acceptance to a given engineering college based on its admission requirements, but are deemed to have high potential and probability for success if a pathway for such can be identified.
Evaluating Academic Success of Tiospaye American Indian STEM Scholars

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Abstract

Nationwide, American Indians represent about 1% of the population and about 0.5% of engineering enrollment. In South Dakota, American Indians represent about 10% of the population and at South Dakota School of Mines about 3.8% of enrollment. Following best practices developed by American Indian educators and model institutions, we are five years into two National Science Foundation grants (S-STEM) to increase the number of American Indian STEM graduates through our Tiospaye Scholar Program. The program has five areas of support: financial, academic, professional, cultural, and social – through an extended campus network. Following the Lakota word for extended family, Tiospaye, the program features positive intervention strategies, extensive classroom support through a combination of campus and small group tutoring sessions, course section cohorts, bi-weekly professional development and group bonding activities, and mentoring that includes academic advising and one-on-one tutoring.

In this paper we present preliminary assessment results focusing on the academic success of our scholars for the first five years of the program, by comparing academic achievement to a control group of SDSMT American Indian students with a similar background (e.g., low income, first generation to college, similar majors, etc.). Once our academic assessment in complete, it will include such dependent variables as graduation rate, retention results, progress toward degree, course completion ratio, and grade point average. Additional program assessments include an attitudinal survey, longitudinal tracking of student cohort groups, student satisfaction, typological assessment, student focus groups, and corporate sponsorship and partnerships.
Dilemmas of becoming in engineering education

Kevin O’Connor, Louisa Harris
University of Colorado Boulder

Abstract

This paper presents preliminary findings of an ethnographic study of a program intended to provide access to engineering careers for “next-tier” students, those falling short of College admission criteria but demonstrating talents that make them likely candidates for eventual success. Our focus, following upon recent work in the learning sciences, is on dilemmas that arise out of students’ understanding of and performance in the first year curriculum. Students view many required courses (e.g., math, physics) both as failing to provide a good sense of what engineering is, and also as central to what they will need to know and do as engineers. Because of their perceived centrality, students devote primary attention to these courses. For some students, these courses pose dilemmas as they attempt to make sense of themselves—that is, to develop an identity—within the College and within what they take to be the discipline of engineering. For example, on the basis of such courses, some students decide that engineering is an overly narrow field and decide to leave the program; others question their own suitability for the profession on the basis of their grades, which they take to be a reflection of their ability to succeed in the discipline. We consider these preliminary findings in light of recent work suggesting that early coursework (e.g., problem sets with given and fixed answers) bears uncertain relationships to later coursework and the workplace, and we explore claims that engineering education should be structured around practices of “technical coordination” that blurs lines between social and technical aspects of work, and places social interaction at the core of accomplished engineering practice.

References

Retention and Recruitment as Part of a Pre-Engineering Education Collaborative

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³Math and Science Oglala Lakota College Kyle, SD

Abstract

Three educational institutions in South Dakota are collaborating to develop pre-engineering courses to increase the enrollment and success of students transferring from Oglala Lakota College (OLC) to 4-year bachelor degree programs in science and engineering at South Dakota School of Mines and Technology (SDSMT) and South Dakota State University (SDSU) through a grant from the National Science Foundation Tribal Colleges and Universities Program (TCUP). Activities of this grant have led to partnerships with the native-led Thunder Valley Community Development Corporation, the University of Colorado-Boulder, an NSF Research Experience for Undergraduates, and other organizations at SDSMT, all of which provide significant opportunities for Native American students in the areas of civil and geological engineering and sustainability. Despite the growing number of collaborations and opportunities that have been established, one of the challenges of the program has been recruitment. In the third year of the five year award, the investigators have tried many different recruitment activities with varying levels of success. These have included presentations at Native American high school summer programs, booths at Native American regional events, and personal contact with students at Oglala Lakota College. This paper describes these efforts and identifies those leading to successful student recruitment into the program. Future initiatives for recruitment and outreach activities are also presented.

Introduction

The OLC, SDSU, and SDSMT Pre-Engineering Education Collaborative (OSSPEEC) is an effort to develop a pre-engineering curriculum that will enable students graduating from OLC with associate degrees to continue their degrees in 4-year engineering programs at the junior level. Summer research and service learning projects are incorporated into the program to provide a hands-on introduction to science and engineering topics, promote community involvement and service, and to stimulate student interest and motivation to pursue these fields of study. The specific project goals in the OSSPEEC grant are: 1) establish collaborative offerings of gateway and bottleneck courses that occur in the first two years of engineering curricula coupled with on-reservation hands-on laboratory experiences and recitation sessions at OLC, 2) transform classical engineering program curricula to follow the constructivist philosophy of learning.
through vertical integration of the first two years by incorporating service-learning and research project learning experiences, 3) increase the pre-engineering and engineering recruitment, retention, and graduation rates for South Dakota Native American students.

At a time when the United States is facing unprecedented global economic competition, not enough young people are preparing to enter the critical science, technology, engineering, and mathematics (STEM) fields. Encouragement and support for enrollment and retention of qualified US citizens in STEM fields is critical to the long-term success of the US economy. The gap between the demand and availability in the area of engineering is particularly striking for Native communities. Nationwide, Native Americans represent about 1% of the US population and about 0.5% of engineering enrollment. In South Dakota, where Native Americans represent about 10% of the population, disparity within engineering programs is even greater. In 2009, Native Americans represented about 2.1% of engineering enrollment at SDSMT and 1.5% of engineering at SDSU. The low retention rate of Native American college students may be partially responsible for disparities in engineering disciplines. The overall Native American college student retention rates were between 7% and 25% in 1995, with the lowest retention rates in STEM disciplines. Tribal colleges, which tend to have higher overall retention rates for Native American students have lower overall retention rates when compared to State institutions.

**Partnerships Established**

The OSSPEEC program has fostered the creation of partnerships that have enhanced and expanded the undergraduate opportunities available for students. Four of these partnerships are described below.

The Thunder Valley Community Development Corporation (TVCDC) is currently developing a sustainable 1,000-person community on the Pine Ridge Indian Reservation. The community will include housing, jobs, community facilities and infrastructure and is being planned by and for the Oglala Lakota people (Figure 1). Sustainability objectives of the community include water use, renewable energy consumption, and agricultural systems to promote and encourage the use of local produce. Students supported by the OSSPEEC program have had the opportunity to investigate alternative structural systems for housing including rammed-earth, straw bale, traditional building, and structural panel (SIPS) construction and wind energy alternatives.

The University of Colorado – Boulder is currently designing and constructing the first planned structures for the Thunder Valley Regenerative Community through their Native American Sustainable Housing Initiative (NASHI). Construction is taking place for the first single-family residential structure, and construction drawings are being prepared for a youth empowerment center. Students supported by the OSSPEEC program have had the opportunity to learn about insulated frost protected foundations and to participate in construction of the residential structure during the summer of 2012 (Figure 2). PEEC students will instrument the house with temperature and humidity sensors upon completion of building.
An NSF supported Research Experience for Undergraduates program at SDSMT will host its second year during the summer of 2013. Research topics are metallurgical related, including welding and materials joining studies, which have been seamlessly incorporated into the structural engineering emphasis of civil engineering. One student from OLC participated in the REU in 2012 after participating in the OSSPEEC program and a second student who worked on a PEEC-sponsored bridge project at the SDSMT Advanced Materials Processing (AMP) lab will participate in the REU during the summer of 2013. Group poster sessions, social and recreational events are coordinated throughout the summer between the PEEC and REU programs to provide student experiences beyond science and engineering.

An educational grant sponsored by the U.S. Environmental Protection Agency was awarded to SDSMT in 2011 which provided funding for one M.S. student and one undergraduate student to work with the Oglala Sioux Tribe Environmental Protection Program to further develop their water quality monitoring, assessment, and implementation programs on the Pine Ridge Indian Reservation. This project presented an excellent service learning and research opportunity for OSSPEEC participants, and one OSSPEEC student participated in several of the grant activities including installation of stream monitoring equipment, storm event stream sampling and outreach to Native American high school students through field trips and presentations related to the project.
Recruitment History

We were relatively successful in recruiting and retaining student cohorts at the three participating institutions in the first year of the NSF OSSPEEC award. Student recruitment focused on Native American students, but the program has accepted other interested students to meet the targeted summer research cohort. Fifteen undergraduate students and three graduate student researchers and project coordinators were recruited during the 2010-2011 academic year. These data are shown in Table 1. Target recruitment numbers for the grant are eight students for OLC, six students for SDSMT and ten students for SDSU. Recruitment results for Year 1 of the grant represent 87%, 66%, and 70% of targeted recruitment numbers for OLC, SDSMT, and SDSU, for the OSSPEEC grant respectively.

<table>
<thead>
<tr>
<th>Table 1 Student Interns and Project Coordinators Recruited in OSSPEEC Year 1 (2010-2011).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year Recruited - Rank</strong></td>
</tr>
<tr>
<td>Fall 2010</td>
</tr>
<tr>
<td>Junior</td>
</tr>
<tr>
<td>Sophomore</td>
</tr>
<tr>
<td>Graduate *</td>
</tr>
<tr>
<td>Graduate *</td>
</tr>
<tr>
<td>Senior</td>
</tr>
<tr>
<td>Spring 2011</td>
</tr>
<tr>
<td>Graduate *</td>
</tr>
<tr>
<td>Summer 2011</td>
</tr>
<tr>
<td>Sophomore</td>
</tr>
<tr>
<td>Freshman</td>
</tr>
<tr>
<td>Freshman</td>
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<tr>
<td>Freshman</td>
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<tr>
<td>Freshman</td>
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<tr>
<td>Freshman</td>
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<tr>
<td>Sophomore</td>
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<tr>
<td>Junior</td>
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<tr>
<td>Sophomore</td>
</tr>
<tr>
<td>Sophomore</td>
</tr>
<tr>
<td>Freshman</td>
</tr>
<tr>
<td>* Project Coordinators</td>
</tr>
</tbody>
</table>

Student participation in the second year of the program included retaining 11 students to continue working in the OSSPEEC grant and recruiting nine new participants. Five of the students from Year 1 (28%) either accepted full-time employment, or graduated. Two students (11%) did not continue their studies in the fall of 2011. The students listed in Table 2 represent 100%, 100%, and 50% of target recruitment numbers at OLC, SDSMT, and SDSU, respectively.
Table 2 Student Interns and Project Coordinators Recruited and Retained in OSSPEEC Year 2 (2011-2012).

<table>
<thead>
<tr>
<th>Year Recruited - Rank</th>
<th>University</th>
<th>Degree Seeking</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall 2010</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Junior</td>
<td>OLC</td>
<td>AA PreEngineering</td>
<td>Retained</td>
</tr>
<tr>
<td>Sophomore</td>
<td>OLC</td>
<td>AA PreEngineering</td>
<td>Retained</td>
</tr>
<tr>
<td>Graduate</td>
<td>SDSU</td>
<td>MS Civil Engineering</td>
<td>Graduated 2012</td>
</tr>
<tr>
<td>Graduate *</td>
<td>SDSU</td>
<td>PhD Biology</td>
<td>Retained</td>
</tr>
<tr>
<td>Senior</td>
<td>SDSMT</td>
<td>BS Civil Engineering</td>
<td>Retained</td>
</tr>
<tr>
<td>Spring 2011</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graduate</td>
<td>SDSMT</td>
<td>MS Industrial Engineering</td>
<td>Accepted FT Employment</td>
</tr>
<tr>
<td>Summer 2011</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sophomore</td>
<td>OLC</td>
<td>AA PreEngineering</td>
<td>Retained</td>
</tr>
<tr>
<td>Freshman</td>
<td>OLC</td>
<td>AA PreEngineering</td>
<td>Retained</td>
</tr>
<tr>
<td>Freshman</td>
<td>OLC</td>
<td>AA PreEngineering</td>
<td>Retained / Graduated, 2012</td>
</tr>
<tr>
<td>Freshman</td>
<td>OLC</td>
<td>AA PreEngineering</td>
<td>Retained / Graduated, 2012</td>
</tr>
<tr>
<td>Freshman</td>
<td>SDSU</td>
<td>BS Geography</td>
<td>Graduated, 2011</td>
</tr>
<tr>
<td>Freshman</td>
<td>SDSU</td>
<td>BS Landscape Architecture</td>
<td>Graduated, 2011</td>
</tr>
<tr>
<td>Sophomore</td>
<td>SDSU</td>
<td>BS Psychology – STEM minor</td>
<td>Retained</td>
</tr>
<tr>
<td>Junior</td>
<td>SDSU</td>
<td>BS Civil Engineering / BS Chemistry</td>
<td>Retained</td>
</tr>
<tr>
<td>Sophomore</td>
<td>SDSU</td>
<td>BS Civil Engineering</td>
<td>Un-enrolled, Fall 2011</td>
</tr>
<tr>
<td>Sophomore</td>
<td>SDSMT</td>
<td>BS Geological Engineering</td>
<td>Junior standing</td>
</tr>
<tr>
<td>Freshman</td>
<td>SDSMT</td>
<td>BS Civil Engineering</td>
<td>Un-enrolled, Fall 2011</td>
</tr>
<tr>
<td>Fall 2011</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graduate *</td>
<td>SDSMT</td>
<td>PhD in Geology and Geological Engineering</td>
<td>Retained</td>
</tr>
<tr>
<td>Spring 2012</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Senior</td>
<td>SDSMT</td>
<td>BS in Geology and Geological Engineering</td>
<td>Retained</td>
</tr>
<tr>
<td>Summer 2012</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freshman</td>
<td>OLC</td>
<td>AA PreEngineering</td>
<td>Stopped Out</td>
</tr>
<tr>
<td>Graduate *</td>
<td>SDSU</td>
<td>MS Industrial Management</td>
<td>Graduated</td>
</tr>
<tr>
<td>Sophomore</td>
<td>SDSU</td>
<td>Undecided</td>
<td>Retained</td>
</tr>
<tr>
<td>Sophomore</td>
<td>SDSU</td>
<td>Undecided</td>
<td>Retained</td>
</tr>
<tr>
<td>Junior</td>
<td>SDSMT</td>
<td>BS Physics</td>
<td>Retained</td>
</tr>
<tr>
<td>Junior</td>
<td>SDSMT</td>
<td>BS Geology</td>
<td>Retained</td>
</tr>
<tr>
<td>Graduate *</td>
<td>SDSMT</td>
<td>MS Civil Engineering</td>
<td>Retained</td>
</tr>
</tbody>
</table>

* Project Coordinators
Recruitment Activities

Recruitment for the OSSPEEC program is a broad initiative that includes targeting students in high school and all levels of experience at the three participating institutions. This approach meets short-term objectives by providing educational opportunities in the present and longer-term objectives that will create a pipeline of students from which to recruit for in the future. Recruitment techniques incorporate methods and activities in three categories; events, media, and relationships.

Event recruitment are outreach activities such as Career/College Fairs, Black Hills Pow Wow, and the Lakota Nation Invitational and basketball tournament. A booth is set up displaying brochures, posters, information from the three participating universities, and service opportunities from the OSSPEEC program (Figure 3). These events are often well attended and provide motivational opportunities for students thinking about math, science, and engineering.

![Figure 3 Recruitment at the OLC Career Fair](image)

Media recruitment activities for the OSPEEC program have included: posting information and flyers, maintaining a website, newsletter write-ups, local news articles and releases, and distributing brochures to inquiring students. The website is convenient for displaying past and current projects with more detailed information on the students that participated and the outcomes of different projects. The information from these sources is distributed throughout the academic year at various department and university events, such as prospective student visits and events sponsored by the Tiospaye Scholars program.

Organizational relationships have also been established to improve recruitment success. These include SDSMT’s Office of Multicultural Affairs and Tiospaye Scholars program, SDSU’s American Indian Education and Cultural Center, and participating departments at OLC, such as the Applied Science Program. These relationships have the capability to reach interested students as opportunities arise, such as when they make a decision to pursue a particular subject or project area, which results in targeted and direct referrals from the participating institutions.
Closely related to the organizational relationships are development and co-teaching of engineering courses as part of the OSSPEEC program. These courses provide potential transfer students from OLC the opportunity to get to know the instructors and the subjects for better informed career and educational choices. The seven students retained from OLC (Table 2) participated in multiple OSSPEEC course deliveries from instructors at each of the institutions and it is believed these relationships contributed to their continued participation in the program.

**Discussion**

Based on the recruitment activities that have taken place during the past two years of the OSSPEEC program, several observations have been made. While the largest number of student contact results from the “events” category, the correspondence is informal and the level of conversation is at a more general level, which may not truly engage or interest a prospective student in the subject or internship opportunity. The difficulty or absence of following up with these students does not provide a second opportunity to answer questions or provide information that could encourage a student to pursue the idea further.

“Media” recruitment is certainly a required component to the efforts of any project targeting interested and motivated students. It is the author’s belief that in addition to the content of the paper and electronic material, marketing is equally important. Ensuring this information is distributed and reaches a large audience at each of the three participating institutions has contributed to more inquiries to the program. In addition, it is an efficient way of distributing information through many different avenues.

Relationships established as part of the OSSPEEC program have been the most successful in recruiting students. Interactions with students at OLC from classroom and project activities have led to the recruitment and retention of nine students from Table 2, which represents approximately 35% of the student cohort from the three institutions through Year 2 of the program. These relationships have identified good advising and mentoring fits for students, resulting in increased retention in the program. It is difficult to determine if and how much the other recruiting efforts described above have contributed to these numbers.

Despite the additional opportunities that have been created through the partnerships described above, recruitment and retention of students continues to be an area of concern for the investigators. A second concern is related to the small proportion of Native American students pursuing engineering versus science. In years one and two of the project we have had difficulties identifying Native American engineering students at SDSMT and SDSU to participate in the project. We are unsure as to whether there are more abundant internship opportunities for engineering students or if the population of Native American science students is greater than the population of Native American engineering students at SDSMT and SDSU. However, given the relatively small Native American population and relatively large set of opportunities

Retention of new students at OLC and first-year matriculating students at SDSMT and SDSU
will be a key factor towards achieving a sustainable increase in Native American graduating rates in engineering. A significant matriculation challenge to be addressed is related to recent changes in the awarding of financial aid through PELL grants. The majority of OLC students in engineering require six semesters of mathematics before calculus I, which is needed for a significant portion of entry-level engineering coursework. This has resulted in students using the majority of their PELL to reach the junior year of civil or geological engineering. There are few other funding mechanisms for first-generation students without outstanding academic success to access. This has led to 100% of OLC students who have completed an AA pre-engineering degree at OLC in 2011 to return to OLC to complete a BS Natural Science degree because of the lack of programs and support mechanisms to continuing their engineering degrees at SDSMT / SDSU. The authors are concerned this trend will continue, impacting recruitment and retention numbers for the remaining 2\frac{1}{2} years of the OSSPEEC program.

**Future Initiatives**

One improvement to the recruitment activities described above is to enhance the OSSPEEC program website. Content under consideration includes recent recruiting events, completed projects, and updates on past and current participants. With a more comprehensive database of projects, and students, a higher likelihood of overlapping with prospective student’s interests will be achieved.

A second initiative includes increasing the level of electronic marketing that is currently done. A comprehensive website can be distributed easily through targeted messages to the Office of Multicultural Affairs, the Tiospaye Scholars Program, and other correspondence that is currently taking place. The authors are considering other outlets such as Facebook to reach out and communicate with students.

The easiest way to recruit students the authors believe, however, is for past participants of the program to encourage their friends and peers to apply, which depends on their overall experience. Adjustments to the service-learning, research, and extracurricular components of the programs are continuously being made, based on feedback and input from the students. One such area is the organization and planning of summer activities of the multifaceted program that includes students, mentors, and advisors from three higher education institutions.

Finally, the concern over support mechanisms for Native American students transferring to SDSMT or SDSU to complete their engineering degree will be addressed by continuing to identify partnerships and pursuing additional funding to enhance the critical infrastructure that has been established through the OSSPEEC program.

**Summary**

The OSSPEEC program objectives include delivering pre-engineering education courses at OLC to increase the enrollment and success of students transferring to 4-year bachelor degree programs in science and engineering. The first two years of the grant have established strong
partnerships and created many service-learning and research opportunities for undergraduate students. Despite these opportunities, the investigators have recruited 27 students from OLC, SDSU, and SDSMT, representing 77% of the targeted recruitment numbers. To improve these percentages, the investigators have evaluated their recruitment methods and have identified focus areas that include expanded electronic media sources and enhanced student experiences. The most successful recruitment method for this program has come from organizational relationships established at each of the three institutions and groups off campus. Traditional recruitment methods with media and participation at regional events will continue and is also considered an important component to the broad recruitment initiative.

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant No. 1037797, which the authors gratefully acknowledge. The authors would like to thank Oglala Lakota College, Thunder Valley Community Development Corporation, and the University of Colorado Boulder for their project support.

References

Globalizing Engineering Education: A Review of Academic Cultures on Both Sides of the Atlantic Ocean

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Abstract

This paper reviews different perspectives of globalizing engineering education. It discusses historical, geopolitical, and socio-economic imperatives for global engineering thinking and global engineering education. The discussion observes the reality that while the concept of globalization of engineering education may be a recent thought in the US, global engineering thinking has been around longer elsewhere. The paper also discusses the historical and socio-economic imperatives that precipitated the globalization of engineering education in post-colonial Africa.

The discussion navigates through time and three continental cultures in Europe, Africa, and the United State to articulate that globalization of engineering education is a practical necessity, and that it is already in progress. Effectively, the current discussion in the US about globalization of engineering education is in part derived from the recognition that, large or small, the world is one. It is also an acknowledgement that the health of the US economy and world partners stands to benefit significantly by embracing a globalized view of engineering solutions.

Like other professionals, engineers are problem solvers or solution makers. In this paper, globalization of engineering education is discussed by (a) identifying the counterproductive views on globalization of engineering education, and (b) defining the essential features of a practical globalized engineering thought and the engineering education needed to support it.

The implication of globalized engineering education is to recognize that while a society can sell products to other geopolitical entities, it is more practical to try to sell products that other entities genuinely need or want. For the purpose of this paper, the author discusses selected examples of engineered products that have had global implications. Examples of such products include the bicycle, Land Rover (motor vehicle), engineered engineering education, and the cell phone, to name only a few. The paper concludes with an invitation to follow up on the thought that even though global engineering perspectives may be taking hold spontaneously, globalization of engineering education needs to be more intentional and that the time for developing a platform for an intentionally globalized engineering education is now.
Engineering Education Elsewhere
An Engineering Curriculum at the University of Dar-Es-Slaam

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Colorado State University-Pueblo

Abstract

There has been an appreciable discussion in the US about why globalizing engineering education is important. Following up on the public discourse regarding globalization of engineering education, the author considered the imperative of sharing information about what is happening elsewhere in order to broaden the perspectives of the discussion. Most of the discussion about globalizing engineering education has been about making a case that it is important, and regarding ideas on how to implement it. This paper is not a discussion about globalization of engineering education, nor is it a presentation in support of or against globalization. The purpose of this paper is to provide information about existing engineering programs elsewhere and, may be, help to guide the current discussion with the perspectives of the objects of globalization. The scope of this paper is limited to one case study about an engineering college in Tanzania.

In keeping with the purpose of this paper, the author will present the engineering curricula configuration in the College of Engineering and Technology (CoET) at the University of Dar-es-Salaam (UDSM). The University of Dar-es-Salaam is a young public university of the United Republic of Tanzania. The author believes that this paper is relevant to the current discussion on globalization of engineering education because the institution and college have been objects and subjects of globalization of education and engineering education during the course of time. When other geopolitical entities were globalizing education, UDSM was an object of globalization. At that time, the institution strived to define its mission and sought to maintain its local identity. Years after its inception, the university has relatively matured and seeks a place in the world stage. It is globalizing!
Infusing Sustainability into an Operations Planning and Control Class through Analyzing the Nissan LEAF Electric Car

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Abstract

Today’s engineer faces a complex variety of challenges in the modern global business environment. Awareness of these challenges should be an essential component of any engineering curriculum, particularly those focused on production planning and supply chain design. The Operations Planning and Control course is a dual listed class for both the BSIE and MSISE with Operations Research EN471-571 and Stochastic Systems Engineering EN365 as pre-requisites. In this course students learn about production and supply chain management with a focus on manufacturing. This course traditionally has a semester project accounting for 25% of the total grade. In this project different challenges of production and supply chain management are addressed by the students.

Sustainability is one of those current challenges students not only need be aware of but also need to have a thorough understanding. Sustainability concepts have not been infused into traditional courses and design projects. Moreover, traditional research experiences based on existing curriculum do not include practical, hands-on projects dealing with sustainability in a production process. Therefore, a group of master students is proposing to perform a Forecasting and an Aggregate planning analysis for the new Nissan LEAF electric car. Today Nissan is globally directing all its energies to different initiatives and one among their recent development is the introduction of the Nissan LEAF electric car to the market, marking an initial step towards realizing a sustainable society. The LEAF is a newly launched Zero Emission Vehicle with zero tail pipe thereby making it a “green car”. The LEAF is built with a XTRONIC engine\(^1\) which is developed and patented by Nissan.

The students decided to select this type of car because of their awareness about the need for zero emissions vehicle category. By developing this project, they will build the skillset required to support sustainable engineering practices and discuss the importance of integrating principles and practices into the design and analysis of products and processes.
**Keywords:** Nissan LEAF, Sustainability, Forecasting, Aggregate Planning, Manufacturing, Logistics, Automobile, Sales, Benchmarking, Battery Electric Vehicle, Hybrid Electric Vehicles, Engineering Management Education

**Introduction**

This paper presents the work of forecasting and aggregate planning of the Nissan LEAF there by developing an integrated sustainable model. The collaborative environment proposed by the investigators allows for concurrent development of the Nissan LEAF capable of addressing identified needs in the realm of global sustainability. The best practice to introduce sustainability is by reducing the carbon emissions which utilize cleaner, greener, more renewable electric grid to power transportation. Grid-rechargeable cars can attain the end goal of zero-emissions and ensure fuel price stability.

Improvements in energy density and price reductions for advanced batteries are evidence of that which is achievable with large format car batteries. Even without massive investment from government, advanced batteries for cars have developed far more rapidly than fuel cell/hydrogen technology. Key elements of this Battery Electric Vehicle (BEV) such as the Battery life and its performance in terms of sales will be observed in this paper and taken into consideration for the Forecasting and Aggregate Planning of the vehicle. As a zero emission vehicle, by developing this project, necessary skillset required to support sustainable engineering practices can be applied towards integrating principles and practices into the design and analysis of products and processes.

**Curricular Context**

The Operations Planning and Control\(^2\) (OPC) course (EN477) is one of the core courses in the Bachelor of Science in Industrial Engineering (BSIE) being offered in the spring semester of the senior year. At the time the undergraduate students take this OPC course; they have gone not only through all the Math and Physics classes but also through the core courses for the BSIE.

A parallel OPC course (EN577) is also a core course for the Master of Science in Systems and Industrial Engineering (MSISE). The OPC course uses the basic mathematical and modeling tools acquired for the students on the other core courses and applies them to address manufacturing planning and scheduling issues. Moreover, the OPC course plays an integrative role for BSIE and MSISE students.

The OPC course not only makes use of the basic set of analytical tools\(^3\) acquired by the students in the other core courses but also develops new concepts regarding the principles and practices of
production planning and control, inventory management, scheduling, and forecasting. Therefore, one of the most important outcomes of this course is to encourage students to apply their analytical skillset to solve real problems found in Industrial Engineering. Table 1 enumerates the general topics discussed in both courses (EN477 and EN577) and presents the outcomes by topic.

Table 1. Operations Planning and Control course topics and outcomes.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Suggested No. of Hours</th>
<th>Course Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategy and Competition</td>
<td>3</td>
<td>1, 3</td>
</tr>
<tr>
<td>Forecasting</td>
<td>6</td>
<td>1, 4</td>
</tr>
<tr>
<td>Aggregate Planning</td>
<td>3</td>
<td>1, 4</td>
</tr>
<tr>
<td>Deterministic Inventory Control</td>
<td>4.5</td>
<td>1, 3</td>
</tr>
<tr>
<td>Stochastic Inventory Control</td>
<td>6</td>
<td>1, 3</td>
</tr>
<tr>
<td>Push and Pull Production Systems</td>
<td>6</td>
<td>1, 3</td>
</tr>
<tr>
<td>Operations Scheduling</td>
<td>6</td>
<td>1, 3</td>
</tr>
<tr>
<td>Supply Chain Management</td>
<td>3</td>
<td>1, 3</td>
</tr>
<tr>
<td>Projects</td>
<td>3</td>
<td>1, 2, 3, 4</td>
</tr>
<tr>
<td>Exams and discussions</td>
<td>4.5</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total hours</strong></td>
<td><strong>45</strong></td>
<td></td>
</tr>
</tbody>
</table>

The outcomes are defined accordingly to the general engineering outcomes (a – k) established by the Accreditation Board for Engineering and Technology (ABET). The outcomes are:

1. An understanding of the basic tools of operations management (e, k)
2. The ability to utilize the varied skills of team members in providing a solution to an operations management problem (b, c, d, g)
3. Ability to recognize the proper operations management technique for an operations problem and recognize the impact such techniques have on business and society (b, f, h, j, l, m)
4. Experience in applying mathematical techniques to practical operations management problems (a, e, i)

In the topics “Forecasting” and “Aggregate Planning” (9 lecture hours in total), the students discuss the most important analytical tools used to perform forecasting and aggregate planning in the context of operations planning for manufacturing. Initially, an expository discussion of several important issues on the topics is presented. Next, the most popular methods for
forecasting and aggregate planning are discussed and examples are developed and solved in class.

**Approach**

The preliminary approach to pursue this project was by collecting the required data for performing a Forecast and Aggregate Plan of the sales figures (in numbers) of the Nissan LEAF’s sold that can be collected either on a monthly, quarterly or yearly basis. Refer Table 3 below. Several sources such as the NISSAN LEAF’s website, the annual reports of Nissan and other third party agencies were referred to collect the past sales figures of the Nissan. The below data represents monthly sales of the Nissan LEAF from December 2010 to February 2013.

Since the Nissan LEAF was introduced in the United States on December 2010, sales figures from the date of its introduction to the market have been collected. In order to calculate an accurate forecast, we would require at least data from 4 previous periods. Considering that the product was newly introduced in the market, based on the data of sales figures available, it would be inappropriate to justify the correct forecasting and aggregate planning for the vehicle.

Our alternative approach to pursue this study would be by determining the previous sales of all Battery Electric Vehicles (BEV’s) and Hybrid Electric Vehicles (HEV’s) during the 2011 and 2012 and compare them with the percentages of market share of the Nissan LEAF. Based on the assumptions that the Nissan LEAF had rectified all the problems encountered during its past sales, we presume optimistic sales figures and proceed to calculate the forecasting and aggregate plan.

As there are several methods of calculating Forecasts & Aggregate Plans, key parameters such as $(\alpha, \beta & \gamma)$ will be assumed based on the nature of the data. Softwares such as Minitab and Excel were used in developing the trend series and calculating the forecast and demand.

The Table 2 below, details the different Forecasting methods that can be adopted for the respective trend series based on the data available.

<table>
<thead>
<tr>
<th>Type of series</th>
<th>Method to be adopted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stationary Series</td>
<td>Moving Average Method or Exponential Smoothing</td>
</tr>
<tr>
<td>Trend based Series</td>
<td>Linear Regression or Holts Method</td>
</tr>
<tr>
<td>Trend based Series with seasonality</td>
<td>Winters Method</td>
</tr>
</tbody>
</table>
Table 3. Nisan LEAF Sales Figures

Data Analysis

The Table 4\textsuperscript{9} below represents the data of sales figures for the last two years (2011 & 2012) from all BEVs and HEVs and are compared to the sales figures of the Nissan LEAF. Summation of monthly sales figures for the BEVs and HEVs were calculated and the ratio proportion of the Nissan LEAF from this category was identified as the market share.

\[ \frac{\sum_{i=1}^{24} S_i}{\sum_{i=1}^{24} (S_i + T_i)} \]  

where \( i \) is the number of periods from January 2011 to December 2012 i.e. 24 months.

Table 4. Sales Figures for the BEV and HEV cars.

<table>
<thead>
<tr>
<th>Month</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>N.A</td>
<td>87</td>
<td>676</td>
<td>650</td>
</tr>
<tr>
<td>February</td>
<td>N.A</td>
<td>67</td>
<td>478</td>
<td>653</td>
</tr>
<tr>
<td>March</td>
<td>N.A</td>
<td>298</td>
<td>579</td>
<td></td>
</tr>
<tr>
<td>April</td>
<td>N.A</td>
<td>573</td>
<td>370</td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>N.A</td>
<td>1142</td>
<td>510</td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>N.A</td>
<td>1708</td>
<td>535</td>
<td></td>
</tr>
<tr>
<td>July</td>
<td>N.A</td>
<td>931</td>
<td>395</td>
<td></td>
</tr>
<tr>
<td>August</td>
<td>N.A</td>
<td>1362</td>
<td>685</td>
<td></td>
</tr>
<tr>
<td>September</td>
<td>N.A</td>
<td>1031</td>
<td>984</td>
<td></td>
</tr>
<tr>
<td>October</td>
<td>N.A</td>
<td>849</td>
<td>1579</td>
<td></td>
</tr>
<tr>
<td>November</td>
<td>N.A</td>
<td>672</td>
<td>1539</td>
<td></td>
</tr>
<tr>
<td>December</td>
<td>19</td>
<td>954</td>
<td>1489</td>
<td></td>
</tr>
</tbody>
</table>
Among the 725,289 BEV & HEV vehicles sold, the Nissan LEAF holds a share of 19,483 vehicles which is equivalent to a market share of 2.68%.

The trend based analysis for the BEV& HEV vehicles is observed in the Figure 1 below.
Forecasting

Demand forecasting\textsuperscript{10} is the activity of estimating the quantity of a product or service that consumers will purchase. Demand forecasting involves techniques including both informal methods, such as educated guesses, quantitative methods and the use of historical sales data or current data from test markets. Demand forecasting may be used in making pricing decisions, in assessing future capacity requirements, or in making decisions on whether to enter a new market.

A growing trend was observed in the sales figures of BEV & HEV vehicles and hence linear regression method was adopted to calculate the forecast of the Nissan LEAF based on the ratio of market share. The calculated benchmarked figures of the forecast for Nissan LEAF for the next 6 months of 2013 are shown in Table 5.

Table 5. Six-months forecasting for the Nissan LEAF.
Aggregate Planning

Aggregate planning\(^{11}\) is an operational activity that does an aggregate plan for the production process, in advance of 2 to 18 months, to give an idea to management as to what quantity of materials and other resources are to be procured and when, so that the total cost of operations of the organization is kept to the minimum over that period.

Table 6 shows the different Aggregate Planning methods that can be adopted based on the type of the product produced.

Table 6. Aggregate Planning methods.

<table>
<thead>
<tr>
<th>Strategy Type Adopted</th>
<th>Type of Aggregate Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant Production Rate</td>
<td>Keeping Production and workforce constant</td>
</tr>
<tr>
<td>Chase Method (Zero Inventory)</td>
<td>Minimizing to zero inventory (to the possible extent)</td>
</tr>
<tr>
<td>Mixed Strategy</td>
<td>Using the above two methods based on Management’s purview to keep costs low.</td>
</tr>
</tbody>
</table>

Considering the fact that vehicles have several parts to be assembled, we assume a simple model where aggregate planning for the vehicle’s battery is considered. By this assumption of 1 battery per vehicle, we can understand the aggregate plan for the entire vehicle. A calculation model was developed at Argonne National Laboratory\(^{12}\) (Argonne) for estimating the manufacturing cost and performance of batteries for electric driven vehicles. The design models provided were used to estimate the annual materials requirements for manufacturing the batteries being designed. This facilitated the next step, which was to extend the effort to include modeling of the manufacturing costs of the batteries.

On broad terms, the manufacturing cost\(^{12}\) of a battery pack are calculated with input from the design information. The design model determines the annual materials and purchased items requirements. The manufacturing cost is then added to these materials costs, along with a warranty cost, to reach the unit cost of a single battery pack. The total manufacturing cost are obtained by summing the process cost with several other additional costs of operating the manufacturing facility.\(^{12}\) A few examples of these additional cost include launch costs, working capital, variable overhead, general, sales, administration (GSA), research and development, depreciation, and profit.\(^{12}\)

Since our Aggregate Planning is done at the baseline plant, key parameters as shown Table 7 below has been considered in the aggregate planning. Further expenses and additional costs as
discussed above have not been taken into consideration as they vary from one manufacturing plant to another.

Table 7. Aggregate Planning for the Nissan LEAF.

<table>
<thead>
<tr>
<th></th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Days</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>180</td>
</tr>
<tr>
<td>Units produced per worker per day</td>
<td>0.39</td>
<td>0.39</td>
<td>0.39</td>
<td>0.39</td>
<td>0.39</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>Predicted Demand</td>
<td>1,142</td>
<td>1169</td>
<td>1196</td>
<td>1222</td>
<td>1249</td>
<td>1275</td>
<td>7253</td>
</tr>
<tr>
<td>Required Workforce</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Available Workforce</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Workers Hired</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Hiring Costs</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Workers Fired</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Firing Costs</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Used Workforce</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Workforce Costs</td>
<td>$2,160,000</td>
<td>$2,160,000</td>
<td>$2,160,000</td>
<td>$2,160,000</td>
<td>$2,160,000</td>
<td>$2,160,000</td>
<td>$12,960,000</td>
</tr>
<tr>
<td>Batteries Produced</td>
<td>1755</td>
<td>1755</td>
<td>1755</td>
<td>1755</td>
<td>1755</td>
<td>1755</td>
<td>10530</td>
</tr>
<tr>
<td>Inventory</td>
<td>613</td>
<td>1199</td>
<td>1755</td>
<td>2291</td>
<td>2797</td>
<td>3277</td>
<td>11935</td>
</tr>
<tr>
<td>Holding Costs</td>
<td>$15,325</td>
<td>$29,975</td>
<td>$43,950</td>
<td>$57,275</td>
<td>$69,925</td>
<td>$81,925</td>
<td>$298,375</td>
</tr>
<tr>
<td>Shortage Costs</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td><strong>TOTAL COSTS</strong></td>
<td>$2,175,325</td>
<td>$2,189,975</td>
<td>$2,203,950</td>
<td>$2,217,275</td>
<td>$2,229,925</td>
<td>$2,241,925</td>
<td>$13,258,375</td>
</tr>
</tbody>
</table>

The key assumptions made in this project are that forecast of the Nissan LEAF is the same as the demand of the batteries. The manufacturing plant operates throughout the month, with its full capacity of workers, on a 3 shift basis, with a capacity to produce 0.39 units of battery per worker per day. A constant workforce strategy has been considered to perform the aggregate planning, as inventory has to be held to meet the demand. Further, due to the scarcity of skilled workforce, they have to be retained as hiring and firing of workforce would be a constraint.

The project deliverables should showcase how the battery of the Nissan LEAF is part of a sustainable supply chain (evolvable, scalable, environmentally-friendly, strategic). The project details the strategic issues on forecasting a new, ground-breaking technology for car manufacturing. Also, it helps the distributors by informing them about the consumer demand.

**Directions for Future Research and Preliminary Conclusions**

Our preliminary conclusions on this paper suggest that there is a possibility for the Nissan LEAF’s market share to rise further from its existing position. Since the HEV’s have been in the market for a longer period than the BEV’s, the present sales figures of the BEV’s are in a transient phase and can be expected to grow higher to support sustainability in the environment.
While the LEAF dominates the market share among all BEV’s, further improvements can be made to alter its position in the electric vehicle spectrum. Our literature review on the LEAF has evinced a ramp up in its yearly production, reduction of the sale prices and also setting up of a new manufacturing in the United States at Smyrna, Tennessee. The manufacturing plant is also expected to use renewable energy to charge the Nissan LEAFs that will be produced are positive signs of infusing sustainability to the local environment there by realizing a step towards a sustainable society.

The curriculum on Operations Planning & Control emphasizes the unique conditions of integrated sustainability and provides students with practical and conceptual knowledge of processes and techniques needed to create scalable supply chain networks based on sustainable infrastructures and energy management. The addition to the realm of engineering conceptual knowledge will create a highly skilled, competitive workforce capable of understanding global forces driving complex environmental systems.

The paper addresses the important concepts of forecasting and aggregate planning that can be useful to understand how automobile manufacturers provide logistics companies with annual forecasts of their monthly shipping volumes from various origins to different destinations. As the logistic companies jointly operate pools of cars to transport automobiles, the forecasting data from the automobile manufacturers would help in preparing planning details for their logistics with respect to optimizing time and proper scheduling.

References

All Aboard: Engineers for an MS in Railroad Engineering

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Department of Engineering
Colorado State University - Pueblo

Abstract

This paper describes a set of requirements for potential graduate students applying to a Master of Science in engineering program with an emphasis on railroad engineering (MSE Railroad Engineering) to be offered at Colorado State University–Pueblo (CSU-Pueblo). Railroad engineering can be defined as a multidisciplinary engineering field that addresses technical problems in railroad industry. Roughly, the field includes parts of mechanical, electrical, civil, and industrial engineering. This work addresses the application requirements for students who have already earned a bachelor of science (BS) degree in a traditional engineering discipline or a BS in engineering with specialization in mechatronics (BSE-Mechatronics) degree. The MSE Railroad Engineering program will be offered starting next fall.

Introduction

The MSE Railroad Engineering program is a 33-credit graduate program that includes fourteen credits of core courses, nine credits of courses (minimum) in a track, and a number of elective courses. The track component is defined as an additional set of courses (nine credits or more) selected by the student and the student’s advisor to advance the professional and/or educational goals of the student\(^1\). The students in the program can select a thesis or a non-thesis option. When finished, the thesis option students will be better prepared for work in a research and development environment. The core courses are: EN 511 Structural Engineering, EN 531 Railroad Power Systems, EN 551 Fleet Management, EN 552 Vehicle Dynamics, and EN 593 Graduate Seminar. A short description of these courses is presented in Jaksic et al\(^1\). Students can choose their elective MS-level courses from mechatronics, industrial and systems engineering, mathematics, chemistry, and/or MBA. Students have opportunities to engage in research through graduate projects or MS theses. An assessment plan describes a set of program objectives which guide student learning outcomes assessed by using associated rubrics.

While the MSE Railroad Engineering program is multidisciplinary, it is expected that the incoming graduate students possess knowledge and skills obtained mostly from traditional engineering disciplines. In this work, the leveling requirements for five groups of incoming students from electrical, mechanical, civil, industrial, and mechatronics engineering are
described and justified. The results of this study will serve as a guide to prospective students and their companies so they can budget an adequate amount of time to complete the program. Also, the results may be used for prospective students to complete the leveling courses at their home institutions before applying to the MSE Railroad Engineering program at CSU-Pueblo.

Program Justification

The role of railroads in the nation’s development is well recognized and described in history. With the sustained population growth and a highway system operating almost at capacity one can stipulate that the role of railroads will change accordingly. Trains will take a more prominent role in transporting passengers and freight as the population grows.

The MSE Railroad Engineering program at CSU-Pueblo was designed in collaboration with experts from Transportation Technology Center, Inc. (TTCI) to serve the needs of the railroad and railroad-related industry in Pueblo and the region. The graduates from the program will be able to infuse new ideas in the railroad industry and rejuvenate its aging engineering population. An immediate goal of the program is to address the needs of TTCI.

In the US, there are only a handful of institutions that offer courses in railroad engineering at the graduate level. For example, University of Illinois at Urbana-Champaign offers railroad engineering courses at the undergraduate and the graduate level\(^2\). The university is a part of the National University Rail Center\(^3\) (NURail) which includes seven universities and institutes predominantly from Midwestern states (Michigan, Illinois, Indiana, Kentucky, Tennessee, and Massachusetts). “The primary objective of the NURail Center is to improve and expand rail education, research, workforce development, and technology transfer in the US\(^3\).” The center is in its first implementation year and it is geographically far from Colorado. Thus, for the prospective graduate students from the region who are interested in railroad engineering the MSE Railroad Engineering at CSU-Pueblo presents an attractive option. In addition, the established collaboration with TTCI, which has some of the best railroad laboratory facilities in the world, makes this option even more enticing.

Requirements

An ideal applicant would have a general engineering degree, a positive attitude toward other engineering disciplines, some experience in the railroad industry, and an ability to thrive in a multidisciplinary engineering environment. Such an applicant would also have an adequate background to enable him or her to finish the program requirements in one year (non-thesis option) or one and a half years (thesis option). Currently, the graduates from our Bachelor of Science in Engineering with specialization in Mechatronics (BSE-Mechatronics) program have
the adequate background to complete the BSE Railroad Engineering program in one year since they don’t need to take additional leveling courses.

**General Requirements**

Admission to the MSE Railroad Engineering program includes admissions to graduate studies and then to the program. Admission requirements for regular status to graduate studies include:

- A baccalaureate degree from an institution accredited by the regional accreditation agency (or equivalent);
- The minimum undergraduate GPA of 3.000;
- Satisfactory scores from a standardized admissions test;
- For international students whose native language is not English, a minimum score of 500 on the Test of English as a Foreign Language (TOEFL) paper based exam, a minimum score of 173 on the TOEFL computer based exam, a minimum score of 61 on the TOEFL internet based (iBT) exam, a minimum score of 80 on the Michigan Test of English Proficiency, or a minimum band score of 5.0 on the international English Language Testing System (IELTS) test is required for admission.

- A completed admissions file; and
- Any additional requirements for the selected program, including completion of leveling courses to correct undergraduate deficiencies.

However, if some of the admission requirements are not met, the student could be admitted under conditional status.

**Discipline-Specific Requirements**

Admission requirements for regular status to the MSE program include:

- A quantitatively based baccalaureate degree from a regionally accredited college or university (Students with non-quantitatively based baccalaureate degrees may be admitted conditionally, but additional prerequisites may be required.); and
- Satisfactory scores from a Graduate Record Examination GRE (minimum 1000 old score or 300 new score); and
- Satisfactory completion of all the leveling courses for the program.

Pre-requisites (leveling courses) required for admission to the program with regular status are mostly covered in undergraduate engineering programs. The following undergraduate courses constitute the list of leveling courses: EN 103 Problem Solving for Engineers, EN 343 Engineering Economy, EN 365 Stochastic Systems Engineering, MATH 126 Calculus I, MATH 224 Calculus II, PHYS 221 Calculus-Based Physics I, PHYS 222 Calculus-Based Physics II, EN
211 Engineering Mechanics I (statics), EN 212 Engineering Mechanics II (dynamics), EN 231/L Circuits, EN 263 Electromechanical Devices, and EN 360 Controls I. Note that some of these courses may have pre-requisites of their own. Applicants who have completed a BS degree in a specific engineering discipline from a specific engineering program may not have completed all the leveling courses required.

**Discipline-Specific Programs of Study**

Flowcharts in Figures 1 – 4 show discipline-specific likely programs of study designed to meet the core course requirements for the MSE Railroad Engineering program. They don’t show the courses in tracks nor any elective courses required for completing the program since the selection of those courses depends on individual student’s interests and goals. Engineering disciplines analyzed here are Mechanical Engineering (ME), Electrical Engineering (EE), Industrial Engineering (IE), and Civil Engineering (CE). BSE-Mechatronics graduates meet all leveling requirements so a flowchart is not produced for them.

In figures below, blocks with dashed border lines represent leveling courses while blocks using italics represent courses that some universities may offer in their undergraduate programs. Solid arrows connect pre-requisites or leveling courses to their core courses while dotted arrows connect co-requisite courses to the courses that depend on them.

According to the flowchart in Figure 1, ME graduates would require EN 260 Basic Electronics which is a co-requisite for EN 263 Electromechanical Devices. Both of these courses are then pre-requisites for EN 531 Railroad Power Systems, which is a core course. Also, ME curricula usually do not include EN 343 Engineering Economy. Some ME programs like University of Michigan and Carnegie Mellon University include EN 365 Stochastic Systems Engineering. For an ME graduate starting in spring it is possible to complete the program in three semesters.
MSE – Railroad Engineering Flowchart
Undergraduate degree - ME

Figure 1. Flowchart – Partial Program of Study for ME Graduates

MSE – Railroad Engineering Flowchart
Undergraduate degree - EE

Figure 2. Flowchart – Partial Program of Study for EE Graduates
Figure 3. Flowchart – Partial Program of Study for IE Graduates

Figure 4. Flowchart – Partial Program of Study for CE Graduates
Figure 2 is a flowchart showing a partial program of study for EE graduates. Some EE programs like University of Michigan and Vanderbilt University offer EN 263 Electromechanical Devices, while Vanderbilt University, Arizona State University, and MIT offer EN 365 Stochastic Systems Engineering course. Arizona State University offers EN 343 Engineering Economy as well. This suggests that EE graduates could complete the MSE Railroad Engineering program in one year.

According to Figures 3 and 4, IE and CE graduates lack depth in electrical engineering and controls required for the two core courses in the MSE Railroad Engineering program. These graduates would have to complete EN 260 Basic Electronics, EN 263 Electromechanical Devices, and EN 360 Controls I as leveling courses for two core courses, EN 531 Railroad Power Systems and EN 552 Vehicle Dynamics. While many CE programs require EN 343 Engineering Economy and/or EN 365 Stochastic Systems Engineering, some don’t. This means that some CE graduates would have to complete those courses as well. Figures 3 and 4 suggest that IE and CE graduates could complete the MSE Railroad Engineering program in one and a half to two years.

Summary and Conclusion

In this work a new MSE Railroad Engineering program was introduced and justified. Admission requirements to graduate studies and the program were articulated. Based on the leveling courses required, a discipline-specific set of partial programs of study is described and analyzed. Assuming non-thesis option, the results indicate that the BSE-Mechatronics and EE graduates have a good chance of completing the program in one year, ME graduates in one year to a year and a half, while the IE and CE graduates would likely take a year and a half to two years. The results of this work can be used by prospective students and their employers to help them plan their studies.

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Teaching of Composites Manufacturing Course into Manufacturing/Mechanical Engineering Technology Program

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Abstract
Composite materials are a class of material that offers numerous benefits when designing and manufacturing structures compared to traditional monolithic materials. Some of the key benefits include corrosion resistance, lower maintenance, higher strength to weight, higher stiffness to weight performance and freedom of design. These benefits result in products with improved life cycle cost, lower fuel consumption, higher payload capacity, reduced energy use, and decreased environmental impact. As a result, the aerospace, automobile and wind energy industries are making a major effort to incorporate an increasing number of composite materials into various components and structures. Many industries are directing their resources to reduce the environmental impact of their produced products and services. To remain competitive in the global economy, these industries to train engineering and technology professionals who understand the impact of their decisions on the environment and society. Thus, it is necessary to include composites manufacturing into manufacturing/mechanical curricula, especially at schools in regions of the country where significant light weight structure manufacturing industry exist. Many technology programs do not offer this type of information to their undergraduate students. This topic is has been applied into the current undergraduate mechanical engineering technology program curriculum at Metropolitan State University of Denver with regard to sustainable green manufacturing. This report focuses on all aspects of these newly developed course materials including course content and student feedback. Finally, the ABET process and the existing curriculum will be reviewed to identify barriers and inclusion of composites manufacturing course into current curriculum.

Introduction
Composite materials are a class of material that offers numerous benefits when designing and manufacturing structures compared to traditional monolithic materials. Some of the key benefits include corrosion resistance, lower maintenance, higher strength to weight, higher stiffness to weight performance and freedom of design. Due to their greater strength-to-weight ratio, the composites are widely used in various structures and components. There is a growing awareness among many manufacturing industries of the need to consider the economic, societal, and environmental performance. Demand for environmentally sustainable products and the advances in sustainable technology have become increasingly important components of engineering and engineering technology education. In order to be able to come up with environmentally sustainable products, lighter weight products need to be a part of the every engineering decision.
This includes every step, from the design phase until the product reaches to its end-of-life, and continues even after that, when the efforts to regain the material’s value may take place\(^1\). The engineering technology education program should reflect the needs and changes of today’s manufacturing industry and prepare young engineer technologists to meet the challenges of the competitive world of manufacturing. This paper presents how this new topic composites manufacturing has been applied in Metropolitan State University of Denver (MSUD). All aspects of these newly developed course materials including course content and student feedback will be presented.

**Integrating Composites Manufacturing Into the Manufacturing/Mechanical Curriculum**

The Engineering Accreditation Commission (EAC) of ABET program criteria for mechanical/manufacturing requires that programs demonstrate that students have proficiencies in five specific areas: 1) materials and manufacturing processes, 2) manufacturing systems design, 3) process, assembly and product engineering, 4) laboratory experience, and 5) manufacturing competitiveness\(^2\). Manufacturing engineering technology programs need to build on the manufacturing competitiveness criteria. Institutions pursuing accreditation must demonstrate that the program meets a set of general criteria. The students in the program must attain “an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability” (Criterion #3)\(^3\). ABET requirements already are addressing the issue of sustainability in Criterion #3 by listing the word “sustainability” as part of the general criteria for all engineering programs. This should also be considered for engineering technology programs. According to the National Academy of Engineering, the growing environmental crisis means that, “Engineering practices must incorporate attention to sustainable technology, and engineers need to be educated to consider issues of sustainability in all aspects of design and manufacturing”\(^4\). However authors are concerned for not including sustainable manufacturing into engineering technology curriculum. The successful integration of sustainability into engineering technology requires that students achieve an understanding of how various courses relate to one another. Because of the popularity and good employment potential of the composites industry, students from many engineering and technology majors want to take a composites class. However, many of these students only have room in their schedule for one or two elective courses. Therefore, the content of the composites class was built around the need to accommodate the diverse backgrounds of the students who would like to take the class and not require extensive prerequisite courses\(^5\).

Many composite courses taught in mechanical engineering and aerospace engineering programs focus on the design of composites with a heavy emphasis on the mechanics of laminate materials. Laminate design is math intensive and requires considerable time to develop properly. Therefore, these courses typical ignore the processing of composites (which includes the chemistry and the various processing methods). The course taught at MSUD and described
herein does just the opposite. The laminate design is treated briefly (only enough to give the fundamentals and provide student with the ability to converse intelligently with the designers). Therefore, the course described in this paper is a general course that might be considered a preliminary course to the more mathematical design course. That is exactly how we teach these course at MSUD where the course is taught in composites manufacturing.

**MET 390K Composites Manufacturing Course at MSU Denver**

The Composites Manufacturing course is designed to provide students with working knowledge in design, manufacturing and selection of fiber-reinforced composite materials for engineering applications. Students will be introduced to inspection, damage control and repair techniques as well as material handling, safety and environmental requirements. The course contains laboratory modules designed to provide hands on experience to emphasize practical aspects of the topics covered. Below are from the syllabus of the course:

**Specific, Measurable Student Behavioral Learning Objectives:**

Upon completion of this course the student should be able to:

1. Understand the theory of anisotropic elasticity.
2. Calculate materials properties depending on the structure configuration and reinforcement orientation
3. Determine the appropriate manufacturing process for a new product based on engineering analysis of the product requirements, basic components characteristics and factory operations.
4. Perform basic damage assessment and identify options for sustainability of fiber-reinforced composites.
5. Use a number of finishing techniques common to the fabrication of composite products.
6. Document laboratory team project work in a clearly written and well structured technical report.
7. Use rework and repair methods common to the fabrication of composite products.
8. Identify the health and safety issues and environmental regulations that currently relate to a composites manufacturing facility.

**Detailed Outline of Course Content (Major Topics and Subtopics) or Outline of Field Experience/Internship (experience, responsibilities and supervision):**

I. Introduction to Composite Materials
   A. Definition and Properties
   B. Type of composites
   C. Constituent materials
   D. Tooling
II. Physical Characterization Composite Materials:
A. Density  
B. FiberVolume  
C. VoidVolumeRatio(Porosity)  
D. Coefficient of Thermal & Moisture Expansion  
E. Glass Transition Temperature  
F. Anisotropy Elasticity

III. Pre-cure Manufacturing Processes  
A. Lay-up processes  
B. Openmolding, closemolding  
C. Resintransfermolding  
D. Spray-up processes  
E. Filament winding  
F. Pultrusion  
G. Prepreg lay-up autoclave processing  
H. Other processes

IV. Post-curing Processes  
A. Drilling  
B. Milling  
C. Turning  
D. Sanding  
E. Bonded Joint  
F. Assembly

V. Basics of Damage Assessment and Repairs

VI. Quality Assessment and Specifications

VII. Basics of factory operations  
A. Project planning  
B. Business of composites  
C. Recycling of composites  
D. Sustainability in composites

VIII. EPA Regulations and Recent Advances

Conclusion

Engineering technology education strives to produce graduates who are ready to perform at a high level immediately after receiving their degrees and who can achieve strong professional growth throughout their careers. There is no doubt that composite manufacturing will continue to be developing, be a benefit to society and improve the environment in various ways. We recognize the need for incorporating an environmental conscious course into our manufacturing curriculum. This paper focuses on all aspects of these newly developed composites.
manufacturing course materials including course content paper has highlighted the importance of infusing this course into current mechanical/manufacturing engineering technology curriculum in order to address current unsustainable practices in industry and society. The concepts/rules define the basic nature of composites, give easy-to-understand concepts that allow prediction of resin properties, outline the major factors for reinforcement fibers, and allow simple comparisons between composite manufacturing processes.

References

Computer Programming Project Requirement in Engineering Courses

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Abstract

I am a firm believer that actual computer programming, not just merely using an application program, is an extremely important learning and design experience for engineering students. Students typically take a programming course such as MATLAB early in their studies, but they rarely have to write a full code in many future engineering courses. Many courses have specific application programs and it is easy for students to think they are programming instead of just using an application program. Based on nearly 25 years of teaching experience, I think programming projects provide great value to overall engineering education experience. Students often do not like these projects at first, but many of them realize later that they accomplished a major task through design and hard work. This paper will discuss types of computer projects assigned in various courses and educational benefits of such assignments.

Background

After taking my required FORTRAN course during my undergraduate study at Penn State, I never had to use it in any of the other courses until one instructor in 1979 did something that was “shocking”, “unusual”, and “cruel”. Dr. E. E. Enscore of Industrial Engineering assigned a programming project on some production topic and mandated that each student had to hand in a code as a set of punched cards along with a report. The instructor then ran each student’s program one by one by shoving the cards into the hopper and assigned a project grade based on the report and his assessment of the performance of the code in FORTRAN. I remember getting an average grade on this assignment, but this course is the best learning experience in my memory. This project required struggling to remember FORTRAN and using it to do something that was much harder than any of the programming assignments in the FORTRAN course. This project also required sleepless nights at the computer center typing and retyping punched cards. Students had to think and work hard and deliver a product to the instructor by the deadline. Good time management skills to use scarce mainframe computer resources had to be learned over few weeks. The program either worked or it did not as there was no middle ground. I remember hating the project initially, but I later realized that the project gave a reason for taking
the programming class as well as making students to do something meaningful with it. I felt like I really designed something and I also learned the material very well due to enormous time spent on it while programming. I remember deciding right there and then that Dr. Enscore’s method was very effective and that I would follow his method in most of the courses I would teach in the future as an instructor myself. I had another similar learning experience later at Virginia Tech during my graduate studies, but most courses only used computer as a calculator not utilizing its full potential.

**Project Description**

A typical project is worth about 20% of the final grade. Most of the students succeed in these projects although many are terrified at the beginning. Some students will not take my class to avoid this “headache”. Students often react by saying “I have not had to program in MATLAB since I took it” and I counter by saying “Why did you take it if you are not going to use it” and “Don’t you think you will be better off at it if you use it more?” I generally maintain an evolving “sink or swim” attitude regarding code development and tell students they should be able to do it right by trying hard enough. I start by sounding very tough, but I later ease up. I find tutors for students and I help myself at times. I spend several lectures on hand calculations related to the project and provide certain key code segments that involve special MATLAB (FORTRAN in the past) features. Students are expected to translate and integrate formulas and other hand calculations into a coherent final product. Programming is never easy and that is another lesson they learn.

Projects always require interactive data input with or without a GUI. Error trapping is a fundamental requirement in the input process. Students learn to reject impossible inputs such as negative probability values and feed rates that exceed the limits on a machine. Most projects require some combination of a search algorithm (often bubble sort) and/or Monte-Carlo simulation using random variables. A well written report with a good flow chart is always required. Students email the codes and turn in a hard copy of the report on due date. I then run each code one by one and make initial assessment. Some codes do not work at this stage and I allow them to fix and resubmit the codes at a loss of one letter grade. Dr. Enscore did not allow any resubmissions in 1979, but he had to deal with a mainframe using punched cards.

**Typical Projects**

1) “Computerized Equilibrium Calculations” in *Engineering Mechanics I*: Students enter inputs to a problem and the program gives the desired results. This project can be done by hand, but it is more valuable this way. Student’s programming skills are enhanced and the results are always correct.
2) “Computerized Orbital Mechanics Calculations” in *Engineering Mechanics II*: The text has a section on orbital mechanics. The program uses inputs and other constants to calculate desired outputs.

3) “Monte Carlo Simulation to identify the distribution of the Internal Rate of Return (IRR) in a Stochastic Cash Flow Problem with Random Project Duration” in *Engineering Economy*: A cash flow profile with random cash flows and random duration is simulated to collect data on various observations of the IRR. The results are compared against a commercial package (@RISK) which is easy to use.

4) “Metal Cutting Parameter Optimization for Turning Operations” in *Manufacturing Processes*: A search program finds optimal cutting speed and feed to minimize part production cost subject to a number of nonlinear operating constraints on an engine lathe.

5) “First Stage Reliability Calculation of the Falcon Heavy Launch Vehicle Using Analytical Methods and Monte-Carlo Simulation” in *Quality Control & Reliability*: This project is in the appendix as an example.

6) “Economic Evaluation of Single Machine Sequencing Rules” in *Production Planning and Control*: A static single machine case is evaluated under several dispatching rules to optimize various objective functions.

7) “Critical Path Simulation” in *Project Planning and Control*: Random activity times and other relevant data are inputs to this program. Project involves simulation of the network to derive the probability distribution of the critical path.

8) “Creation of MPS formatted data files to solve one dimensional Cutting Stock Problem at the ABC Rail Corporation” in *Operations Research*: This totally realistic project taught students the value of operations research in a case of one dimensional cutting stock waste minimization problem. A different linear program needs to be written for each new demand mix (lengths to be cuts and quantities) and available rails (40’, 80’, 100’ and quantities). The company manufactures frogs to use in railroad switches. The code writes out MPS (industry standard) formatted linear program that software LINDO can read and optimize. The model is very hard and error prone to write manually even for small (but not toy) problems. This project automated model creation, but did not solve the model. Our program was able to tie with the foreman who was somehow able to figure out the right decisions for most cases. Our O.R. students with no rail cutting experience were able do as well as the production foreman with 25 years of field experience.

9) “Single Facility Minimum/Maximum Sum Problem with random weights” in *Facility Planning & Design*: This project is about finding optimal facility locations with random demands. As usual, it involves sorting and simulation approaches.

10) “Single Server Queuing System Simulation” in *Simulation*: This project only requires copying a code from a text and modifying it later. This is very hard task to code and students realize this when their codes do not work for a long time although they are copied from a text. This project teaches students simulation languages (SIMAN and SLAM of the past and ARENA) are all based on codes that someone had to write. Every line of a simulation language is equivalent to pages of actual code in the background.

11) “External Codes that Interface with Simulation Languages” in *Simulation*: Certain event driven simulation scenarios cannot be written using a simulation language and external
subroutines or functions must be written and carefully interfaced with the simulation language. This project teaches students that old fashioned code writing will always be needed even with powerful ready to use simulation languages.

12) “Decision Support System for Evaluation of Procurement Policies for a Multi-item Inventory System using Simulation” in Production Planning & Control: This project involves simulation of inventory systems with random demands and lead times. The goal is to calculate the probability density function of the total inventory cost under various policies. For convenience, a car dealership with a limited number of models was considered.

Conclusions

I believe my relentless push over 25 years to require actual programming, not just using the computer as a tool or calculator, in almost every course is not popular with students at least at the beginning of the semester. In addition to learning the material better and really improving their programming skills, students learn the following fact: it is never too early and often too late start a programming project and that a computer program can be constantly improved. Some see my approach as “busy work” with little value and complain. I do this because I sincerely believe it is the most effective way to teach the material and enhance programming abilities of the students. I do not think many of my colleagues share this opinion with me, but I am totally committed to it. Under criticism at times, I sometimes wonder why I still continue this practice. This practice takes a lot of my time and it would be much easier for me and students to give it up. But, I do not give up because I think programming is an excellent example of design of an engineering system and that I continue to see the benefits of my practice on many students over and over again.

Sample Project

QUALITY CONTROL & RELIABILITY

“THE FIRST STAGE RELIABILITY CALCULATION OF THE FALCON HEAVY LAUNCH VEHICLE USING ANALYTICAL METHODS AND MONTE-CARLO SIMULATION”
Falcon heavy launch vehicle has not been launched yet, but it is only one that can send space vehicle Dragon to Mars.

Sample Student Report

Abstract

For this project, we used two methods for determining if the Falcon Heavy launch vehicle could perform for the required stage one time duration: the analytical approach and the simulation approach. The analytical approach involved the binomial distribution to find equations for 6, 7, and 8-out-of-9 engines performing. We then used the cumulative distribution functions of the Uniform, Normal, and Weibull distributions to find a p value. The p value would then be used the 6, 7, or 8-out-of-9 equations to find the probability of success. A Monte-Carlo Simulation was used for the other approach. The Monte-Carlo Simulation is a model of computational analysis that is useful when actual data does not exist, is hard to attain. In the project, we drew random lives based on the Uniform, Normal, and Weibull distributions. The results were as predicted. The lower the minimum number of engines required to successfully complete stage one, the higher the probability of success. This was true for all three of the distributions.

Discussion

Our curiosity for what lies beyond our planet is universal and enduring. We as humans are driven to discover the unknown. In this drive, we exceed technical and scientific boundaries. The benefits of these accomplishments can be seen around us today, and for years to come. Human space exploration helps us gain knowledge about our place in the universe and the history of our solar system. The challenge now falls on us to not only return to the moon, but to go deeper into space. Mars is a goal that inspirers both explorers and scientists. Robotics rovers such as Spirit and Opportunity, including Curiosity in the near future, have shown that Mars has characteristics similar to Earth, but there is still much to learn about our red neighbor. A manned mission to the nearest terrestrial planet would be an amazing opportunity to unite the world and bring a new understanding of the human prowess. The technology and space systems needed to travel and sustain explorers will drive innovation and encourage creative ways to address challenges (Why We Explore).
At this very moment, new technologies in the form of space traveling vehicles are being developed to help humanity get back to the International Space Station, the Moon, and eventually Mars. One such vehicle is SpaceX’s Dragon spacecraft. Dragon is a free-flying reusable spacecraft that will eventually replace NASA’s retired shuttle program. Although the current model of the Dragon spacecraft is designed the go from Earth to Lower Earth Orbit (LEO), future models can be modified to make a further journey into the unknown. The start of that journey will happen aboard SpaceX’s Falcon Heavy rocket. The Falcon Heavy will be the world’s most powerful heavy lift launch vehicle. It will have the ability to carry interplanetary spacecraft weighting over 53 metric tons (117,000 lbs) to LEO. Built upon the flight proven Falcon 9, the Falcon Heavy’s first stage will be made up of three nine-engine cores.

Comparing Results

Given sample data to compare with our code. This sample data was performed in the Excel add-on @RISK. Below is the result of a Uniform distribution with a minimum engine time of 100, a maximum engine time of 200, a required stage one time of 112, and on a 7-out-of-9 system.

![Figure 19. @RISK Comparison Data. Created in Excel.](image)

Below are the output of the MATLAB code for the same parameters done with the analytical approach and the simulation approach:

- The reliability of the 7 engine system is 0.7704 (Analytical)
- The reliability of the 7 engine system is 0.7792 (Simulation)

As we can see, the three results are all very close. The simulation results might be a little better, given the fact we can run the situation n number of times. In this case, the simulation was run 5000 times.
MATLAB User Instructions

Welcome/Start  
User input: 6, 7, 8 engines  
Is # 6, 7, or 8  
YES  
User Input: 1 or 2  
NO

Is # 1 or 2  
YES  
User input: 1 or 2  
(1) Analytical  
YES  
(2) Simulation  
NO

User Input: 1 or 2  
YES  
(1) Uniform  
User enters min, Max, & ST1  
NO  
Is input correct  
YES  
Give Reliability  
NO

(2) Normal  
User enters mean, std, & ST1  
NO  
Is input correct  
YES  
Give Reliability  
NO

(3) Weibull  
User enters theta, beta, & ST1  
NO  
Is input correct  
YES  
Give Reliability  
NO

User enters # of trials  
NO  
Is # > than 0  
YES

Would User like to restart

Goodbye/End

Figure 20. Flow Chart for the program. Created in Visio.

The MATLAB code for this project was built specifically for the task of determining if the Falcon Heavy rocket could reach the required stage one time. Because this is stand alone code, the new or average user may need some instructions for running the program. The first thing the user should do is open MATLAB. Once open, the user needs to needs to find the correct .m file. In this case XXXX_EN443_Project.m. The code will open up in the editor window. It is important the user not change any of the code. Changes the code can cause errors, and keep the program from running properly. To run the program, the user can simply hit the run button, or F5. From this point, Figure 2 above follows the path the program will take. The flow chart starts in the top left corner and ends in the bottom right corner. It is always important that the user carefully reads the question they are given, and input the correct data. If the user happens to input incorrect information, error traps will catch it and ask for the correct data again. Finally, answers to the probabilities are given as a decimal point. So .876 means that there is an 87.6% the Falcon Heavy rocket will complete the required stage one duration time.
Conclusion

The results we obtain from the code are very intriguing. As one would expect, the probability of an 8-out-of-9 system successfully completing the stage one time requirement is far less than the probability of a 6-out-of-9 system. Common sense tells us that the chances of everything working are less than the chances of 2/3s of everything working. As for the real life case of 7-out-of-9 engines working, the probability seems to hover around the mid 70s for the required 112 seconds of the stage one process. These odds are good, but can be proven upon. In any case, writing this MATLAB code has given myself and others the opportunity to see the real life application of the material we have been learning in class. For me personally, it sparks that universal and enduring curiosity for what is beyond our planet. It also gives me a great sense of pride as an engineer to someday I could be a part of this movement to take us further into space.

Appendix A

(Section of the MATLAB Code)

```matlab
fprintf('Welcome to SpaceX''s Falcon Heavy Stage One Reliability Calculation and Simulation Program! \n');
fprintf('                          |       | |\n');
fprintf('                          |       |  |\n');
fprintf('                        / \       | |\n');
fprintf('                       |----|o====|\n');
fprintf('                     |_________|  |\n');
fprintf('                   _____|__|--\n');
fprintf('End = 1;
while End == 1
  k = 0;
  while k~=6&&k~7&&k~8
    k = input(\nEnter 6, 7, or 8 for the minimum number of working engines. ');  
    CODE DELETED TO SAVE SPACE
  end
end
if process == 1
  AC=0;
  while AC==1&&AC==2
    AC = input(\nEnter 1 if you want to enter a probability, or enter 2 to use cdf. ');  
    if AC==1&&AC==2
      fprintf('\nError!!! Your entry must be 1 or 2');  
      fprintf(\n');
  end
  if AC == 1
    reli=1;
    while reli<0||reli>1
      reli=input(\nEnter the desired reliability. The number must be between 0 and 1. ');  
      if reli<0||reli>1
        fprintf('\nError!!! The reliability must be between 0 and 1.\n');
      end
  end
end
```

distribution. ');
```
Developing a Low-Cost Control System Lab Station

Duane B. Swigert

Abstract

Recently, the Control System Analysis lecture course, required by undergraduates, was combined with the optional Controls Lab course. The lecture course typically had an enrollment of 15 to 20 students and the lab may have had 2 to 8 students when offered. The lab course was run as a self-paced independent study course, where the students completed 6 labs during the semester. The lab equipment consisted of two commercially available lab stations with an associated computer and its proprietary software. Once the class and lab were combined, the need for additional lab stations became apparent. However, when examining the cost to replicate the existing stations, and trying to have a desired limit of two persons per lab group, it was obvious that there was not enough in the current budget to allow for an additional set of 5 to 8 lab stations.

The solution to this problem was to develop low-cost lab stations. Aside from just providing an affordable platform, the stations needed to flexible enough to allow for a number of meaningful lab experiments. The components for the station also needed to be readily available and durable. This last requirement then allows for additional lab stations to be replicated as needed and facilitates in the repair of existing stations. This paper describes the development of the low-cost lab stations and its associated lab experiments.

The Need

For many years, the undergraduate Control Systems Analysis course was a lecture only class. Those students who desired a lab could enroll in an optional Controls Lab class. In the fall of 2011, the undergraduate Control System Analysis lecture course was combined with the optional Controls Lab course in the Electrical Engineering Technology curriculum. The lecture course typically had an enrollment of 15 to 20 students and the lab may have had 2 to 8 students when offered. The lab course was run as a self-paced independent study course, where the students completed 6 labs during the semester. The lab equipment consisted of two commercially available lab stations each with an associated computer and its proprietary software.

Once the class and lab were combined, the need for additional lab stations became apparent. Our previous lab equipment consisted of two stations with a dedicated computer. As mentioned, the lab equipment was a commercially available set-up which came with a set of experiments. Each lab station would cost approximately $12,000 to replicate. The instructions for the labs were very confusing and usually the assigned instructor had very little idea as to what the labs were trying to accomplish. Hence, they were of little help to the students. Most semesters, the lab class was
not offered and when it was, the enrollment was just a few students. Keeping the stations fully functional was the job of the overall lab manager. He had a limited set of instructions that he would follow to see that basically things were connected correctly and that the devices operated. If parts were missing or broken, he would then order replacements as needed.

Now that the lecture and lab classes were combined, adding five to eight additional lab stations would not be possible as there would be neither the space and resources nor the budget to add the extra equipment. Attempts were made to find other lower cost solutions. One initial solution was to re-work the existing labs and create a number of similar labs so that a few groups could work without using identical lab arrangements and obtain different results. Still, there were only two lab stations and the need to share the time was an issue.

After attending the IEEE Multi-Conference on Systems and Control (MSC) in Denver, Colorado in August 2011, I was able to observe the use of different types of equipment used to create lab experiences at different universities across the world. In particular, I noticed the use of LEGO® MINDSTORMS® being used by a Czech Republic university in Prague¹. One problem with this solution is they used already fabricated items which snapped together and then the student would need to change the software until they were satisfied with the results.

The Solution

I began to realize that we could design and build our own low-cost solution. Although the use of the LEGO® system may solve the low-cost criteria I thought it would be worthwhile to look into designing and using items at a more fundamental level. This would be at a level that would demonstrate to the students that they could develop all the necessary items and not rely on what other companies had already tested and developed. The hope is that this would inspire and build confidence so that they realize that they indeed have learned enough to be able to tackle problems once they enter the workforce.

I proposed the concept of developing a low-cost lab station based on readily available and inexpensive items such that it would be easy to add more stations in the future and of course, to be able to repair stations as needed. This would not only solve the issues already mentioned but, it may help to encourage students to see that the knowledge and information they learned in the class could be used without the high cost and expensive equipment that they may associate with the previous lab environment. The new lab equipment could also be easily taken down and put away when not in use. Therefore, existing lab benches could be used but not dedicated to this equipment.

After the initial proposal was accepted by the department chair, I began work in the spring semester of 2012 using two students who were graduating seniors to help in the research of what materials and equipment would be required. With their help, we began to purchase equipment and try various experiments to see what would be suitable for our lab stations. Finally, we began
to converge on some useable ideas which revolved around the use of commonly available model train components.

The equipment chosen uses a short straight section of model train track, locomotive engine and gondola car, able to carry varying amounts of weight. To control and power the train, I needed to design and fabricate a box which supplied power to the tracks and have a built-in PID (proportional, integral and derivative) controller.

The intention for each station is that students will be able to control where the train will end its short journey after starting out at the beginning of the track. The final location may be varied as well as the mass of the train. In order to determine the position of the engine on the track and feed this back to the control box and to an external computer for printing the results, an optical sensor monitoring the position of the flywheel of the train engine was added to the locomotive. Other than this sensor, no other changes were made to the model train and track.

Refining the Idea

Our system was designed to have an HO scale train, which could be loaded with various weights, travel down a track to a chosen location and stop. This would require a controller as well as an interface to a PC to record the distance and velocity of the train. The complete system showing all the components is depicted in figure 1.

![Figure 1 Schematic of the system](image)

The HO scale train and track are no different than what anyone would purchase as a toy train. As previously mentioned, the only modification to the actual train engine was to insert a couple of optical sensors to help determine the engine’s velocity and distance traveled. In the electric locomotive, half of the flywheel connected to the electric motor of the engine was painted flat black so that the sensors would turn on and off for each rotation of the engine. By using a sensor on each end of the motor/flywheel combination, see figure 2, and off-setting the painted/unpainted sensor arrangement, it was possible to not only count engine revolutions but to determine the direction of the engine rotation. Counting the engine rotations in a given direction allows for determination of position. Keeping track of the counts in a given time span allows for
determining the velocity of the engine.

The required track length was determined using a few criteria. We started by choosing six feet as the track mounting board size since the lab benches are six feet in length. Thus, the track section can be easily placed on the bench. A section of track was attached to a six foot board so that experiments could be carried out to determine how much track would be required to allow the train to reach its final velocity for a given applied voltage. Also tested were distances traveled when the voltage was suddenly reduced to zero and the train slowed to a stop. From the fastest speed, there needed to be enough remaining distance so that the locomotive would not be damaged by running off the end of the track. The train itself would have to be limited to only the locomotive and a gondola car so that the six foot limitation would still offer enough distance to allow for meaningful experiments. All of these criteria were met using the six feet, or approximately 1.8 meters of track.

The final distance limitation would occur based on the bit size required for the position counter. Let me explain what I mean by this. The electric motor in the locomotive was found to turn approximately 360 revolutions per meter. This allowed for a counter of 8 bits to be used, as this would cover a distance of approximately 1.33 meters. This was accomplished by using each rotation of the electric motor to be used in determining that the train was either going forward or reversed, and using every other revolution to trigger the count for position. Using this method, position granularity was found to be 5mm (less than 1/4 inch) per unit change of the counter. Having a useable track of less than the 1.8 meters, after mounting on the board, and having a train (locomotive and gondola car) of about 40 cm, the 8-bit counter provides enough range. The 8 bits proved useful in keeping other costs low as other logic interfaces at the 8 bit level were very economical.
Testing a simple HO train controller provided the voltage and current requirements that would be needed in the design of our controller. The train engine needed a source of voltage from +15volts to -15 volts to power it in either a forward or reverse direction. The controller was split into two functional halves. The first half performed the same functionality of the simple controller which can be purchased. Thus, the locomotive and track can be used to determine if there are problems with the equipment and connections. The second half incorporates the position counter, the interface to the PC and the three parts of the PID control.

To provide this, a simple voltage amplifier circuit was designed. The input to the amplifier was from either from a voltage divider circuit, which could have the polarity reversed so that manual control of the train engine could be done, similar to the simplest model train controller. The other input to the voltage amplifier was from a set of operational amplifier (op-amp) circuitry that provided a PID (proportional, integral, and derivative) controller so that parameters could be set to control the train. Feedback from the train’s position is provided so that a set position could be compared to the actual desired locomotive position. Once the various pieces were assembled, the ranges for the proportional, derivative and integral controllers needed to be determined.

They are required to have enough range to allow for the various configurations and yet stay within reasonable limits to minimize non-linear behavior.

The train engine’s position count is also sent to a PC via a USB (Universal Serial Bus) connection so that its performance can be plotted and analyzed. The Arduino UNO processor was chosen because it had an 8-bit parallel interface and the required USB interface. This count information is fed into a parallel port on an Arduino processor and then sent via a USB link to the PC. The Arduino processor needed to have the 8 bits of counter information as well as a control lead. This control lead is used to signal when the processor should read the 8 bits and send the data to the PC and when it should terminate reading bit values.

Software is necessary for both the Arduino processor and the PC. The Arduino UNO processor creates a file which provides time and position count information to the PC. The PC may then take this file and store it for further processing. This file can be used by either MATLAB or spreadsheet software for further examination. As mentioned the file that is sent to the PC from the Arduino consists of a time stamp with an 8-bit binary number representing the position on the track.

Labs

New laboratory experiments were written for the new lab equipment. The first lab is used to determine the physical model characteristics of the system. Once the particular characteristics are found, then appropriate values could be used with the controller to achieve the desired controlled results. To create a set of experiments that would not be the same for all students, a different number of weights are added or subtracted by placing them in the gondola car, thus changing the mass of the train. The position for stopping is also a variable, thereby adding variation into the
The second lab incorporated the proportional only control. Each group should have determined the physical parameters from the first lab and will now use MATLAB to help them determine the optimal proportional control gain value to be set for their particular mass and distance requirements. Once they have a theoretical solution, they use the hardware to verify the results. Of course, things do not always work exactly as planned, and they are allowed to try additional attempts until they reach a satisfactory result. In the lab report, they describe what they found and try to explain what additional factors may have caused the experimental results.

In the third lab, both proportional and integral control gains are determined and used. The previous lab should have demonstrated that due to friction, it was impossible to get the engine of the train to stop exactly where desired. Thus, it is now necessary to add the integral portion so that the final positional error can be eliminated. As in the second lab, the system is modeled on MATLAB® and the gain values determined for the particular configuration. As before, once the theoretical solution is determined, the experiment is carried out using the actual lab equipment.

For the final set of experiments, all three of the controller’s parameters are examined. The proportional, integral and now derivative theoretical gains are determined using MATLAB® and then verified using the lab equipment. As before, there may be a few iterations required for the student to achieve their desired results. This lab demonstrates that by using a controller and proper modeling, satisfactory results may be achieved consistently, even with changes to the requirements such as final position and the mass of the combined locomotive and gondola car.

Concluding Remarks

While developing the equipment and making preliminary designs, two students who were helping me both commented on how much they were actually learning, not only about control systems but on how to determine what might be required for the lab stations and how to determine specifications. This was a great benefit to these individuals as it helped serve some of its objective. From a project completion point of view, remember and factor in that the student helpers have a learning curve before they are able to contribute.

As far as achieving the goal of a much more cost effective lab station, the cost of previous lab stations is approximately $12,000. The cost of the new lab stations is less than $600; 5% of the old stations! Having 10 lab stations is far less than the cost of one of the original stations. Finally, lab stations also proved the ability to develop the system from the ground up using commonly available parts for the system.

Acknowledgements

I would like to thank the help and support I received from my Department Chair, Professor Richard Pozzi. In addition, I would like to thank Keith Ball for his help in the acquisition of parts and materials. I would also like to thank the two students who helped in their Senior year with
the initial investigations and development of the lab stations, Mark Nenninger and David Chavez.

References

Matlab Software for an Artificial Intelligence Class

Jude L. DePalma, Ph.D.

Abstract

Matlab based software is in the process of being developed for a new graduate level artificial intelligence class based on the textbook, *Artificial Intelligence A Modern Approach*, by Stuart Russell and Peter Norvig. The authors have a web site for the textbook (http://aima.cs.berkeley.edu/) that has an online code repository. The supported language implementations are Java, Python and Lisp. There are also three unsupported language implementations in Prolog, C++, and C#. Here at CSU-Pueblo, the main programming tool for students is Matlab. Therefore this instructor has started to develop the algorithms described in the book in Matlab. First a new data class was defined for a node for use in search trees. The node has four properties: state, parent, action and path-cost. Then the following algorithms have been developed in Matlab: breadth-first search and depth-first. The next algorithm to be developed was a uniform-cost search. This algorithm uses a priority queue. In order to implement this queue a "heap" class was defined with insert, delete, sift-up and sift-down methods. Finally the A* search algorithm was developed. The algorithms have been tested and found to work on the textbook problem of an agent traveling from the Romanian city of Arad to the city of Bucharest. Also Matlab code will be developed to solve the 8-puzzle and 8-queens problems. As the course continues to be developed, more algorithms will be implemented.
Teaching Sustainability - an Increment into the Engineering Courses or a Paradigm Shift in Engineering Education?

Ananda M Paudel
Colorado State University-Pueblo

Abstract

Studies have suggested that first year engineering courses are good to start sustainability education. These courses are effective to provide a sense of sustainability by demonstrating its relevance in engineering activities. Environmental impacts and ability to explain how engineering systems are interrelated is a basic question but how they need to formulate a design problem statement in an environmental, social, and economic context is crucial and need more reinforcement. Although continual offerings of sustainability related problems and tasks along their progression into the program seems serving well to have basic understanding in sustainability, some of the more complex concepts and detail life-cycle effects of processes and products and implementing LCA is not a trivial. In addition the very basic philosophical questions of 3R (reduce, reuse, and recycle) seems simple in the first glance but its effective use and relevance in engineering education is yet to be explored. Students are aware that they need to reduce the waste, but they may not have knowledge of the alternatives to minimize waste.

It is also advocated that sustainability is a lifelong habit but the trait of sustainable living is not clear and is continuously evolving, which might require a passion and a continual strive of lifelong learning. This paper will present benefits and challenges of infusing sustainability into engineering education.

1. Sustainability is a theme in Engineering Education

Engineering educators are paying attention in sustainability. There is a consensus on the need of sustainability education for future engineers although method of program implementation might be different. Some of the universities in North America have developed institutional strategic plans to implement sustainability education in various disciplines in their engineering colleges; developing and implementing learning module, senior design project and green internships are some of the examples of this category. In many cases individual departments or faculty is taking personal initiatives in teaching some topics of sustainability such as recycling, carbon footprint, use of renewable resources, etc.

Some disciplines in engineering are developed around sustainability and environmental theme: Environmental Engineering, Sustainability engineering might be far ahead in comparison with other. Broader Environmental impact analysis and sustainability development is a major
component in civil engineering. It might be a greater challenge in other traditional engineering programs to understand the sustainability concepts and accommodate it into existing hard and dry cut courses. Anyway, it is clear that engineering educators are becoming more receptive about Sustainability and trying to incorporate this into the curriculum. The need of the imminent future and its attraction among the engineering students is fueling its deployment.

2. Challenges of infusing Sustainability into the Engineering Education

Despite a consensus on the need of sustainability instruction, there is confusion on what to include and how to integrate sustainability into the existing curricula.

Zhang et al identified rigidity in existing education system, lack of proper instruction method, insufficient resources and shifting paradigms around sustainability are some of the challenges to deal with the pressing issues. The recent philosophical change about the perception of environment and contradictory habitual traits of focusing on exploitation of natural resource sets engineering professors into a dilemma. Due to the shifting focus, and not an enough expertise, educators find themselves in the awkward position. Learning from peers either as a formal education or training or informal personal interaction is started. Learning from each other under a guidance and facilitation of a sustainability expert through collaborative learning might lead a way of towards sustainability. Some resources are available for instructors to educate themselves and incorporate sustainability in their courses. The National Science Foundation’s support networks and Center for Sustainability in Engineering (CSE) are some of the programs helping educators to learn about sustainability. In Colorado State University-Pueblo, faculty in engineering department are working to find a way to develop their courses to infuse sustainability as a summer institute. This paper proposed a structural approach of integrating sustainability into all engineering courses that are offered in CSU-P.

The author did an experimental study of teaching sustainability as a part of Engineering Graphics course and realized that the sustainability concepts are going to be more complicated as we go deeper into the constituents and their impacts. For example, it is understandable that selecting different materials can produce different levels of environmental impacts, but numerous factors come into the equation if one tries to compute the impact. Assigning proper weight for an individual factor and deciding its impact become challenging, especially in mechanical and electrical engineering courses. The author realized that teaching sustainability for general understanding is possible by incorporating some example in our courses but preparing our graduates with expertise in sustainability needs more time, effort and need to be addressed with a holistic approach.

Some of the thought and challenges faced by the author are presented here:

1. General understanding of Sustainability
2. Understanding the impacts in detail of a design/product or project
1. Soldering/ circuit's boards/ transformers
2. Energy loss- toxicity
3. Go to depth on these issues and tech, which might take forever.
   a. Bring the example from newer sustainability technology and teach them
      i. Electric circuits – solar PV circuits
      ii. Design- eg. Truss/ frame to support PV Panels
      iii. Talk about Solid Works or other Software
   b. A significant change in material science course/ design
   c. One problem domain addition in majority of courses

CSU-P has only two engineering disciplines: Industrial Engineering (IE) and Mechatronics. By their name it is evident that they are interdisciplinary program. Although the base of industrial engineering is to improve the efficiency and quality of industrial/manufacturing processes, in recent years, its focus is shifting towards the areas of energy, health, a human factor etc., and is one of the front runners in sustainability studies. One of the most talked relationship: cost, quality and time, in IE, which is shown in Figure 21, sustainability fits well in quality.

![Figure 21. Cost Quality and Time Triangle](image)

Mechatronics on the other hand is a more technical with a niche in system integration and control. Balancing mechanical, electrical, and computer engineering components of the program is already a challenge, which could easily be strained by sustainability if proper attention is not given, while including its concepts and impacts. Functional requirement and cost are the existing design criteria for mechatronics devices. Sustainability is needed to be incorporated as a third dimension as shown in Figure 22 Sustainability as an Addition to Functional and Cost requirements.

![Figure 22. Sustainability as an Addition to Functional and Cost requirements](image)
An incremental method which will start with an evaluation of current content as a baseline and adding more step by step. Again, a philosophical question of whether we want to consider sustainability in everything we do vs. check for sustainability after you do anything remain as it is.

3. Understand, Evaluate and Apply (UEA)- A Structural Approach

A Structural approach of infusing sustainability throughout the engineering courses from a holistic approach is presented here: Understand, Evaluate and Apply (UEA).

Constant coherent development of sustainability knowledge will enable students to serve the future need of sustainable endeavors. Understanding the concepts, evaluating alternatives and applying the best option are the three steps in sustainability study for engineering courses.

- Understand-concepts and terminology
- Evaluate: measure the impacts using metrics and Tools
- Application: with verification of the results

Courses offered in CSUP engineering department and their UEA status is shown in Table 2

<table>
<thead>
<tr>
<th>Course</th>
<th>Component</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN 101 Intro. to Engineering</td>
<td>U</td>
<td>Energy, sustainability, Pollution, Environment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Green technology, Net Zero Energy, Green house Gases</td>
</tr>
<tr>
<td>EN 103 Problem solving</td>
<td>U</td>
<td>Mathematical Relationships and calculations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plot a graph of energy consumption rate/ CO2 Emission rate</td>
</tr>
<tr>
<td>EN107 Engineering Graphics</td>
<td>U,E</td>
<td>Matrices, Tools</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compare the impacts of various constituents of a product development</td>
</tr>
<tr>
<td>EN 211 Statics</td>
<td>E</td>
<td>Real Examples from sustainability domain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Force analysis of a frame supporting solar panel (fixed)</td>
</tr>
<tr>
<td>EN 212 Dynamics</td>
<td>E</td>
<td>Real Examples from sustainability domain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Force analysis of a frame with tracking mechanism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Force and torque calculation in wind turbine</td>
</tr>
<tr>
<td>EN 321 Thermodynamics</td>
<td>A</td>
<td>Matrices, Tools, simulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heat vs electricity in PV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heating fluids for CSP (Heat exchange and efficiency)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Efficiency of CSP</td>
</tr>
<tr>
<td>EN324 Material Science</td>
<td>E,A</td>
<td>Materials for Renewable technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Properties of PV Cells, composites,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rusting in machine elements used in renewable energy</td>
</tr>
<tr>
<td>Course Code</td>
<td>Course Title</td>
<td>Instructor(s)</td>
</tr>
<tr>
<td>------------</td>
<td>-------------------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>EN 363</td>
<td>Machine Design</td>
<td>E,A</td>
</tr>
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<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EN 260</td>
<td>Control I</td>
<td>U,E</td>
</tr>
<tr>
<td>EN263</td>
<td>Electro Mechanical Devices</td>
<td>E,A</td>
</tr>
<tr>
<td>EN 361</td>
<td>Digital Electronics</td>
<td>U,A</td>
</tr>
<tr>
<td>EN 420</td>
<td>Simulation</td>
<td>A</td>
</tr>
<tr>
<td>EN 441</td>
<td>Engineering Mfg. Proc</td>
<td>A</td>
</tr>
<tr>
<td>EN 443</td>
<td>Quality Control &amp; Rel.</td>
<td>A</td>
</tr>
<tr>
<td>EN 460</td>
<td>Control Systems II</td>
<td>E,A</td>
</tr>
<tr>
<td>EN 462</td>
<td>Industrial Robotics</td>
<td>E,A</td>
</tr>
<tr>
<td>EN 477</td>
<td>Operation Planng. &amp; Ctrl.</td>
<td>E,A</td>
</tr>
<tr>
<td>EN 487</td>
<td>Engineering Design</td>
<td>E,A</td>
</tr>
<tr>
<td>EN 507</td>
<td>Virtual Reality Application</td>
<td>E,A</td>
</tr>
</tbody>
</table>

The three steps laid out in Table 2, are sequential, but sometimes they could be used simultaneously or in reverse order as a complementary of each other. In general, in 100-200 levels courses focus will be in teaching sustainability concepts and terminology developing a basic understanding of sustainability. Analysis of the problems from sustainability in 200 level courses provides students an opportunity to see the concepts in a real life situation. Students can evaluate both sustainability and an impact of a system into sustainability. Evaluation stage of sustainability analyzes a much broader question of sustainability worthiness of any activity and investigates every action engineers do from the angle of sustainability. If there is no significant difference between the competing options, extensive sustainability analysis might only be an additional burden.
4. Conclusion

Sustainability is an increment before an impending paradigm shift in everything engineers do. Various initiatives are in place to get our students ready for the future role of an engineer. Relevance of sustainability instruction will be greater if we can bring some real world situation into the classroom or engage students into communities for the development and implementation of engineering solutions. This will help to reinforce their knowledge and realization about the sustainability and the purpose of engineers to serve the community.

References

Synergy between MSISE and MSE Curricula at
Colorado State University - Pueblo

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Department of Engineering
Colorado State University - Pueblo

Abstract

This paper describes an efficient implementation of a Master of Science program in engineering (MSE) in synergy with an already existing Master of Science program in industrial and systems engineering (MSISE). The MSE program includes two emphasis areas, the mechatronics emphasis (MSE-Mechatronics) and the railroad engineering emphasis (MSE Railroad Engineering).

Standard MSISE programs usually create engineers with multidisciplinary skills. Mechatronics curricula with their combination of mechanical, electrical and computer engineering also create engineering generalists. Railroad engineering can be defined as a multidisciplinary engineering field that addresses technical problems in railroad industry. Generally, the field includes topics in mechanical, electrical, civil, and industrial engineering. Thus, MSE-Mechatronics and MSE Railroad Engineering emphasis areas can also be defined as multidisciplinary. Based on the nature of these emphasis areas it is possible to offer them efficiently in conjunction with the MSISE program. In addition, since the department offers two engineering programs at the undergraduate level, BS in industrial engineering (BSIE) and BS in engineering with specialization in mechatronics (BSE-Mechatronics) some senior level courses are dual-listed further improving efficiency of all the programs.

Introduction

The Department of Engineering at CSU-Pueblo offers two engineering programs at the graduate level: a Master of Science program in engineering (MSE) and a Master of Science program in industrial and systems engineering (MSISE). The mission of the MS programs is to prepare students from diverse educational backgrounds to function as engineers in advanced projects in mechatronics or railroad engineering areas (MSE), or industrial engineering and operations research areas (MSISE), and to continue their studies and obtain other advanced degrees especially at the doctoral level. The MS programs’ mission closely follows the mission of the
Department of Engineering which is to provide the highest quality engineering education in preparation of graduates for professional positions and/or doctoral studies. Furthermore, the MS programs are a part of the University’s mission which states that “…The University shall also offer selected masters level graduate programs…” (Colorado Statutes 23-55-101).

Synergy at the Program Level

The two MS programs (MSISE and MSE) are both 33-credit graduate programs that include either fifteen (MSISE) or fourteen (MSE) semester credits of core courses, nine credits minimum of courses in a track, and nine credits maximum of elective courses. The track component is defined as an additional set of courses (nine credits or more) selected by the student and the student’s advisor to advance the professional and/or educational goals of the student. Apart from the standard tracks like the Industrial Engineering and the Engineering Management track, individualized tracks are tailored to meet the needs of individual students. The programs are designed to allow breadth and depth. The track is intended to provide a focus tailored to the student’s goals and interests.

Both programs share EN 593, the Graduate Seminar core course. The other MSISE core courses are: EN 520 Simulation Experiments, EN 571 Operations Research, EN 575 Facilities Planning and Design, and EN 577 Operations Planning and Control. The MSE-Mechatronics core courses include EN 507 Virtual Reality, EN 513 Artificial Intelligence, EN 560 Advanced Controls, and EN 562 Intelligent Robotics. The MSE Railroad Engineering core courses include EN 511 Structural Engineering, EN 552 Vehicle Dynamics, EN 531 Railroad Power Systems, and EN 551 Fleet Management. For both programs, students can choose their elective MS-level courses from industrial and systems engineering, mechatronics, railroad engineering, mathematics, chemistry, and/or MBA.

Students have opportunities to engage in research through graduate projects or masters theses. Namely, in both programs students can choose either a thesis or a non-thesis option. If a student chooses the thesis option, the student must enroll in EN 599 Thesis Research course for a minimum of six credit hours, perform research, and write a masters thesis. Assessment plans for each program/emphasis describe a set of program objectives which guide student learning outcomes assessed by using associated rubrics. The assessment plans are developed concurrently and are designed to have many similarities.

The Department of Engineering also offers two engineering programs at the undergraduate level, BS in industrial engineering (BSIE) and BS in engineering with specialization in mechatronics (BSE-Mechatronics). The synergy between these two programs is already documented in Jaksic
et al.\(^1\) A few senior level courses are dual-listed with the graduate courses thus further improving the efficiency of offering the MS programs. A dual-listed course has dual designation like EN 420/520. Seniors take such a course as an EN 420 while graduate students take the course as an EN 520. While both groups (the seniors and the graduate students) listen to the same lectures, the course objectives and student learning outcomes differ. Usually, there is an additional research component which accounts for 15 to 20\% of the course grade as well as a different grading standard for graduate students. The graduate students solve level-appropriate problems during testing or for homework assignments. The syllabi reflect the dual-listing nature of the courses with a clearly stated set of requirements for graduate students.

Until the end of this school year, graduate students are allowed to take up to twelve credits of senior level courses which would count towards their MS degrees. However, due to the changes in graduate program policies at the university level, this will not be the case in the future. Therefore, where appropriate, the faculty who teach these courses will design and implement their dual-listed equivalents.

While the MSISE courses are fairly standard (the program has been in existence for over 25 years), and MSE-Mechatronics courses are described elsewhere\(^2\), the MSE Railroad Engineering courses will be described here. These courses were developed in collaboration with the personnel from Transportation Technology Center, Inc. (TTCI).

**MSE Railroad Engineering Core Courses**

In this section the four core courses in the railroad engineering emphasis area are briefly introduced. They include EN 511 Structural Engineering, EN 531 Railroad Power Systems, EN 551 Fleet Management, and EN 552 Vehicle Dynamics. A course outline for each course is presented in an appropriate table. Each course is a 3-credit hours course and runs for 15 weeks. The above courses will be offered starting this fall.

**EN 511 Structural Engineering** provides students with an understanding of the fundamental factors in designing railroad track route geometry and structure with the understanding in controlling the response of track structure under dynamic loading. Table 1 shows the course outline with the suggested number of contact hours.

**EN 531 Railroad Power Systems** engages students in a comprehensive analysis and design of electric power systems for railroads including power supplies, AC/DC and linear motors, third rails, catenaries, and substations/distribution systems. Table 2 presents the course outline with the suggested number of contact hours.
Table 1. EN 511 Structural Engineering Course Outline

<table>
<thead>
<tr>
<th>Topic</th>
<th>Suggested No. of Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loads, basic track structure, special trackwork (intro), general</td>
<td>6</td>
</tr>
<tr>
<td>safety and regulations</td>
<td></td>
</tr>
<tr>
<td>Horizontal and vertical alignment (siding, yard design)</td>
<td>6</td>
</tr>
<tr>
<td>Basic track components</td>
<td>3</td>
</tr>
<tr>
<td>Advanced track components</td>
<td>3</td>
</tr>
<tr>
<td>Track structure analysis and design</td>
<td>6</td>
</tr>
<tr>
<td>Track geometry and safety standards</td>
<td>3</td>
</tr>
<tr>
<td>Track stability and CWR management</td>
<td>3</td>
</tr>
<tr>
<td>Rail welding, flaws, and general rail management (rail profiles,</td>
<td>6</td>
</tr>
<tr>
<td>friction management, etc.)</td>
<td></td>
</tr>
<tr>
<td>Maintenance, inspection, condition assessment</td>
<td>3</td>
</tr>
<tr>
<td>Special topics</td>
<td>3</td>
</tr>
<tr>
<td>Exams and discussions of exams</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total hours</strong></td>
<td><strong>45</strong></td>
</tr>
</tbody>
</table>

Table 2. EN 531 Railroad Power Systems Course Outline

<table>
<thead>
<tr>
<th>Topic</th>
<th>Suggested No. of Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traction Power System (TPS) design and usage</td>
<td>3</td>
</tr>
<tr>
<td>Overhead Catenary System (OCS)</td>
<td>3</td>
</tr>
<tr>
<td>Electromechanical interfaces</td>
<td>3</td>
</tr>
<tr>
<td>3-phase systems</td>
<td>3</td>
</tr>
<tr>
<td>Third rail design</td>
<td>3</td>
</tr>
<tr>
<td>AC motors and drives</td>
<td>3</td>
</tr>
<tr>
<td>DC motors and drives</td>
<td>3</td>
</tr>
<tr>
<td>Linear motors and drives</td>
<td>6</td>
</tr>
<tr>
<td>Substation/distribution systems</td>
<td>6</td>
</tr>
<tr>
<td>Power electronics</td>
<td>6</td>
</tr>
<tr>
<td>Exams and discussions of exams</td>
<td>6</td>
</tr>
<tr>
<td><strong>Total hours</strong></td>
<td><strong>45</strong></td>
</tr>
</tbody>
</table>

*EN 551 Fleet Management* provides students with basic sufficient knowledge of fleet management so that they can supervise and operate the fleet. Table 3 shows the course outline with the suggested number of contact hours.
Table 3. EN 551 Fleet Management Course Outline

<table>
<thead>
<tr>
<th>Topic</th>
<th>Suggested No. of Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction to mass transportation</td>
<td>3</td>
</tr>
<tr>
<td>Fleet management business and economics</td>
<td>9</td>
</tr>
<tr>
<td>Fleet information system</td>
<td>6</td>
</tr>
<tr>
<td>Maintenance management</td>
<td>6</td>
</tr>
<tr>
<td>Vehicle fuel management</td>
<td>1.5</td>
</tr>
<tr>
<td>Asset management</td>
<td>3</td>
</tr>
<tr>
<td>Risk management</td>
<td>6</td>
</tr>
<tr>
<td>Safety standards and procedures</td>
<td>3</td>
</tr>
<tr>
<td>Hazmat (Hazard Material Transport)</td>
<td>3</td>
</tr>
<tr>
<td>Exams and discussions of exams</td>
<td>4.5</td>
</tr>
<tr>
<td><strong>Total hours</strong></td>
<td><strong>45</strong></td>
</tr>
</tbody>
</table>

*EN 552 Vehicle Dynamics* enables students to acquire analytical and computer skills to analyze the dynamic characteristics and response of rail vehicles including the influence of various components on the dynamic behavior. Table 4 presents the course outline with the suggested number of contact hours.

Table 4. EN 552 Vehicle Dynamics Course Outline

<table>
<thead>
<tr>
<th>Topic</th>
<th>Suggested No. of Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamentals of rail vehicle modeling</td>
<td>6</td>
</tr>
<tr>
<td>Vehicle dynamics and quasi-static curving behavior</td>
<td>6</td>
</tr>
<tr>
<td>Wheel-rail geometry</td>
<td>6</td>
</tr>
<tr>
<td>Track geometry</td>
<td>3</td>
</tr>
<tr>
<td>Introduction to train longitudinal dynamics</td>
<td>3</td>
</tr>
<tr>
<td>Stability analysis and simulation</td>
<td>6</td>
</tr>
<tr>
<td>Vibration fundamentals including random vibrations</td>
<td>6</td>
</tr>
<tr>
<td>Ride quality and lateral vibrations in railway vehicles</td>
<td>6</td>
</tr>
<tr>
<td>Exams and discussions of exams</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total hours</strong></td>
<td><strong>45</strong></td>
</tr>
</tbody>
</table>
Synergy at the Course Level

There are many possible combinations of MS-level courses students can take to fulfill the requirements for one or multiple programs/emphasis areas. Table 5 presents the synergistic relationship between various graduate level courses offered by the engineering department and the MS programs they serve. In Table 5, R means that the course is required; E means that the course can be used as an elective course or for a track, and X means that the course is an unlikely candidate for other programs/emphasis areas.

There are a number of elective courses that can be used for any of the programs. However, some of these electives, like EN 595 Independent Study or EN 599 Thesis Research, are tailored for individual students and do not contribute much to efficiency of offering courses for different programs. In addition, some of the elective courses may require prerequisites that are not common to all incoming graduate students. For this reason, the engineering faculty are evaluating the current offering of senior level courses for possible adaptation to dual-listing level. In this work, four such courses (400-level) are listed in Table 5. After these courses are well established the faculty will evaluate other senior level courses like EN 435 Microprocessor Control Systems, EN 439 Time and Motion Studies, and EN 460 Control Systems II.

Table 5. Synergy between Graduate Courses and MS Programs

<table>
<thead>
<tr>
<th>MS Course</th>
<th>MSE Railroad Engineering</th>
<th>MSE-Mechatronics</th>
<th>MSISE</th>
<th>Dual-listed</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN 503 Ergonomics</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>NO</td>
</tr>
<tr>
<td>EN 504 Scheduling and Sequencing</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>NO</td>
</tr>
<tr>
<td>EN 507 Virtual Reality</td>
<td>E</td>
<td>R</td>
<td>E</td>
<td>NO</td>
</tr>
<tr>
<td>EN 511 Structural Engineering</td>
<td>R</td>
<td>X</td>
<td>X</td>
<td>NO</td>
</tr>
<tr>
<td>EN 513 Artificial Intelligence</td>
<td>E</td>
<td>R</td>
<td>E</td>
<td>NO</td>
</tr>
<tr>
<td>EN 520 Simulation Experiments</td>
<td>E</td>
<td>E</td>
<td>R</td>
<td>YES</td>
</tr>
<tr>
<td>EN 530 Project Planning and Control</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>YES</td>
</tr>
<tr>
<td>EN 531 Railroad Power Systems</td>
<td>R</td>
<td>E</td>
<td>X</td>
<td>NO</td>
</tr>
<tr>
<td>EN 540 Advanced Engineering Economics</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>NO</td>
</tr>
<tr>
<td>EN 551 Fleet Management</td>
<td>R</td>
<td>X</td>
<td>E</td>
<td>NO</td>
</tr>
<tr>
<td>EN 552 Vehicle Dynamics</td>
<td>R</td>
<td>E</td>
<td>X</td>
<td>NO</td>
</tr>
<tr>
<td>EN 560 Advanced Controls</td>
<td>E</td>
<td>R</td>
<td>X</td>
<td>NO</td>
</tr>
<tr>
<td>EN 562 Intelligent Robotics</td>
<td>X</td>
<td>R</td>
<td>E</td>
<td>NO</td>
</tr>
<tr>
<td>EN 571 Operations Research</td>
<td>E</td>
<td>E</td>
<td>R</td>
<td>YES</td>
</tr>
<tr>
<td>EN 575 Facility Planning and Design</td>
<td>E</td>
<td>E</td>
<td>R</td>
<td>YES</td>
</tr>
<tr>
<td>EN 577 Operations Planning and Design</td>
<td>E</td>
<td>E</td>
<td>R</td>
<td>YES</td>
</tr>
<tr>
<td>EN 588 Graduate Projects</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>NO</td>
</tr>
<tr>
<td>EN 590 Special Projects</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>NO</td>
</tr>
<tr>
<td>EN 591 Special Topics</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>NO</td>
</tr>
<tr>
<td>EN 593 Graduate Seminar</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>NO</td>
</tr>
</tbody>
</table>
EN 595 Independent Study | E | E | E | NO
EN 598 Internship | E | E | E | NO
EN 599 Thesis Research | E | E | E | NO
EN 440 Safety Engineering* | E | E | E | YES
EN 441 Engineering of Manufacturing Processes* | E | E | E | YES
EN 443 Quality Control and Reliability* | E | E | E | YES
EN 473 Computer-Integrated Manufacturing* | E | E | E | YES

*These courses are currently under review for possible adoption as dual-listed courses.

Examples of Students’ Curricula

The limited size of each core plus the availability of electives allows the faculty advisor and student to design a program to meet the student’s goals and interests. Table 6 shows a possible program plan for a student pursuing the MSE with railroad engineering emphasis who plans to seek employment in fleet management. Table 7 shows a program plan for a student pursuing the MSE with railroad engineering emphasis who plans to seek employment in research and development of mechatronics systems.

Table 6. Sample MSE Railroad Engineering Curriculum with a Fleet Management Track

<table>
<thead>
<tr>
<th>Type</th>
<th>MS Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>EN 511 Structural Engineering</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>EN 531 Railroad Power Systems</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>EN 551 Fleet Management</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>EN 552 Vehicle Dynamics</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>EN 593 Graduate Seminar</td>
<td>2</td>
</tr>
<tr>
<td>Track</td>
<td>EN 504 Scheduling and Sequencing</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>EN 520 Simulation Experiments</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>EN 577 Operations Planning and Design</td>
<td>3</td>
</tr>
<tr>
<td>Other Courses</td>
<td>EN 575 Facility Planning and Design</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>EN 599 Thesis Research</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td><strong>Total Credits</strong></td>
<td><strong>33</strong></td>
</tr>
</tbody>
</table>

Table 7. Sample MSE Railroad Engineering Curriculum with a Mechatronics Track

<table>
<thead>
<tr>
<th>Type</th>
<th>MS Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>EN 511 Structural Engineering</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>EN 531 Railroad Power Systems</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>EN 551 Fleet Management</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>EN 552 Vehicle Dynamics</td>
<td>3</td>
</tr>
</tbody>
</table>
Conclusion

In this work, an efficient implementation of two MS programs is described and analyzed. An MSE program with two emphasis areas (mechatronics and railroad engineering) is implemented in synergy with an already existing MSISE program. The core courses of the MSE Railroad Engineering emphasis are briefly described. This emphasis is in the implementation stage. Since both the MSE and the MSISE program are multidisciplinary, the structure of the MSE program was designed to be similar to that of the MSISE program. Both programs are 33 semester credit hours long and include a five-course core, a minimum nine-hour track, and a number of elective courses. Both programs have a thesis and a non-thesis option. Both programs draw from the departmental experiences in offering dual-listed courses. Finally, the development of new dual-listed courses will benefit both programs.

Acknowledgment
MSE with Railroad Engineering emphasis became possible with generous expert help from Stephen Dick, Robert Florom, Robert Fries, Duane Otter, R. B. Wiley, and Matthew Witte, all of Transportation Technology Center, Inc.

References

The Role of Engineering Education in Building Workforce Capacity for the Railroad Industry

Ananda M. Paudel, Nebojsa Jaksic, Robert Florom, Jane M. Fraser, Timothy McGettigan

Abstract

Engineering has modernized human society; the railroad is one of the greatest inventions of engineering. Since early industrialization railroads have served as a circulatory system of the nation and are well regarded for passenger as well as freight transportation. For the last few decades the momentum of railroad development has been slower in comparison with economic growth.

Tremendous capability and thrifty energy and environmental emissions requirements have put the railroad back into the spotlight globally. Although future growth of the industry is imminent, a few setbacks have challenged the North American railroad industry: impending retirements in the workforce, inadequate interest of youth in railroad careers, and the recent economic recession. A lack of STEM qualified workforce is one of the concerns identified by studies. None of the traditional engineering programs are designed or tailored to serve the railroad industry. This paper investigates the challenges of the railroad industry workforce development and proposes a methodology with a greater breadth and depth in engineering education. One of the proposed solutions - an interdisciplinary Master’s Degree in Engineering with a Railroad focus - is set to be offered by Colorado State University-Pueblo starting fall semester 2013.

1. Railroad Industry Benefits and Challenges

Since early industrialization railroads have served as a circulatory system of the nation and are well regarded for passenger as well as freight transportation. For the last few decades the momentum of railroad development has been slower in comparison with economic growth. Cross-country passenger operations are falling behind due to competition from the airline industry. However, the freight railroad industry has steadily grown since the 1980s deregulation. The growth was managed via productivity improvements (use of modern technology, negotiation with unions to eliminate obsolete positions and mergers). The transit agencies for both heavy and light rail passenger operations have also steadily grown in the number of agencies and in ridership in most cities over the last decade.

Tremendous capability and thrifty energy and environmental emissions requirements have put the railroad back into the spotlight globally. Although future growth of the railroad is imminent, a few setbacks have challenged the North American railroad industry: impending retirements in
the workforce, inadequate interest of youth in railroad careers, and the recent economic recession. Most of the delay in growth for the railways has been driven by the downturn in the US economy. Studies in the early 2000s predicted that the freight railroads would be reaching their capacity limits in many places in North America by now but the 2008 recession has delayed that prediction.

People are excited about trains from early childhood, even after they are attracted to cars or other toys. The study team observed a discontinuation in those passions as children grow up due to various reasons. One of the distractions is the excessive exposure to toy cars and lack of railroad access either as a toy or as a personal ride. As reported by Reinach and Viale, the young generation considers the railroad industry as “Grandfather’s Railroad”.

Employment data available in FRA’s report titled “Railroad Industry Modal Profile, an Outline of the Railroad Industry Workforce Trends, Challenges, and Opportunities 2011” presented a grim scenario of the workforce gap which leads to a danger of knowledge loss as the workforce is retiring and a significant time period is needed to train a new workforce (at least five years, implied by the use of incremental pay system in the industry). The FRA report suggests a tremendous amount of future growth in the industry but the labor forecast presented by the Department of Labor is not encouraging.

Contrary to the FRA study, Department of Labor (DOL) projections show little or no change, with railroad employment growing one percent from 2010 to 2020. It seems DOL forecasts do not encompass potential retirement numbers. Many workers stay in these occupations for a long time, and currently more workers are nearing retirement than is the case in most occupations. When these workers begin to retire, many jobs should become available. Although demand for rail transportation is expected to grow, some occupations might be obsolete or affected by increases in productivity. Advanced remote-control locomotive technology allows engines to be moved around rail yards remotely and might replace some of the current job content and bring in high technology jobs. To understand the cause of unfulfilled workforce demand in the railroad industry even in the situation of hundreds of thousands of people without jobs, the authors investigated the labor department’s database and discussed it with a focus group. The DOL website presents almost fifty thousand annual salaries and during the discussion the focus group confirmed and mentioned an exceptionally better benefits package for its employees with a high school degree minimum qualification. A typical job description and required qualification and pay are presented in the Table 3 for clarification.
Table 3 Typical Railroad workforce Qualification and Pay

<table>
<thead>
<tr>
<th>Responsibility</th>
<th>Education</th>
<th>Median Pay</th>
<th>Jobs (2010)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductors and yardmasters</td>
<td>Coordinate the daily activities of both freight and passenger train crews. Conductors work on the train. Yardmasters work in the rail yard.</td>
<td>High school (HS)</td>
<td>$49,770</td>
</tr>
<tr>
<td>Train Engineers and Operators</td>
<td>Ensure that freight trains and passenger trains stay on time and travel safely</td>
<td>HS</td>
<td>$46,100</td>
</tr>
</tbody>
</table>

As shown in Table 3, locomotive engineers with high school diplomas earn a median salary of $49,770. This is significantly higher pay in comparison with other profession with similar qualifications. Competitively higher remuneration in the Railroad industry might be advantageous. In further investigation, it was also noticed that higher salary and greater benefits are attached to jobs with complexities and inconvenience such as long travel, irregular schedule, etc. whose trains travel long routes can be away from home for long spans of time. Those who work on passenger trains with short routes generally have a more predictable schedule. Workers on some freight trains have irregular schedules.

A study “An Examination of Employee Recruitment and Retention in the U.S. Railroad Industry” using U.S. freight railroad employees as a focus group suggested similar findings. In addition to railroad work schedules, they pointed out an incremental pay rate system, and difficulty in finding individuals with the right skill sets for the job. Relocation, furlough adjustments and unclear job previews during the hiring process are some of the other challenges of the Railroad industry’s workforce. The study also concluded that the employees who were working were satisfied with their jobs and willing to remain in the industry for their entire careers.

Lack of STEM qualified workforce is another concern identified by the studies. Traditional engineering degrees in civil, mechanical, and electrical engineering serve as a foundation for most of the industry. However, none of these programs is designed or none of the programs is geared to serve the railroad industry.

2. Railroad Engineering Education Needs

The presence of alternative transportation modes and their stealth aesthetics have hidden railroads from the eyes of both the public and educators. Although passenger transit has been modernized and expanded in the last 10 years, the appearance of aging infrastructure of freight transit as well as inconvenient services might be the reasons for lower attraction. However, the increases in gas prices and growing concerns for the environment have brought mass transit back
into the spotlight. Railroads are a major means of mass transit meeting freight as well as passengers’ transportation needs.

Again, for every position that becomes available in the railroad industry there are many candidates. This is especially true for the blue collar jobs that only require a high school education due to the excellent salary and benefits offered by the railroads. It is not uncommon for individuals to leave jobs they have held for years when they get the opportunity to go to work for the RRs. There is a need for matching qualifications of the candidates and job requirements. To avert the persistent lack of attraction among the new generations, the team proposed a holistic view comprised attracting and educating, hiring and retaining, and ensuring the well being of potential candidates for work in the railroad industry. The approach is presented in a graphical form in Figure 23.

![Proposed Workforce Development Strategy](image)

**Figure 23** Proposed Workforce Building and Retention Approach for Railroad Industry

In Figure 1, the distance from the center of the diagram shows the emphasis the team recommends should be placed on each strategy for recruiting workforce for the railroad industry. As shown in the figure, the team has put more emphasis on education with the perception of an expanding knowledge gap between the current workforce and newer technology as well as the discontinuity the railroad education suffered in the last few decades (from the early 70’s). Traditional foundational engineering degrees that prepare students for railroad industries are not in touch, and do not seem concerned, with the railroad industry. A few universities are trying to address the needs of the industry by incorporating railroad education partially but none of these programs are designed to serve the railroad industry in its entirety. Apprenticeship or on the job training seems to work well in the railroad industry although there is a need to improve effectiveness and efficiency. Studies pointed out a need of clear description of the job’s responsibility and working conditions during the hiring process. The incremental pay and on the job training seem to work well to retain the workforce. A multi level comprehensive module is developed to address the current situation of railroad education starting from the very beginning of human life to a stage of career selection and beyond as show in Figure 2.
Although the railroad education in schools as well as research and development are crucial parts of the industry, the team focuses more on STEM workforce development at various levels: junior colleges, four year colleges and Masters Degree granting intuitions. The model is presented in Figure 24.

3. Methodology

3.1 Need Identification

Information was collected from an interaction with individuals in the railroad industry and academia. Discussions of an informal focus group and concerns expressed during networking events further reinforce the urgency of the Railroad engineering education. The need for railroad education is also addressed in academia and various papers are presented at ASME/ASCE/IEEE joint conferences.

3.2 Assessment of Existing Engineering Programs

Multiple forums such as the annual conference of AREMA, joint conferences of railroad engineering as well as ASEE conferences were reviewed to understand the status of the railroad engineering program in the nation. Input from the TTCI human resource group was useful to understand the knowledge gap and challenges in hiring qualified employees. A focus group has a survey and few brainstorming sessions of seven faculty from the engineering and social sciences departments from CSU-P and more than ten experts from TTCI and other railroad companies. A preliminary study has shown a growing number of railroad worker training programs offered by Universities and private companies in the United States. Some of them are listed in Table 2.
Table 4 Railroad Education in United States

<table>
<thead>
<tr>
<th>University/Institutions</th>
<th>Program</th>
<th>Focus Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michigan State University</td>
<td>Railway Management</td>
<td>Management</td>
</tr>
<tr>
<td>University of Wisconsin at Madison</td>
<td>Railroad Engineering</td>
<td>Short Course</td>
</tr>
<tr>
<td>University of Illinois-Urbana Champaign</td>
<td>Railway Engineering Program</td>
<td>Graduate/Undergraduate Research</td>
</tr>
<tr>
<td>California State</td>
<td></td>
<td>Civil Engineering</td>
</tr>
<tr>
<td>Michigan Technological University</td>
<td>Rail transportation</td>
<td>Graduate/Undergraduate</td>
</tr>
<tr>
<td>Johnson County Community College</td>
<td>National Academy of Railroad sciences</td>
<td>Hands on training</td>
</tr>
<tr>
<td>University of Tennessee</td>
<td>Center for Transportation research</td>
<td>Safety and maintenance</td>
</tr>
<tr>
<td>Sacramento City College</td>
<td></td>
<td>Hands on</td>
</tr>
<tr>
<td>CSX Railroad education and development institute, Atlanta, GA</td>
<td>Railroad Management</td>
<td>Management</td>
</tr>
<tr>
<td>BNSF</td>
<td>Railroad Management Training</td>
<td>Management</td>
</tr>
</tbody>
</table>

As shown in Table 4, there are very few railroad engineering programs in North America; most of them are research based and are offered in conjunction with some traditional engineering program.

The higher level of workforce with advanced research qualifications is educated in world class universities. Big universities with sufficient infrastructure could contribute to research and development as well as prepare designers to reface the railroad industry and rejuvenate it with high technology and bullet train technology. Medium and small size universities offer four year bachelor degrees and Master’s degrees in railroad disciplines. Chao Ma and Pasi T. Lautala studied the status of railroad education in various countries around the globe. They portray a similar picture and suggested a need for an international collaboration in railroad development and education. The authors investigated various alternative options to address the need of workforce development and weighed the various engineering programs at different levels to find a relevance to the Railroad industry.

3.3 Options in Railroad Engineering Education

3.3.1 Railroad engineering at undergraduate or graduate level?

Railroad industry needs not only engineers but interdisciplinary engineers. It’s a general perception that engineering degrees should be at the graduate level. Undergraduate education is not enough to manage and work in a modern technology environment. Thus, undergraduate education is not enough for railroad engineers or managers seeking an interdisciplinary skill set.
Therefore, a railroad degree at the graduate level is a better option for the future. This allows students with traditional engineering undergraduate degrees to broaden their horizons and work in a framework, which makes them ready to work in the railroad industry.

3.3.2 Is standalone railroad engineering curriculum sustainable?

Maybe not! It might be difficult to get well qualified faculty with the background in railroad engineering. It is observed that automotive departments or aeronautical departments are struggling due to their direct association to a specific industry and narrow focus or deeper knowledge of specific industry lacking the breadth of the program. This makes students disadvantaged when entering another industry.

3.3.3 Is it possible to teach railroad related courses with the faculty of traditional departments?

Yes, but the instructional focus will remain on the traditional field rather than on railroad engineering. The faculty has a higher stake in their primary department pushing railroad down to second in their priority. This might compromise depth and vigor of a railroad program.

3.3.4 How about five years masters program?

This is a good option. After further investigation, an accelerated Master Degree in one year appears to be closest to this with a potential of serving broader population.

3.4 Self Evaluation: Can we contribute?

An interdisciplinary team of faculty in the engineering department brings a broader perspective into the program. Their experience of developing curriculum, teaching graduate courses and supervising master thesis as well as research will be an asset to strengthen the program. A center of railroad study can be established at Colorado State University-Pueblo in future.

TTCI is a wholly owned subsidiary of the Association of American Railroads (AAR), a trade association that represents the interests of North American Railroads. TTCI/AAR have operated the Transportation Technology Center (TTC), a USDOT national laboratory focused on intermodal transportation research, testing, and training located in Pueblo, CO since 1982. TTCI is a world-class facility unique in the world, offering a wide range of capabilities for research, development, testing, consulting, and training for railway-related technologies. The site also enables testing of all types of freight and passenger rolling stock, vehicle and track components, and safety devices. Computer models are designed and developed in house to predict railroad
equipment performance and simulate the train with multi-body dynamics, which might be useful to teach courses in vehicle dynamics.

The Rail Dynamics Laboratory (RDL) has the capability to test vehicles by simulating stresses that might be induced during train operations and to make predictions on fatigue life and reliability. Rolling Load Test Machines, Dynamometer, Track Loading Vehicle (TLV), Instrumented Wheelsets, and Bridge Infrastructure testing are some of the crucial facilities at TTCI, which offers a quality lab facility for Railroad education. In addition, these lab facilities expose students to the stringent test requirements of the AAR’s Specification.

In support of the program, TTCI can play a pivotal role in connecting the university with the representatives from the various freight and passenger railways who are members of TTCI’s Board of Directors: New York City Transit Authority, Amtrak, Union Pacific Railroad, Burlington Northern Santa Fe Railroad, and the American Passenger and Transit Association. These companies might offer internships opportunities for our students; they are the potential employer of our graduates, too. An advisory committee will be constituted by inviting the representatives from these companies, which will help to improve the program and meet their current and future workforce needs. This connection might be helpful to bring a larger pool of students into the program. In addition to the traditional academic environment of a typical university at CSUP, students in Railroad engineering will receive instruction from the world leading experts and and access to the world class research facility of TTCI.

4. Research Results and Proposed Solution

The TTCI team played a crucial role in developing this program by utilizing their vast unbiased knowledge of the railroad companies around the nation. TTCI’s Human Resource department worked very closely with the North American freight and passenger railroads when identifying typical job openings, recruiting and employee training programs. The TTCI team leveraged this relationship to support the data gathering requirements for the program.

This research created a better picture about current railroad educational systems, and challenges the railroad industry is facing in terms of workforce development. A panel of engineering educators, social scientists and railroad industry experts proposed a practical recommendation for railroad education and training after analyzing educational deficiencies and the changing requirements of the industry. After examining the available options and to satisfy the needs of the railroad industry, Colorado State University-Pueblo has worked closely with railroad industry experts during the last couple of years. This collaboration effort finally sprouted a Master of Science degree with a Railroad engineering emphasis. The engineering department at CSUP is set to start a railroad engineering program at the graduate level in fall 2013 in collaboration with the TTCI. Professors with multidisciplinary educational preparation, broader perspectives, international exposure, and experience of working with a diverse population facilitate understanding of the problem and set the course for collaboration. Small universities with small
class sizes have proven more effective in teaching and training with the one-to-one approach. Students will learn better with the engagement and individual attention of the faculty in a smaller size classes. The specific objectives of the MS degree are to provide engineering graduates who:

1. Understand the interdisciplinary fundamentals of mechanical engineering, electrical engineering, control systems, and their integration pertinent to railroad Industry.
2. Have strong team skills to solve complex problems that cross disciplinary boundaries.
3. Perform research, design, and implementation of intelligent engineered products and processes enabled by the integration of high tech railroad solutions.

5. Key features of the Program

The objectives of these broad ranges of courses are to prepare a well versed engineer with the proper knowledge of railroad engineering ready to join the workforce. The program is designed to keep up with the technical and business needs of the railroad industry. Students with any engineering background can take the classes after completing certain leveling courses. Students looking for a railroad career on the operations management side will take only the four core-courses and can choose remaining courses from the industrial engineering program or business school. Students having a preference for research and development will get an option to select thesis credit. Students will be working with the industry’s experienced researchers for their thesis.

Most of the courses are designed by railroad experts and will be taught by these experts in conjunction with engineering faculty. Engineering faculty have a background from all major engineering programs. Instructed by industry experts and conducted in a close collaboration of multiple faculties will assist in fostering the interdisciplinary niches of railroad engineering.

6. Limitations and Recommendations for Future Studies

A solution of offering a Master Degree is presented in this paper to support the educational need of railroad industry. To start the program, courses are planned to be taught by the TTCI experts but developing knowledge base in the department is essential for the better ownership and accountability in the engineering department. This needs direct involvement of the existing faculty in railroad engineering and they need to align their research interest towards railroads. A train the trainer program might be approach for faculty professional development in railroad engineering that prepares educators for the railroad education. This paper proposed a solution for higher level workforce development but railroads suffer workforce shortage in a wide range of occupations at various levels. Further investigations of the followings factors need be studied in future to fulfill these unmet requirements.

1. Quantify the decline in the number of railroad employees in the United States with respect to overall demographic information (numbers, relative ages, and areas of expertise)
2. Estimate future demand and the potential gap in meeting that demand (a correlation analysis will be performed for education vs. skill sets requirement of the railroad industry)
3. Project availability and demand for such employees during the next 5, 10, and 20 years.
4. Develop decision tools along with the inputs to develop strategies for overcoming workforce shortages.
5. Identify best practice examples of existing workforce training programs and prepare case studies to determine the ability of these programs to meet demand for workforce requirements at all levels, including both professional and technical workforce needs.
6. Perform a comparative case study to analyze best practices and preparation of other industries that may have experienced similar challenges.
7. Update existing railroad training programs in different forms, format and locations and means of entrance into the industry
8. Identify possible methods to alleviate long-term decline, including strategies and tools for building and retaining additional professional and technical workforce capacity for the rail industry at all levels.
9. Identify strategies and tools for building and maintaining an adequate workforce over the course of the next 20 years.

References

Electronics Engineering Technology Student Recruitment Design Project

Justin B. Jackson, Ph.D.

Abstract

Many potential students are unaware of the engineering technology programs offered at Weber State University. These students visit Weber State throughout the year for scheduled events such as Majorfest. Majorfest allows high school seniors an opportunity to visit campus and learn about the different majors offered at WSU. Students are given information handouts along with trinkets from the different departments. The Electronics Engineering Technology program participates in this event annually.

Weber State University also hosts junior high school students during the year who are interesting in STEM fields. These students visit the different departments and perform simple laboratories for each field. The Electronics Engineering Technology program has had students build and test various circuits on breadboards for this event.

A design team of senior students was tasked with the development and design of a recruiting tool for the Electronics Engineering Technology program (EET) for these events. These students were given realistic design constraints regarding power, size, cost, and performance. The recruiting tool they developed was a small circuit board shaped as a block W to represent Weber State University. It also includes a button that when pushed plays initiate a light display and plays the Wildcat fight song. The design represents both the EET program and the institution. The circuit board is handed out to potential students at recruiting events for the Electronics Engineering Technology program. The circuit board is also used to give hands on construction experience for outreach programs.
ASEE-RMS Officers, 2013

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